EVALUATION OF THE RELATIONSHIP BETWEEN SOIL EROSION AND THE MINERAL COMPOSITION OF THE SOIL: A CASE STUDY FROM A COOL CLIMATE WINE REGION OF HUNGARY

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Abstract: Sedimentological investigations and thermal analyses were carried out in a steep slope vineyard in 2007 (Nagy-Eged hill – located in the north-eastern part of Hungary). This area is proned extremely eroded due to its significant steepness and vine-growing cultivation. Soil thickness is approximately 50 cm near the top while at the bottom the thickness of horizon A alone reaches up to 150 cm. According to the results the ratio of fractions smaller than 0.02 mm and those larger than 2 mm between the top and the bottom is reverse. In the lower slope section the ratio of particles smaller than 0.02 mm is three times that in the upper slope section. Similarly the ratio of particles larger than 2 mm in the lower slope section is five times that in the upper slope section. The quantity of clay minerals measured by thermal analysis is larger than that measured by elutriation indicating that a part of them exceeds the diameter of 2μm. Our results revealed the effects of soil erosion on the mineral composition of the soil. The amount of clay minerals (e.g. montmorillonite) is about the double in the lower section, than in the upper of the slope. Clay minerals caused negative water budget in the upper levels resulting in the occurrence of anthropogenic water deficit as the consequence of soil erosion. Therefore vegetative growth of plants in the lower areas is better than that of those in the upper areas.

Keywords: terroir, soil erosion, sedimentology, thermal analysis, clay mineral, lack of water, vegetative growth

1. INTRODUCTION

Land-use practice of Hungarian vineyards changed in recent decades. These changes occur at several levels. Taking landscape and environment these changes can be evaluated from the aspect of the "terroire" due to their comprehensive character. The terroire is composed of four elements (Vaudour, 2001; Biancotti, 2003) including production site factors, spatial organization of natural and social systems in order to achieve viticulture targets, landscape forming aspects of vine-growing and it also functions as a kind of trade-mark applied in marketing.

Hungarian experts consider only the natural conditions (primarily soil and micro-climate) of the production site as decisive considering the terroire (Lóczy & Nyizsalovszki, 2005).

Considering production site factors, (apart from climatic and relief studies), soil analyses also have increasing role in recent years. Several studies revealed that the exposition, steepness of the vineyard and the physical properties of the soil have a significant effect on grape yield and quality (van Leeuwen & Seguin, 2006; Coipel et al. 2006). Vineyards in cool climate wine regions – like Eger wine district – mild to moderate water deficit may occur due to the southern, steep slope aspect and/or the poor soil water retaining capacity (van Leeuwen & Seguin. 2006; Coipel et al. 2006; Bálo et al., 2007; Zsófi et al., 2009). In addition, this effect can be also increased by soil erosion. Moreover the soil quality has a relevant role in shaping rural landscape patterns in Hungary (Szilassi et al., 2010).

The present paper aims to discuss the consequences of relative situation on soil properties (mineral and granulometrical composition) and thus on the vine ecophysiological processes (canopy measurements and gas-exchange) in a cool climate vineyard (Nagy-Eged hill, Hungary).

Our investigation consists of two parts: (1) grade and consequences of soil erosion intensified by anthropogenic effects are studied by grain-size and mineral composition analyses of the soil (2) a study of vine ecophysiology affected by water deficit due to soil characteristics and erosion.

2. MATERIALS AND METHODS

2.1. Research area

Nagy-Eged hill is located 1.5 km from Eger towards the north-east in the southern foreland of the Bükk Mountains, North Hungary. Due to its excellent conditions it has been an area of vine production for centuries and experiencing an upswing since the 1990s.

Due to the mesoclimatic characteristics of this area, Nagy-Eged hill is one of the most unique, however, typical grape growing filed of the Eger Vine Region. This is partly the result of that grape fields reach over 500 m on the cultivated southern slope making the production field the highest one in this vine region. On its steep southern slopes angle of incidence of sunlight is almost 90° in summertime. The rocky upper slopes provide excess heat for the grapes at night due to their heat retaining capacity while at daytime the bright stone surface reflects some part of the sunlight. These factors naturally play important roles in the water loss of the soil as well. Soil erosion plays a role in the production field also.

