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THE EFFECT OF LAND USE ON SOIL AGGREGATE STABILITY IN THE VITICULTURE DISTRICT OF MODRA (SW SLOVAKIA)

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Abstract

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Lack of information still exists on relationships between the land use and various soil management practices on soil aggregate stability. This work focuses on the effect of soil management on soil properties and aggregate stability in the viticulture region where the soils are influenced by management practices such as deep ploughing before vineyard establishment and the long-term cultivation of grapevines and forestry. The obtained results showed marked differences in physical and chemical soil properties between the four study sites. In particular, the soil pH values and the contents of organic carbon and clay-fraction differed significantly. The comparison of the aggregate stability values determined for the various soil management systems indicated differences between the vineyard and forest sites. Soil aggregate stability decreases approximately according to the order where comparable original forest soil and afforested vineyard soil have greater stability than vineyard soil which is more stable than deeply ploughed vineyard soil. From all the soil properties studied, the soil organic matter content appears to be the main determining factor controlling aggregate stability.

Key words: vineyard soils, forest soils, soil erosion, aggregate stability, soil properties

Introduction

The sloping regions of Slovakia with suitable exposure were most likely devoted to viticulture from as early as the 5th century (Slavkovský, 2002). The effect of viticulture on landscape processes is manifold, especially in regard to deforestation of the sloping areas which have favourable exposure to sunlight. Since Slovakia occupies a marginal position within the European wine-growing sphere, increasing effort to locate the most advantageous areas has led to deforestation and the use of relatively steep slopes. This is significant in relationship to the creation of conditions for surface water runoff and erosion processes. Additional fact significantly affecting the water infiltration and erosion in deforested areas is the subsequent destruction of the overlying litter biomass, whose existence plays a very important role in the soil surface.

Another effect of viticulture arises from modification of the soil profile by the deep-ploughing prior to vineyard establishment. This practice involves overturning the soil horizons and moving the humus horizon to a depth of 40–60 cm where grapevines develop their best root system. Subsurface horizons (B_V or even C) with low humus content, coarser texture and stones are then relocated to the surface as a result of this deep ploughing practice (Kolény, 2001). Grapevine cultivation comprizes a planting system which maintains wide rows between grapevine plants without vegetation cover. This planting system together with the orientation of the plant rows along the fall line resulted in the increase of the surface runoff after heavy rainfall.

The change of the soil structure immediately after vineyard establishment can lead to increased soil erosion and reduction in the soil depth. Soil structure influences water movement into the soil profile and therefore controls soil system functioning. This facilitates development of vegetation cover, and both factors indirectly affect soil erosion rates. Soil aggregate stability is of major importance in regard to many aspects directly and indirectly related to the soil erosion and degradation (Mataix-Solera et al., 2011). The soil aggregates are the result of the organization of soil mineral and organic particles. Soil aggregation can be defined as any stable association of individual particles of the same or different nature, as a result of granulometric composition, soil biology and soil physico-chemical properties (Mataix-Solera et al., 2011).

The aim of this paper is to investigate 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 surface runoff formation. Attention was paid not only to the present grapevine fields but, for comparison, to the original forest soils and also to vineyard soils damaged by grape phylloxera at the end of 19th century and abandoned over a hundred years ago. The results are supported by the data from laboratory analysis and from experiments using a rain simulator.

Material and methods

The study area is located on the south eastern slopes in the central part of the Malé Karpaty Mts, in the Modra city surrounds (Fig. 1). Soils in this study developed from granitic rocks and they belong to the Haplic Cambisol (Dystric, Skeletic) group according to the WRB (2006).

Ten soil samples (2–3 kg) were taken from topsoils (0–10 cm) at each of four study sites, which are characterized as follows:

1. Forest soil (FS), localization: 48°19'41.8" N, 17°16'43.7" E, vegetation: the Carpathian oak-hornbeam forests of the *Carici pilosae-Carpinetum* Neuhäusl et Neuhäuslová-Novotná 1964 association. The studied stand has a strongly developed tree and shrub layer which is formed by the *Quercus petraea* agg. and *Carpinus betulus* and a poor herb layer dominated by forest mesophytes.

