COMPUTATION OF ANTI-EROSION EFFECTS OF VINEYARDS BASED ON FIELD EROSION MEASUREMENTS – CASE STUDY FROM THE VRÁBLE VITICULTURAL DISTRICT (SLOVAKIA)

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ABSTRACT

This paper describes the evaluation of the anti-erosion effect of vineyards, represented by the Universal Soil Loss Equation (USLE), cover-management factor (C factor), and support practice factor (P factor). The calculations are based on measured soil loss data. The erosion and deposition rates were evaluated from aboveground vineyard poles as their exposure lengths change between the year of vineyard plantation and the year of measurement. The lengths increased on the erosion areas, because the soil had been washed away. On the deposition areas the poles had been covered by soil, so the exposed lengths for aboveground poles decreased. The measurements were taken in Horný Ohaj vineyards, which belong to the Vráble viticultural district. The calculations were based on a comparison between the measured erosion, and the erosion modelled with USLE model. The cover management factor was evaluated for ploughed vineyard. Different C factor values were substituted to the USLE until the root mean squared error between measured and modelled data was minimal. The support practice factor for hoed and rotavatored vineyard was calculated simultaneously. The cover-management factor was determined to 0.692. The support practice factor for ploughed vineyard is 1.000, for hoed vineyard is 0.586, and for rotavatored vineyard is 0.719.

Keywords: soil erosion, vineyards, erosion measurement, USLE, Vráble viticultural district

1. Introduction

According to comparative studies, vineyards are reported as one of the most erosion-prone categories in Europe (Cerdan et al., 2010), especially in the Mediterranean region (Kosmas et al., 1997; Hooke, 2006). Most of this data have been collected in Spain, Italy, and France. The classical method of measurement is through the use of portable rainfall simulators (Wainwright, 1996; Ramos, Martínez-Casasnovas, 2007; Arnaez et al., 2007; Blavet et al., 2009), sediment collectors (Bini et al., 2006) or volumetric methods (Augustinus, Nieuwenhuyse, 1986; Casalí et al., 2006; Quiquerez et al., 2008). A more modern approach uses remote sensing methods (Hill et al., 1994; Martínez-Casasnovas, 2003) or leveling methods as geodetic measurements (Martínez-Casasnovas, 2002) or botanical benchmark as marker of land leveling (Brenot et al., 2008; Casalí et al., 2009; Paroissien et al., 2010). The erosion research in Slovak vineyards was conducted by the Research Institute of Viticulture and Enology (Ochaba, Fic, 1961) in Modra and Malá Tŕňa. Zachar (1982) reported the huge erosion event caused by rainstorm in Myslenice vineyard.

Even with widely known low erosion resistances, there are not many studies devoted to analyze the anti-erosion effect of vineyards. The anti-erosion effect is generally defined as a ratio between the erosion rate measured in analyzed conditions (e.g. conditions benefiting from vegetation cover or management practices) and the erosion rate in standard (e.g. unprotected) conditions. A variety of soil erosion models use the anti-erosion effects of land cover and management practices as one of the main input parameters for erosion simulation. Because many of the empirical and semi-empirical models are based on the Universal Soil Loss Equation USLE (Wischmeier, Smith, 1978), we decided to compute the anti-erosion effect of vineyards as an input for USLE-based erosion models.

For USLE-based models, the anti-erosion effect of vegetation cover is represented by the cover-management factor (C-factor), which is defined as the ratio of soil losses under actual conditions to losses measured under standard conditions of clean-tilled continuous-fallow. The effects of erosion control practices are represented by the support practice factor, or P factor, defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight-row upslope and downslope tillage. Most anti-erosion studies have been devoted to the estimation of cover-management and support practice factors for arable land (Morgan, 1995; Alena, 1991; Malíšek, 1992; Hrnčiarová, 2001; Gabriels, et al., 2003), but only a few studies use the C-factor for vineyards (Malíšek, 1992; Jordan, et al., 2005; Bakker, et al., 2007; Pelacani et al. 2008). The aim of this study is to use field erosion data for estimating the value of the cover management factor of vineyards and the support practice factor of downslope ploughing, hoeing, and rotavatoring.