Taking geology, Oligocene loose Buda Marl Formation (This formation is characteristically light-yellowish grey, generally well-bedded, thick-bedded sandy calcareous marl with 60-80% carbonate content. The formation is 20-50 m thick.) appears at the foot of the southern slope of the hill overlain by the Eocene Szépvölgy Limestone Formation. This formation built up of light-greyish-yellow, frequently nodular, massive limestone with thinner or thicker marl layers intercalating them. It is a typically biogenic limestone; its dominant elements are red algae. The total thickness of the Szépvölgy Limestone is about 50 m. On top above 500 m the Triassic Felsőtárkány Limestone Formation (ftT3) covers the series (Fig. 1), which is built up of light grey to dark aphanitic and fine-crystalline limestone. It consist of chert nodules and chert intercalations in a fluctuating density. The thickness of the formation in the South

Bükk ranges from 300 to 500 m (Pelikán, 2005). These formations dip towards the south giving way to soil erosion and the rapid run-off of surface water.
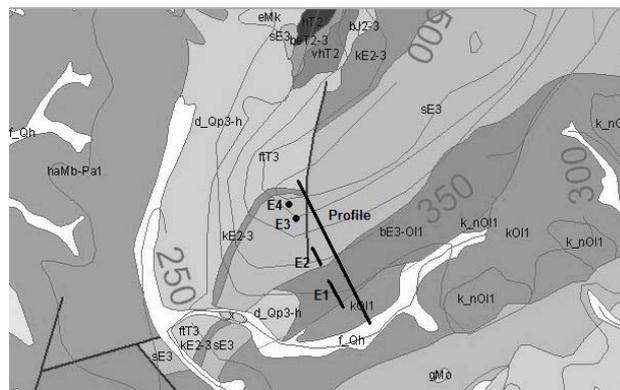

Figure 1. Geological map of the study area and its surroundings

Legend: hT2 – Hámori Dolomite Formation; beT2-3 – Berva Limestone Formation; vT2 – Várhegy Formation; ftT3 – Felsőtárkány Limestone Formation; kE3 – Kosd Formation; sE3 – Szépvölgy Limestone Formation; bE3-Ol1 – Buda Marl Formation; kOl1 – Kiscell Clay Formation; gMo – Gyulakeszi Rhyolite Tuff Formation; haMb-Pa1 – Harsány Rhyolite Tuff Formation; eMk – Egyházasgerge Formation; d_Qp3-h – Deluvial sediments f-Qh – Fluvial sediment; (Source: www.mafi.hu – United Geological Map pf Hungary Scale=1:100.000)

Original soil type of the Nagy-Eged is clay rich brown forest soil (Cambisols and Luvisols) that has been eroded significantly as a result of centuries long cultivation (Szabó, 2000). Soil erosion was strongest in the areas elevated above 450-500 m where soil thickness stays below 50 cm at places. Here the soil was degraded into a deteriorated lithosoil abundant in stone fragments. Downwards accumulated material increases and the thickness of horizon A of the soil reaches 90 cm at the height of 380 m while it is 150 cm at the bottom of the hill (at 298 m).

Original vegetation in the southern slope of the hill remains only in a very limited area due to grape-growing enabling soil erosion. Grape rows are parallel the slopes for easier cultivation. Terraces are constructed only along extremely erosion prone gullies (Marosi & Somogyi, 1990).