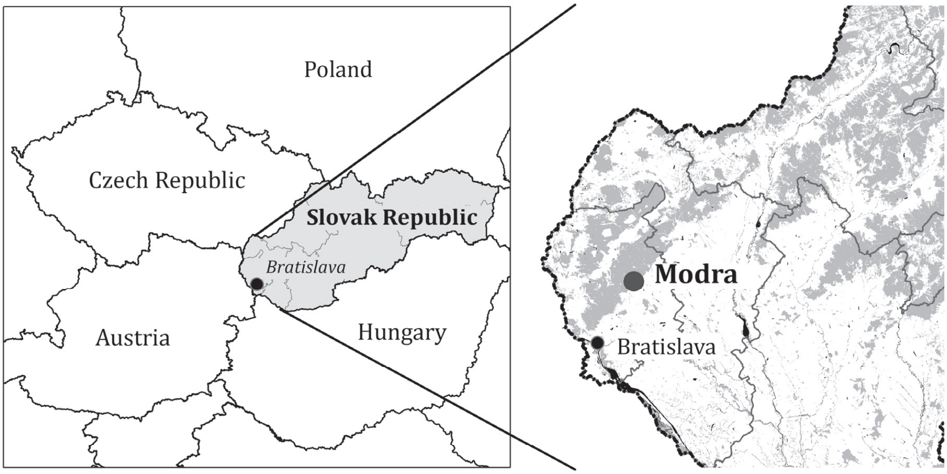

Fig. 1. Location of the study area.

2. Afforested former vineyard soil nominated (AVS), localization: 48°19'23.1" N, 17°16'50.3" E, vegetation: forest in the advanced succession stage aiming at the natural oak-hornbeam forest mentioned above. Here, the tree layer is dominated by the *Quercus petraeae* agg. The herb layer species composition consists of both natural and synanthropic species (a mixture of mesophytes and nitrophytes).
3. Vineyard soil (VS), localization: 48°18'53.0" N, 17°16'58.3" E, vegetation: variable segetal vegetation, traditionally classified into the *Veronico-Euphorbion* S i s s i n g h ex P a s s a r g e 1964 alliance; its actual state depends on the particular management.
4. Deeply ploughed vineyard soil nominated DPVS, localization: 48°18'56.2" N, 17°16'54.1" E, vegetation: as mentioned above.

Gravel and plant residues were removed from the samples. Soil samples were air-dried and ground to pass a 2 mm sieve before physical and chemical analyses. Additional samples for aggregate stability analysis contained soil aggregates 4–0.25 mm separated by sieving after air-drying.

The determinations of soil pH, total organic carbon content, and particle size distribution were made by standard methods (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 (C_{org}) was determined by oxidation with $K_2Cr_2O_7$-H_2SO_4 and titration of non-reduced dichromate.

Aggregate stability was measured in triplicate per soil sample with the rainfall simulator method described in Mataix-Solera and Doerr (2004). This method examines the proportion of aggregates (4–0.25 mm) that remain intact after the soil sample is subjected to artificial rainfall with the specific intensity of 270 J m^{-2} for 1 minute.

Results and discussion

The effect of soil management on the soil properties

The average values of soil chemical properties and particle size distribution are listed in Table 1. The soils developed from the granitic rocks and their weathering produced acid soil

T a b l e 1. Average values of chemical and physical properties determined for soil samples from viticulture district of Modra.