2. Study area

The research was carried out in Horný Ohaj vineyards (48°16'11"N, 18°18'05"W), located in southwest

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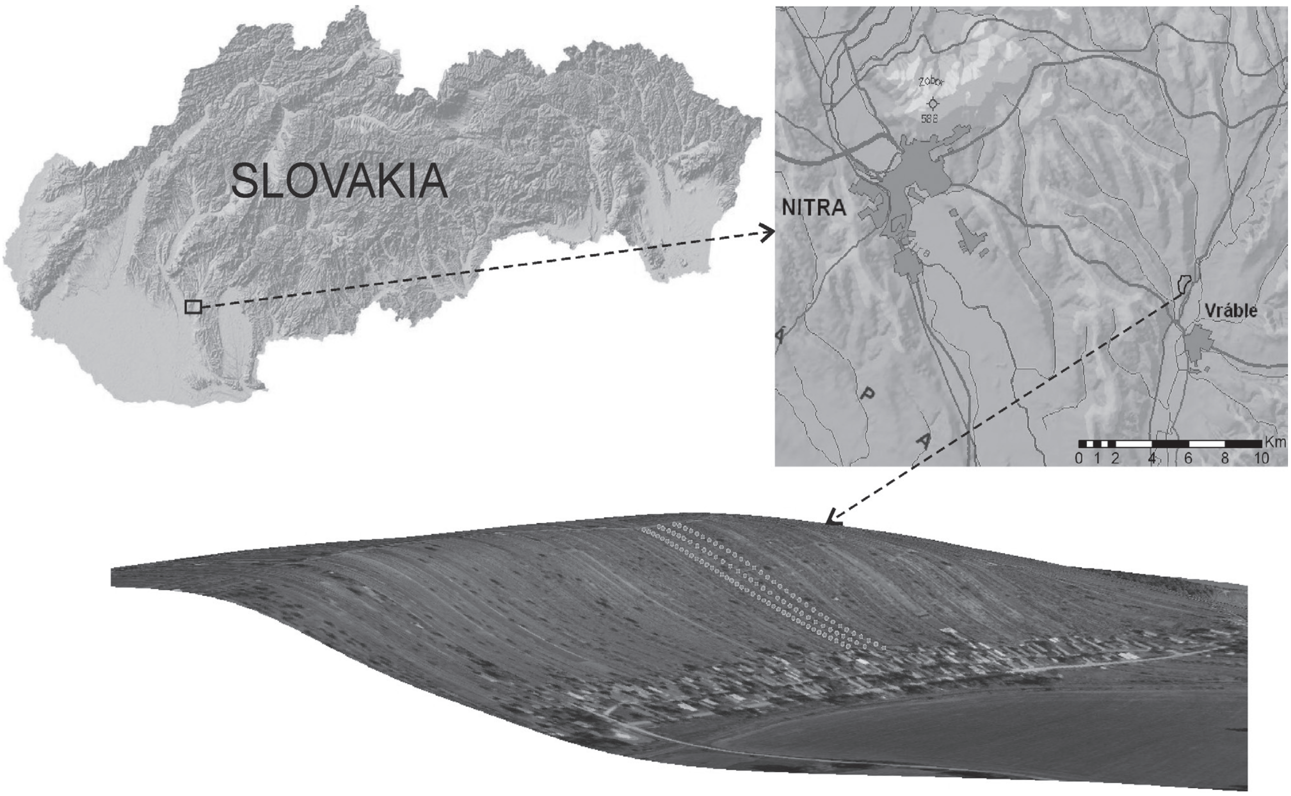

Fig. 1 Location of the vineyards. Dots on the picture above represent the measured fields (right: ploughed field; middle: hoed field; left: rotavatored field)

Slovakia in Vráble viticultural district (Figure 1). The vineyard area is comprised of small fields of private rows of wire-trained vines. Each field contains 2–4 rows of 120–160 vines. The vines are planted and cultivated along the slope with the slope grade between 5° and 14°. Soils in the area are characterized by luvisols and regosols formed on the aeolian loess deposits. The soil analyses showed a truncation of the A horizon caused by erosion. The climate is warm and dry, with a mild winter. Mean annual temperature is 9.5 °C. Average precipitation is about 552 mm where main erosive rainfall events occur in July and August.