2.2. Applied methods

Mixed samples were taken in three sections (E1, E2, E3) of the southern slope of the Nagy-Eged in September 2008 for sedimentological and thermal analyses. 39 soil samples were taken in order to describe the three slope sections depending on the estimated magnitude of denudation and accumulation and on soil thickness. In the cases of E1 and E2 model areas samples were taken from

every 30 cm down to 180 cm while in section E3 only two samples were taken from 35 and 50 cm due to the thin soil layer (Figs. 2 and 3). Sampling was performed by profile digging or by an Eijkelkamp sampler depending on the composition of the soil. Location and elevation of all sampling sites were recorded by a GPS.
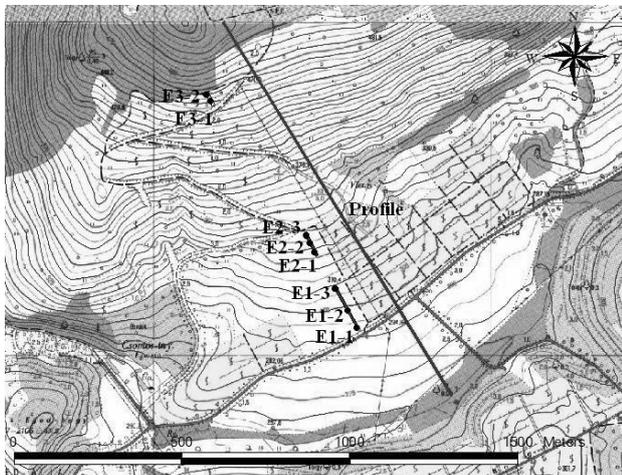

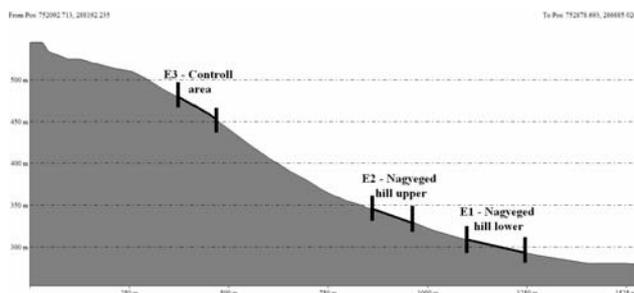Figure 2. Sampling sites and the slope profile

Figure 3. Studied slope sections

In the course of preparation the samples to be analysed sedimentologically were filtered by 0.2 mm sieves after boiling and then they were dried at 105 °C. Grain-size distribution was determined by sieving and settling in the case of fractions larger and smaller than 0.2 mm respectively. Settling analyses was not possible to perform in the case of samples marked E2 90-120, E2 120-150 and E2 150-180 because the ratio of particles smaller than 0.2 mm was less than 10% (it was below 3.5%).

Samples for thermal analysis were dried at 75°C for 24 hours then differential thermal analysis (DTA), thermal gravimetry (TG) and derivative thermal gravimetry (DTG) were performed on them. Measurements were performed by a MOM Derivatograph-C type instrument. Al_2O_3 heated to 1000°C with volume equal to that of the soil samples was used as inert material. Weight of samples was 100 mg +- 0.1 mg. In the course of the measurement soil samples were heated to 1000°C with steps of 10°C thus thermally active minerals were determined.

As the result of heating the following reactions took place (Földvári. 1986):

1. adsorptive water content and the interlayer water of clay minerals were released at between 25°C and 250°C;

2. between 250 °C and 450 °C organic matter is oxidised;

3. between 450°C and 600°C dehydroxilation of clay minerals (primarily degraded montmorillonite) takes place;

4. between 650°C and 850°C disintegration of calcite and release of CO_2.

Quantity of thermally active minerals was calculated as the product of multiplication of weight loss due to decomposition and the stoichiometric factor of the reaction. Minerals identified in the samples and the stoichiometric factors are given in table 1 (Földvári & Rozs, 1989).

Table 1. Minerals identified by the thermal analysis, their reactions and stoichiometric factors

Mineral	Reaction	Stoichiometric factor
montmorillonite	H_2O loss	4.2
montmorillonite	OH loss	23.8
chlorite	OH loss	9
kaolinite	OH loss	7.17
ferrihydrite	OH loss	5.9
calcite	CO_2 loss	2.21
organic matter	burning	1

Thermal analyses gave information on the composition of the soil samples taken from different sections of the slope. Assessment of the curves was performed by the software WINDER that is based on previous analyses (Szöőr 1982, Szöőr et. al., 1984, 1991).