Study site	n	C_{org}		pH		pH		Particle size fractions (%)						SA	
		%		H_2O		KCl		2 – 0.05 mm		0.05 – 0.002 mm		< 0.002 mm		%	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev
VS	10	2.03	0.14	7.52	0.16	6.77	0.16	47.1	2.5	38.2	1.0	14.7	1.9	49.1	6.2
DPVS	10	1.83	0.50	6.95	0.61	6.00	0.73	49.9	3.2	38.9	2.4	11.3	1.1	28.8	8.3
FS	10	5.72	1.73	4.33	0.14	3.16	0.06	55.8	3.8	34.6	3.1	9.6	0.9	91.5	2.1
AVS	10	7.32	1.16	5.67	0.43	4.90	0.51	63.2	2.8	30.7	2.7	6.1	0.9	88.5	2.7

Abbreviations: VS – vineyard soil, DPVS – deeply ploughed vineyard soil, FS – forest soil, AVS – afforested vineyard soil, n – number of samples, , C_{org} – organic carbon content, SA – stability of aggregates.

profiles which had a dominance of coarse sand fraction in fine earth (< 2 mm). The original soils developed under forest conditions and these have an extreme acid reaction (pH/H_2O 4.33; pH/KCl 3.16). Non-cultivated forest soil is rich in organic matter content (C_{org} 5.72%). The soil contains 56% and < 10% of sand and clay fractions, respectively. The extremely acid character of the soil is attributed to the absence of liming measures and to the parent rock's resistance to weathering, since it mainly consists of quartz and feldspars.

The opposite situation was found in the case of old vineyard soil. This soil has properties significantly changed due to long-term cultivation, and soil pH values were increased up to the slightly alkaline values of pH/H_2O 7.52; pH/KCl 6.77. Although the soil has increased stone-content, it also has the highest clay-content fraction of all the studied soils. This is approximately 15%. Organic carbon content, which was reduced during vineyard establishment, is now 2%, and this is most likely due to the suitable cultivation practices in the past.

An extreme situation is noted at the newly established vineyard where deep ploughing was previously applied. Consequently, the soil was extremely stony with the lowest content of organic matter (C_{org} 1.83%). The soil contains a lower clay-fraction content compared to old vineyard soil but it is still higher compared to both soils under forest conditions. The soil reaction of pH/H_2O 6.95; pH/KCl 6.00 is lower than in old vineyard soil, but it is significantly higher than in the forest soils. Similarly, the clay-fraction content is intermediate between the old vineyard soil and soils under forest conditions.

A specific case is the afforested former vineyard soil affected by grape planting which continued until the end of the 19^{th} century. Surprisingly, this soil has the highest organic matter content (C_{org} 7.3%), which is most likely due to the organic amendments, higher nutrient supply and better microbial properties compared to the original forest soil. The soil reaction of pH/H_2O 5.67; pH/KCl 4.90 is intermediate between the original forest soil and both vineyard soils. Compared to the properties at the end of 19^{th} century, it can be assumed that the organic matter content has risen and the soil pH decreased during the last hundred years. In the formerly homogenized soil profile, the distinct humus horizon is visible at a thickness of approximately 10 cm.

Soil aggregate stability

Soil structure is considered as an important indicator of soil quality, and soil aggregate stability is commonly used as an indicator of soil structure (Bronick, Lal, 2005; Six et al., 2000). Land use and soil management influence soil aggregation and soil aggregate stability (Emadodin et al., 2009), through alteration of soil properties such as pH, organic matter and soil texture. Changes in soil organic matter are typically due to an increase in mineralization as a result of annual ploughing practices. Soil organic matter has frequently been reported in the literature as being an aggregate linking constituent (e.g. Sollins et al., 1996; Bronick, Lal, 2005). A decrease in soil organic matter content is typically caused by deep ploughing and erosion-facilitating practices (Emadodin et al., 2009), so that soil organic matter content is directly related to the soil erodibility.

The relationship between soil aggregate stability and land use systems has been reviewed by Shrestha et al. (2007). They concluded that different land use systems and management practices have a strong impact on the soil's properties, and that organic carbon dynamics and soil aggregation are particularly affected (Shrestha et al., 2007). Increasing organic matter content enhances the stability of soil aggregates, and this is more distinct in soils with higher clay-fraction content. Soils with higher organic matter and clay-fraction contents have better soil structure and a greater resistance to wind and water erosion (Emadodin et al., 2009).