Erosion was measured on three differently cultivated fields. The first field was planted in 1983, and since than it has been ploughed by garden tractor annually. The field consists of two rows of 33 poles and one row of 30 poles. A deep ploughing is applied before and after the vegetation season, and a shallow ploughing is applied a few times per season to clear any 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. There are two rows of 33 poles and one row of 30 poles. The third field is cultivated with a rototiller since 1970. Deep cultivation is applied two times per year, and shallow cultivation a few times per year. The field consists of four rows of 41 poles.

3. Methods

In order to estimate the anti-erosion effects of vineyards, we had to measure the erosion intensity on the field. A simple procedure, based on the change of the aboveground lengths of poles placed in each vineyard, was used to obtain a large amount of long-term erosion data within a short time. The calculation was based on a comparison between the measured erosion, and the erosion exemplified through the USLE model. Different values of C factor and P factor were substituted to the USLE until the root mean square error between measured and modelled data was minimal.

Erosion measuring

The measuring method is based on an assumption that the uniform vineyard poles were placed at the same aboveground height when the vineyard was founded. Due to the effect of erosion and deposition, the poles' aboveground heights have been changed. The exposed lengths have increased on the erosion areas, because the soil had been washed away. On the deposition areas the poles had been covered by soil, so the lengths of the aboveground poles have decreased (Figure 2).

Information about the total pole height, initial pole deepness, aboveground pole height, and year of vineyard