Differences between the different parts of the profile was analysed by Mann-Whitney test. Since the sample size was small this non-parametric test and the Monte-Carlo permutation method (based on 10.000 random assignments) were applied to control the asymtotic probability value of the tests (Sokal & Rohlf, 1969). The effect size (as statistical power) shows the extent of the difference found between the examined groups in a standardised, thus comparable form (Cohen, 1992).

The vines at both vineyards (E1 – Nagy-Eged hill lower, E2 – Nagy-Eged hill upper) were umbrella trained, with south–north row orientation with 3 m Ą 1.2 m row and vine spacing, at the same pruning level (6 buds/m) on Teleki 5C (Berlandieri X Riparia) rootstocks.

In situ gas-exchange parameters were measured by CIRAS-1 portable infrared gas analyser

(PP System, UK) in 5–10 replicates per sampling. Measurements were taken on different plants (selected randomly from each vineyard), on mature, undamaged leaves that had grown fully-exposed to the sun. During the gas-exchange measurements there were no significant differences between the sites with regard to light intensity (PAR – Photosynthetically active radiation) vapour pressure deficit (VPD) and temperature (T), although seasonal fluctuations were observed in these parameters. All measurements were taken at both sites within 1 hour in order to obtain comparable data. Due to the local weather conditions and the south–north row orientation the most proper time for these measurements was early afternoon, when leaves were fully exposed to the sun.

Canopy measurements were carried out using the point quadrate method according to Smart & Robinson (1991). Measurements were taken during the ripening period in 4-5 replicates per sites at both vineyards. LLN (Leaf Layer Number), CW (Canopy Width) and PG (Percent Gaps) data are presented. Duncan's test was applied to reveal the significant differences in the statistical analysis.

3.RESULTS AND DISCUSSIONS

3.1. Sedimentological investigations

The studied slope sections can be classified into two groups according to their grain-size (Fig. 4). In the upper areas (E2, E3) the ratio of gravel is (>2mm) larger than 30% while the ratio of the fine fraction, especially that of grains <0.02mm is

relatively small (Fig. 4). With increasing depth the ratio of coarse fragments increases while that of fine fraction decreases. For example, in the depth of 120-150 cm zone of slope section E2 the ratio of grains larger than 2mm exceeds 90% and clay fraction is almost completely missing (less than 1%). Difference between slope sections E2 and E3 is soil thickness. In the case of slope section E3 located in the upper parts, soil thickness is less than 50 cm.

However, there is no significant difference between the grain-size distributions of the layers located at similar depths in the two sections. The other group is represented by slope section E1 at the bottom of the hill with the dominance of fine grains over the coarse fraction. In contrary to the upper slope sections the ratio of fine fraction especially that of the clay fraction within it increases with depth.

It is worth mentioning that the ratio of the gravel fraction larger than 2mm is significant in the 0-30cm layer of slope sections E1 and E2. This can be explained by the erosion of the last decades. Slope orientated rows and bare areas between rows enabled the accumulation of not only the fine fraction but that of the gravel eroded from the upper areas.

3.2. Thermal analyses

Following the assessment and comparison of the measurement results it was revealed that in slope section E1 clay mineral content increases with depth, which is the result of clay filtration. Ratio of clay minerals also increases towards the lower accumulation areas.
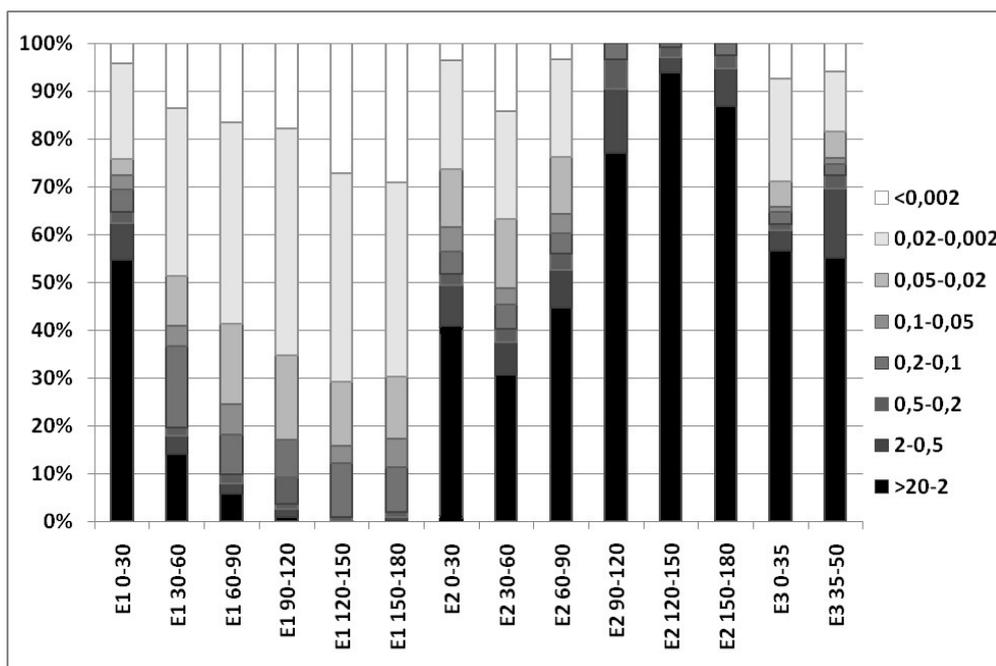

Figure 4. Cumulative grain-size distribution diagram of the given slope sections (E1, E2, E3)

In areas of greater erosion calcite content increases while it decreases in areas of accumulation. This can be explained by the fact that the larger and heavier mineral grains of calcite are more resistant to erosion than clay minerals (Figs. 5, 6, 7 and table 2). These results support the results of sedimentological investigations presented above.
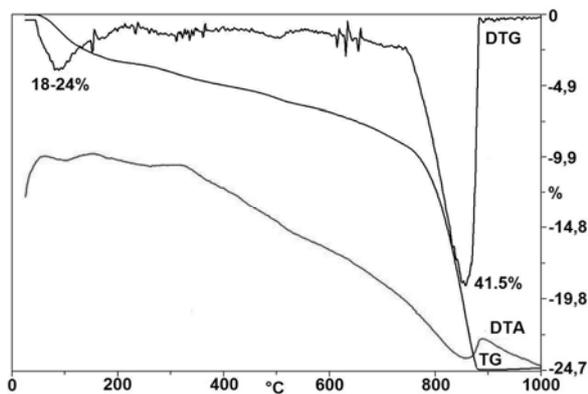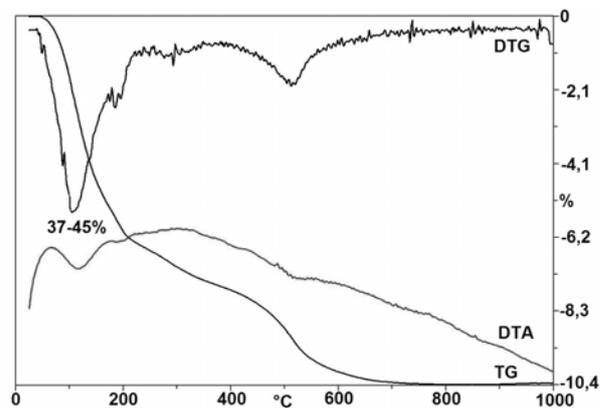

Figure 5. Thermal curve of layer E3 35-50 cm

Figure 6. Thermal curve of layer E2 60-90 cm

For comparison thermal analysis of some soil samples from the Síkhegy was performed as well (Fig. 8). Síkhegy is located 1.5 km south of Nagy-Eged and it is also cultivated by vine-growing. The hill is composed on the sandy-tuff weathered mixture of the Oligocene Egri Formation (^{e}Ol) and the Gyulakeszi Rhyolite Tuff Formation (^{g}M). Based on the results it can be stated that the thermal curves, the clay mineral and calcium carbonate content of the samples (marked as SH) from here are nearly exactly the same as those of the samples from E1. The difference is that these values can be associated with the natural clay content of the soil at Síkhegy while high ratio of clay content is the result of soil erosion and accumulation at Nagy-Eged.