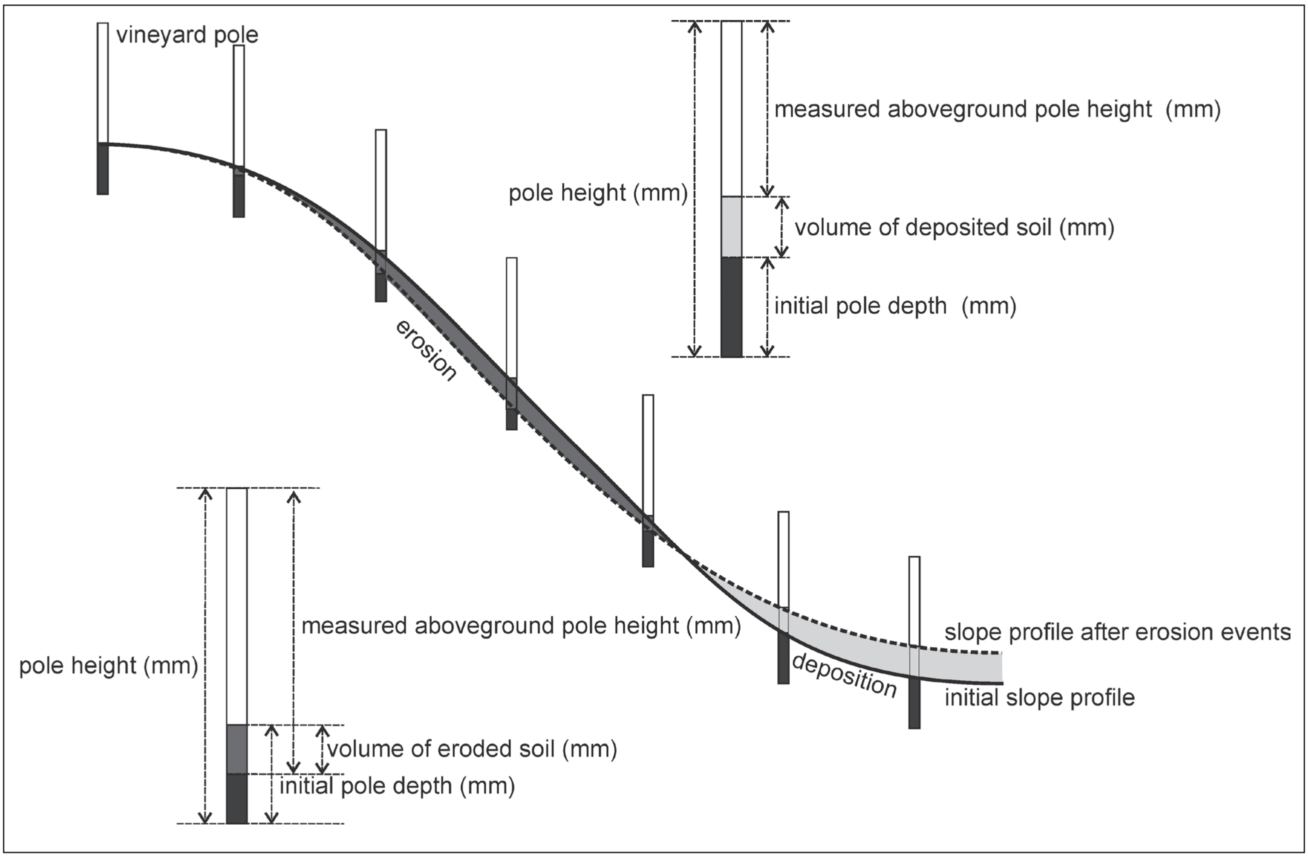

Fig. 2 Change of aboveground poles heights caused by erosion and deposition

founding were needed to calculate the volume of erosion or deposition at the test sites. The owners of the vineyards provided this information. The exposed aboveground lengths of the poles were then measured. The annual erosion or deposition (Δh) in mm year^{-1} was calculated as a difference between initial and measured exposed pole length (Eq. 1), where h_i is the total pole height (mm), d_i is the initial underground pole deepness (mm), h_m is the measured aboveground pole height (mm) and Δt is the vineyard's age (years).

$$\Delta h = (h_i - d_i - h_m)/ \Delta t \tag{1}$$

Obtained values in mm year^{-1} were transformed to annual erosion or deposition rates in t ha^{-1} year^{-1} (ΔA) with use of soil bulk density (ρ_d) in g cm^{-3} (Eq. 2).

$$\Delta A = \rho_d \cdot 10 \cdot \Delta h \tag{2}$$

The poles were uniformly manufactured, so the pole length remains the same. The holes for the poles were machine-dug, so the initial deepness remains the same with a deviation of ±1 cm. This is a source of error, the impact of which could be reduced by including many poles in our sample. A second source of error is caused by the possible vertical tilt of the poles. It could be due to a disturbance during the management of the vineyard, or due to the pressure of vines thru the wire. Thus any non-perpendicular tilted poles have been excluded from analysis.

Erosion modelling and calculation procedure

The Universal Soil Loss Equation (USLE) proposed by Wischmeier and Smith (1978) is a widely used basic equation for water erosion modelling. It has been revised often, and many erosion models are based on its equation input parameters. Even through there are more sophisticated erosion models derived from the USLE (Eq. 3), this experiment uses the USLE for computing the cover management and support practice factor of vineyards because all of the input parameters used in any derived models were originally measured and calibrated for the USLE

$$E = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{3}$$

where
E – Annual soil loss (t ha^{-1} year^{-1}),
R – Rainfall erosivity factor (MJ ha^{-1} cm H^{-1}),
K – Soil erodibility factor (t h MJ^{-1} mm^{-1}),
L – Slope length factor,
S – Slope gradient factor,
C – Cover management factor,
P – Support practice factor.

Rainfall erosivity (R factor) is determined as a function of a storm's total kinetic energy at its maximum 30-min intensity. For this experiment the value R = 25.71 was determined from data provided by the Vráble meteorological station, and derived by Malíšek (1990). Soil erodibilty (K factor) is a function of soil texture, organic matter content, structure, and permeability. The K factor values were derived from Bonited Soil-Ecological Units according to Ilavská, Jambor, Lazúr (2005). A digital elevation model (DEM), as an input for computing L and S factors, was derived from 1:10,000 scale contours maps. The elevation data were refined by geodetics measurements with the use of the ProMark 3 GPS device. The DEM was interpolated by using the regularized spline method.