We proved the significant differences of montmorillonite and calcite between the upper and lower section of the profile (Table 3).

Table 3. Differences between the profile sections according to Mann-Whitney test (M.sig.: significance of montmorillonite; C.sig.: significance of calcite)

Sections	M.sig.	Effect size	C.sig.	Effect size.
E1-E2	0.01	-0.72	0.002	0.81
E2-E3	0.85	0.06	0.64	0.18

Figure 7. Thermal curve of layer E1 60-90 cm

Figure 8. Thermal curve of layer SH 60-90 cm

Section E1-E2 differs significantly and the signs of the effect size show that montmorillonite and calcite behave contrary: calcite does not move downwards, stay in the upper zone, but montmorillonite does and accumulates in the lower zone. Difference of the investigated minerals does not reach the significance level (p<0.05) in the case of Section E2-E3. It means that both parts are eroded regardless of the elevation.

3.3. Grapevine ecophysiological investigation

Water deficit induce significant effect on plant ecophysiological responses. In higher plants gas-exchange (transpiration rate and CO_2 assimilation rate) is particularly sensitive to drought (Mouthinho-Pereira et al., 2004, Pou et al., 2008).

Table 2. Results of derivatograph analyses of samples from the Nagy-Eged and the Síkhegy (%)

| Sampling place	Depth (cm)	montmor-illonite	illite	kaolinite/chlorite	calcite	iron hydroxide	organic matter	pyrite
E1	0-30	17-28	<30	<9	20	<9	<2	-
E1	30-60	31-37	<21	<6	7-8	<12	<2	1
E1	60-90	35-40	<14	<5	1	<13	<2	2
E1	90-120	36-40	<11	<3	-	<12	<2	1
E1	120-150	40-44	<14	<4	-	<9	<2	1
E1	150-180	49-52	<9	<3	3	<7	1	-
E2	0-30	15-25	<30	<9	27	<11	<2	-
E2	30-60	26-31	<11	<4	23	<10	<2	-
E2	60-90	18-24	<15	<5	41.5	<9	<2	-
E2	90-120	8-11	<10	<3	74	<3	<1	-
E2	120-150	15-17	<6	<2	59	<1	-	-
E2	150-180	16-21	<17	<5	45	<2	-	-
E3	0-35	14-19	<11	<4	20.5	-	<3	-
E3	35-50	18-20		<5	58	<13	<3	-
Sh	30-60	44-49	<15	<5	-	<7	<2	-
Sh	60-90	37-45	<26	<8	-	<5	<1	-
Sh	90-120	47-51	<14	<4	-	<5	<1	-
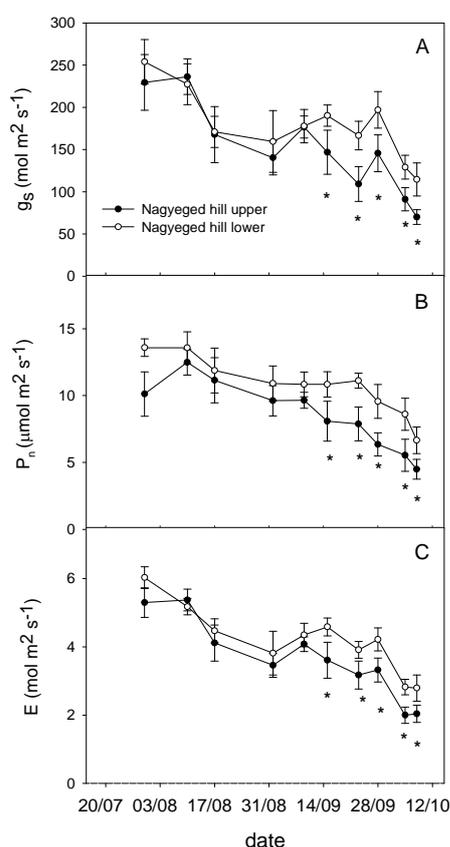
Figure 9. Midday stomatal conductance (g_s - A), net CO_2 assimilation rate (P_n - B) and transpiration rate (E - C) at the lower (line with open symbols) and at the upper part of Nagy-Eged hill (line with filled symbols) during the growing season. Each symbol represents the average±standard error (SE) of 7–10 replicates from early afternoon. SE values marked by asterisk are significantly different from the values at the other site ($P < 0.05$) according to Duncan's test.