Calculation of cover management and support practice factor

The calculation was based on a comparison between measured and modelled erosion. The support practice factor is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight-row upslope and downslope tillage, therefore we could estimate the value of the support practice factor for downslope ploughed vineyard at 1.000. According to that, it was possible to use the ploughed vineyard as a reference plot for the cover management factor computing. The erosion was modelled with the USLE model, and different values of C factor were substituted to the equation until the root mean square error between measured and modelled data was minimal (Eq. 4). With the known C factor value for the vineyards, the P factor for hoed and rotavatored vineyards could then be calculated in a similar fashion. The different P factor values were substituted to the USLE and modelled erosion or deposition values (P_i) were compared to measured values (O_i), until the root mean square error (RMSE) between measured and modelled data was minimal.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (O_i - P_i)^2} \tag{4}$$

4. Results

The measurements were carried out on 14 October 2008, and repeated on 26 October 2009. For this experiment, 102 poles in the ploughed vineyard, 81 poles in the hoed vineyard, and 168 poles in the rotavatored vineyard were measured. In 2009, the measurements were repeated for the ploughed and hoed vineyards only, because the vineyard that had been rotavatored until 2008 is now chemically weeded. The vineyards are located within the same soil and climate zones, and their slope profiles are also very similar.

The measured results show three situations on the each part of the slope. On the shoulder of the slope, erosion and deposition are in equilibrium. The part of deposited material is coming from an unpaved road above the slope. The backslope is characterized by the prevailing erosion process, which slightly increases with slope length and steepness. On the footslope, where the slope gradient decreases, soil is deposited at an increasing rate.

The ploughed vineyard appeared to be the most eroded, as the average erosion rate on the eroded part of the slope reached the value of 42.15 t ha^{-1} year^{-1}. Average erosion on the rotavatored vineyard was determined at 29.64 t ha^{-1} year^{-1}. Less eroded is the hoed vineyard with an average rate 24.40 t ha^{-1} year^{-1}. Ammount of the sediment is transported to the fields from the road above, and most of it is deposited on the lower part of the slope. Therefore the net erosion from the slope occurs at a lower rate. Total erosion occurs at a rate of 23.38 t ha^{-1} year^{-1} on ploughed vineyard, 4.39 t ha^{-1} year^{-1} on hoed vineyard, and 13.58 t ha^{-1} year^{-1} on vineyard tilled by rototiller cultivator.

The USLE model is designed for evaluating the erosion process only, and the transportation and deposition of eroded material are not modeled. Therefore, only the data measured at the eroded part of the slope could be compared with modeled data. The cover management factor for these vineyards was calculated to 0.692; the RMS error between modeled and measured data was 24.528. The support practice factor for the ploughed vineyard was estimated to 1.000. For the hoed vineyard is the support practice factor 0.586 with the RMS error 17.340; and for the rotavatored vineyard is the P factor 0.719 with the RMS error 24.316. The measured and modeled erosion rates are shown for each vineyard on Figure 3.

Based on calculated cover management and support practices factors, the USLE model could be used for estimating the erosion rates of the whole study area in different management scenarios (Figure 4). The erosion risk is very high in all cases, mainly on the steeper slopes and the lower backslope areas. Through the use of the USLE model and the recordings in the sample, the data determined that the highest estimated erosion would occur in ploughed vineyards, and the lowest estimated level of erosion would occur in hoed vineyards.

5. Discussion and conclusion

The method of measuring change in the exposed aboveground lengths of vineyard poles belongs to the group of erosion research leveling methods (Zachar, 1982). The use of this method can provide a large amount of long-term erosion data within a short time of data collection. A disadvantage is that the measurement could include changes caused by factors other than erosion, such as humidity variations, freezing and thawing, and cultivation, for example. To minimize these errors the measurements were taken in October, when the spring tillage furrows were evened and the soil was dry. Any effect of tillage erosion on soil leveling could be neglected because the tillage is formed parallel to the slope, so any soil displaced during tillage is moved along its contours. One source of error is the difference in the initial poles'

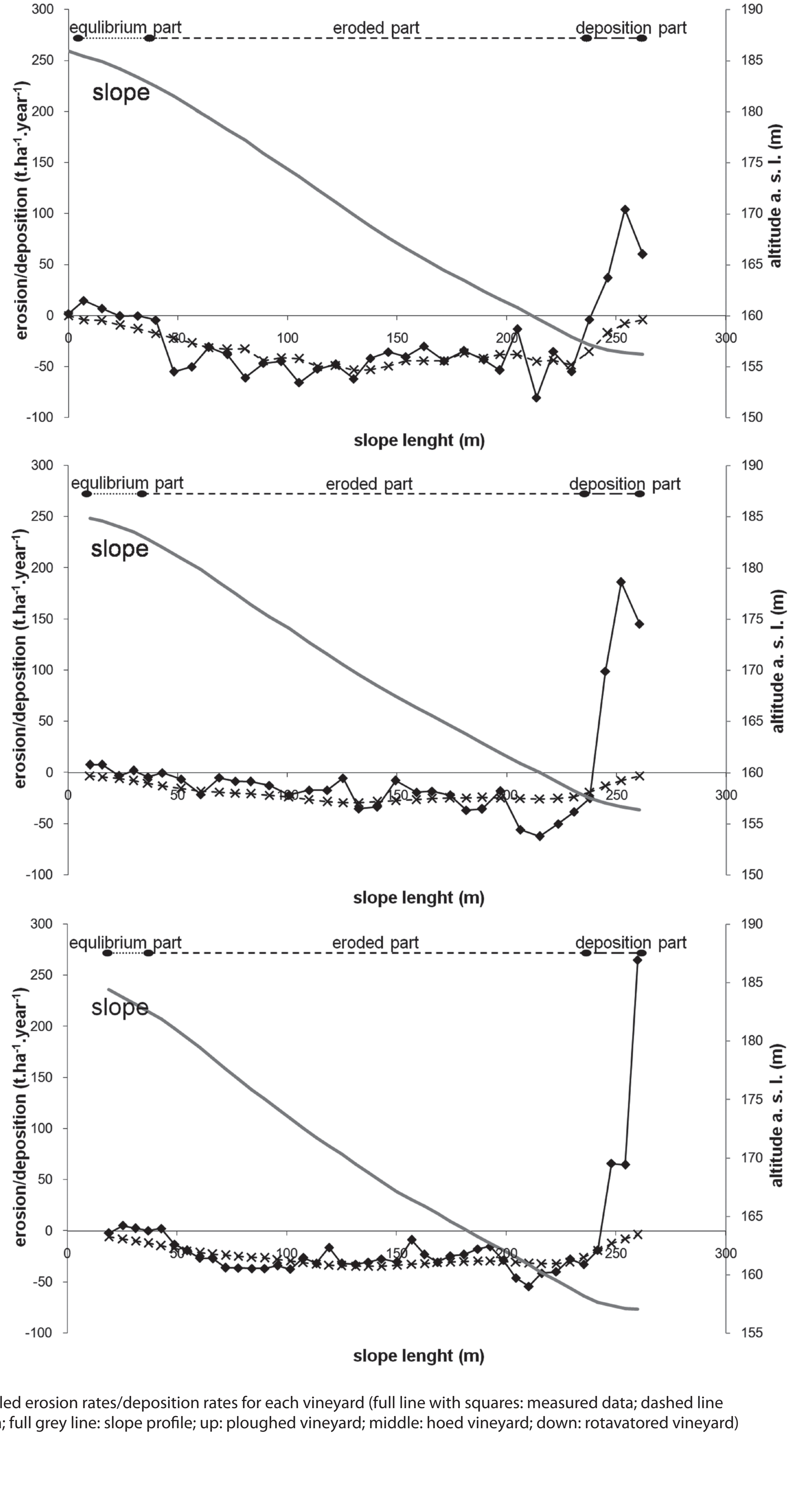

Fig. 3 Measured and modeled erosion rates/deposition rates for each vineyard (full line with squares: measured data; dashed line with crosses: modeled data; full grey line: slope profile; up: ploughed vineyard; middle: hoed vineyard; down: rotavatored vineyard)