Under mild to moderate water deficit transpiration and assimilation are decreased because of stomatal regulation (Medrano et al., 2003; Zsófi et al., 2009). Severe drought results in non-stomatal limitation such as decayed electron transport, reduced RuBP regeneration capacity (Medrano et al., 2002, 2003) and oxidative stress damages (Flexas et al., 2006). Stomatal conductance is one of the earliest and most sensitive responses against water deficit; therefore g_s value can be used as an integrative parameter to assess degree of water deficit (Medrano et al., 2002, Cifre et al., 2005). In our study the upper part of Nagy-Eged hill generally presented slightly lower values of gas-exchange parameters compared to the lower part of the hill in many times, (Fig. 9) indicating lower water supply at this site.

Table 4. Leaf layer number (LLN), canopy width (CW) and percentage of gaps (PIC) measured at the ripening period in 2009. Different small letters indicate significant differences between the sites according to Duncan's test ($P < 0.05$).

Vineyard	Leaf layer number	Canopy width (cm)	Percent gaps (%)
Nagy-Eged hill upper	2.9±0.32[b]	29.08±2.48[b]	12.5±5[a]
Nagy-Eged hill lower	3.9±0.26[a]	41.62±4.84[a]	2.00±4.47[b]

As a result, intensity of assimilation rate and transpiration rate was also lower at the upper part of the hill. Decreased carbon assimilation has a significant effect on grapevine vegetative growth (Zsófi *et al.* 2009). Our point quadrate measurements indicated that there was a higher

canopy density (LLN, CW, PG) at the hill pediment than towards the upper experimental site (Table 4).

In conclusion, at the upper part of the hill lower water supply resulted in lower carbon assimilation of grapevine canopy and therefore it had a significant influence on vegetative growth

4. CONCLUSIONS

Natural soil conditions of the Nagy-Eged have been altered significantly due to erosion by today. This alteration affected the upper areas disadvantageously from where the fine fraction components of the soil and the clay minerals together with them have been almost completely removed. The same processes were identified in several areas in Hungary (Szabó, 2002; Kitka et al. 2006; Lóczy & Pirkhoffer, 2009; Centeri et al. 2010; Vágó, 2010; Czigány et al., 2011).

Calcite is important because of the Ca-demand of the vine and its continuous availability is ensured by the parent material. However, montmorillonite, which has serious effect on the water regime of the soil, cannot form again. Montmorillonite forms from silicates (dos Muchangos, A.D. 2006). The main rock type that contains silicate is the rhyolite tuff. Nagy-Eged hill was covered with it in the Tertiary Period, but it had been denuded (Nagymarossy. 1981). Nowadays, there is no more rock to provide clay minerals in the upper section.

Alterations mentioned above are proved by the ecophysiological investigations as well. However, as grapevine (*Vitis vinifera* L.) is a very drought tolerant plant, these changes may result in the improvement of grape and wine quality (Ojeda et al., 2002). A slight and moderate water deficit is one of the most important components of production site effect (van Leeuwen & Seguin, 2006) therefore these changes are beneficial for quality wine making. This is why the quality of wine in the upper areas is higher than that of wine from the lower areas. However, in dry vintages, the upper area may be exposed to severe water deficit that can be harmful for the quality of the grape. In the lower area of the hill, shoot growth might result in abundant vegetative activity that may reduce grape and wine quality.

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