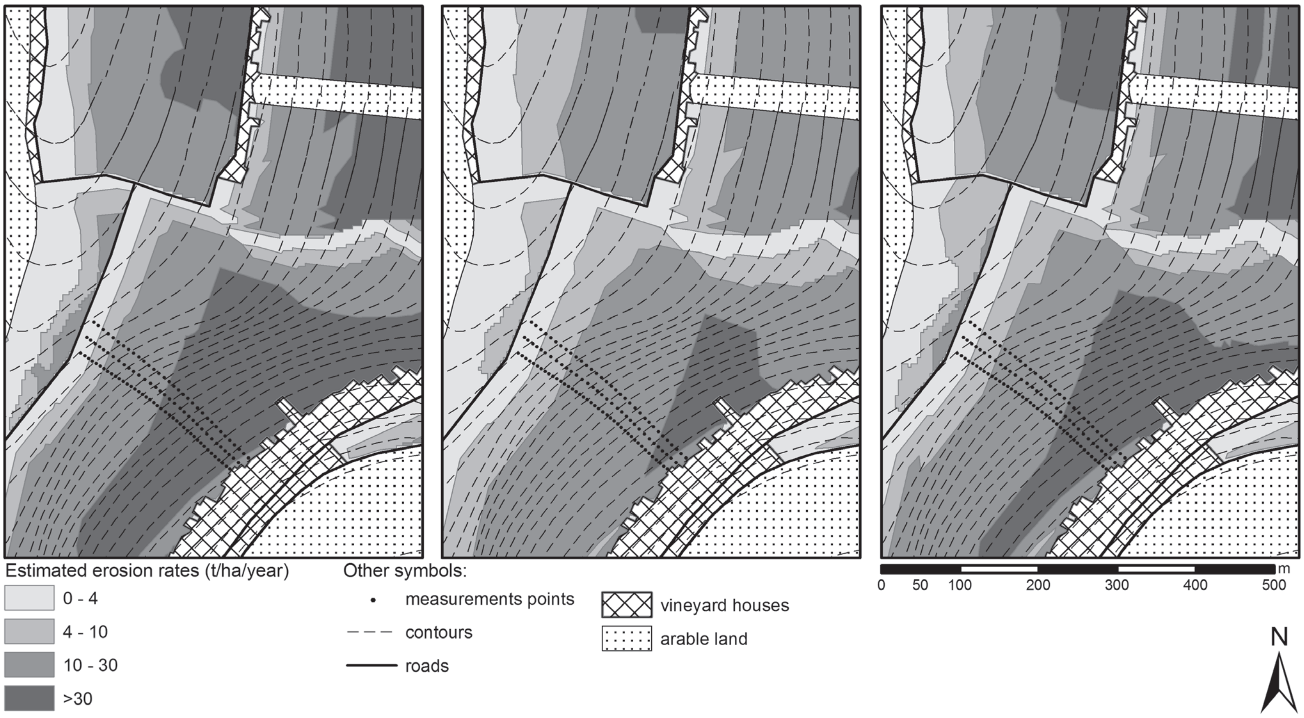

Fig. 4 Estimated erosion rates from the study area with use of three different management practices (left: ploughing, middle: hoeing, right: rototiller). Legend: estimated erosion rates (t ha^{-1} year^{-1}) 1. 0–4; 2. 4–10; 3. 10–30; 4. >30; other symbols: 5. measurements point; 6. contours; 7. roads; 8.vineyard houses; 9. arable land

heights, as described previously. Possible vertical shift of the poles could be a second source of error. The measuring method can be used in wire-trained vineyards only, with the known initial poles' total lengths and the year of founding.

The cover management factor and erosion control factor were computed as the result of a comparison between modeled and measured data. The cover management factor for vineyards is 0.692, which means that the vineyards experience a 30% reduced effect of erosion intensity in comparison with bare arable soil tilled along the slope gradient. Different tillage practices have anti-erosion effects as well; with the erosion control effect of hoeing being 0.586 and the effect of rototiller is 0.719 in comparison with ploughing along slope gradient. The accuracy of the results is influenced by the accuracy of the model input parameters and the method of erosion measurements. The high RMS error between modeled and measured data can be due to natural erosion data variance and measurement errors. However, by using a large sample of measured data the experiment minimizes the total error.

Even though there are a variety of soil erosion models (see Harmon, Doe, 2001), this experiment used the basic USLE for analyzing the vineyards' C and P factors due to the fact that all values of cover-management and support practice factors, used in empirical and semi-empirical USLE-based models, were originally derived for the USLE itself. Obtained C and P factor values could be used in more sophisticated USLE-based models like RUSLE, USPED, WaTEM-SEDEM, or SWAT in future studies.

The computed anti-erosion effect of vineyards (C = 0.692) is very low, which is in compliance with previous studies reporting vineyards as the most erosion-prone land use category (Cerdan et al., 2010; Wicherek, 1991; Kosmas et al., 1997; Hooke, 2006). There is high erosion in these areas because the vineyards are located on steep slopes, there is an absence of vegetation cover in inter-row areas, and the cultivation is often performed parallel to the slope gradient.

In comparison with other studies that use USLE-based models for erosion analysis in vineyards, the C factor value for the ploughed vineyard in this study (C = 0.692) is quite high. Jordan et al. (2005) used the value C = 0.5 for modeling the impact of land use changes on sediment fluxes in the Balaton basin vineyard area. Pelacani et al. (2008) used the USPED model to simulate the erosion and deposition rates in changing land use in central Tuscany, with a C factor value ranging from 0.163 to 0.451 for new vineyards less than 3 years old, and a value of 0.451 for older vineyards. The value derived by Malíšek (1992) for vineyards in Slovakia is 0.62. The lowest C factor value, C = 0.2, was used by Bakker et al. (2007) for modeling the response of soil erosion and sediment export to land use change in four areas of Europe (Lautaret, France; Hageland, Belgium; Amendoeira, Portugal; and Lagdas, Greece). The C factor value computed in this study is higher because it was evaluated for the most eroded vineyard ploughed along the slope gradient. Use of alternative methods of cultivating could reduce the erosion susceptibility. Otherwise, the C factor value for the rotavatored vineyard is 0.498 and for the hoed vineyard the value is only 0.406. Obtained results were tested on Horný Ohaj vineyards only. There is a need to repeat the experiment in other vineyards to get more experimental data comparing the anti erosion effect of different vineyards in different conditions.

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RÉSUMÉ

Výpočet protierozního účinku vinic na základě naměřených údajů – případová studie z vinohradnického okrsku Vráble (Slovensko)

Vinohrady Vrábelského vinohradnického rajónu, který patří do Nitranské vinohradnické oblasti, jsou vysazené na sprašových půdách Hronské pahorkatiny. Výzkum intenzity půdní eroze a depozice ve vinohradech byl realizovaný v letech 2008 a 2009 na úzkopásových soukromých vinicích v katastru obce Horní Oháj, severovýchodně od města Vráble. V předložené studii je hodnocena míra eroze, respektive protierozní vliv vegetačního krytu a způsobu obhospodařovaní vinohradů, jako hlavní faktor pro erozní modely založené na univerzální rovnici ztráty půdy (USLE). Protierozní účinek vinic byl hodnocený porovnáním naměřených hodnot intenzity eroze a depozice s hodnotami zjištěnými pomocí erozního modelu půdy USLE. Intenzita eroze a depozice byla měřena změnou nadzemní výšky viničních sloupů způsobenou odnosem půdy na erozní části svahu a akumulací na depoziční části svahu. Do modelu USLE byly vloženy různé hodnoty faktoru vegetačního krytu (C faktor) a vlivů protierozních opatřeni (P faktor), až byla dosažena minimální střední kvadratická chyba mezi naměřenými a namodelovanými údaji. Tímto způsobem byl vypočítán faktor protierozního vlivu vegetačního krytu vinic a zpracování půdy orbou, pomocí rotavátoru a okopáváním. Vinice snižují erozi přibližně o čtvrtinu v porovnání s půdou nechráněnou vegetací (hodnota vegetačního faktoru je 0,692), orbou po spádnici se eroze nesnižuje (hodnota faktoru protierozní opatření je 1,000). Okopáváním lze snížit erozi takměř o polovinu (hodnota faktoru je 0,586), protierozní účinek zpracování půdy pomocí rotavátoru je nižší (hodnota faktoru je 0,719).

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