The comparison between aggregate stability values determined for different soil management systems indicates differences between vineyard and forested study sites, as shown in Table 1. The soil aggregate stability decreases approximately in the following order: forest soil ≈ forested former vineyard soil > vineyard soil > deeply ploughed vineyard soil. The statistical analysis confirmed that management practices have a quite significant impact on soil aggregate stability at the $P < 0.001$ significance level (Table 2).

The effect of soil organic matter and its fractions on soil aggregation processes is well known and has been reported by many authors (e.g. Bronick, Lal, 2005). The soils' aggregate stability order complies with the average soil organic-matter content in these four study sites. This result indicates a link between the aggregate stability and organic matter content in the soils. It also confirms that following the deep ploughing measures instituted for vineyard soil establishment, soil material with low organic matter content and consequently with lower aggregate stability appears on the soil surface. Aggregate stability values lay within the interval of 18–43% with a mean value of 29% (Table 1). In this stage of vineyard soil development, the soil is easily erodible and soil erosion is a risk. However, cultivation of vineyard soil gradually increases soil aggregate stability as indicated for the old vineyard soil in Table 1, where the aggregate stabilities appeared within the interval of 42–57% with a mean value of 49%. A marked increase in soil organic matter content was observed in the forested old vineyard soil which had the highest organic carbon content of all four study sites. A high

T a b l e 2. Probability values for t-test on differences in soil properties between study sites in the Viticulture district of Modra.

C_{org}

	VS	DPVS	FS	AFS
VS		0.244	< 0.001	< 0.001
DPVS	0.244		< 0.001	< 0.001
FS	< 0.001	< 0.001		0.026
AFS	< 0.001	< 0.001	0.026	

pH/H_2O

	VS	DPVS	FS	AFS
VS		0.009	< 0.001	< 0.001
DPVS	0.009		< 0.001	< 0.001
FS	< 0.001	< 0.001		< 0.001
AFS	< 0.001	< 0.001	< 0.001	

pH/KCl

	VS	DPVS	FS	AFS
VS		0.004	< 0.001	< 0.001
DPVS	0.004		< 0.001	< 0.001
FS	0.009	< 0.001		0.001
AFS	< 0.001	< 0.001	0.001	

Clay fraction content (< 0.002 mm)

	VS	DPVS	FS	AFS
VS		< 0.001	< 0.001	< 0.001
DPVS	< 0.001		< 0.001	< 0.001
FS	< 0.001	< 0.001		< 0.001
AFS	< 0.001	< 0.001	< 0.001	

SA

	VS	DPVS	FS	AFS
VS		< 0.001	< 0.001	< 0.001
DPVS	< 0.001		< 0.001	< 0.001
FS	0.009	< 0.001		0.013
AFS	< 0.001	< 0.001	0.013	

Abbreviations: VS – vineyard soil, DPVS – deeply ploughed vineyard soil, FS – forest soil, AVS – afforested vineyard soil, SA – stability of aggregates.

organic carbon content is accompanied by soil-aggregate high stability. This averages 89%, which is comparable with the aggregate stability in original forest soil (92%) listed in Table 1. The observed order of soil aggregate stability at the four study sites is mainly closely associated with actual organic matter content which is affected by different soil management practices applied at the present time (in the case of newly established vineyard soil) to those of more than a hundred years ago (for original forest soil).

The effect of other soil properties is less pronounced. The clay-fraction content increases from that in afforested vineyard soil at 6.1%, to forest soil at 9.6% to deeply ploughed vineyard soil at11.3% and finally to old vineyard soil which has 14.7% (Table 1). Differences between study sites were all significant at the $P < 0.001$ significance level (Table 2). The importance of the clay-fraction in soil aggregate stability has been reported by many authors (e.g. Singer et al., 1992; Sollins et al., 1996; Bronick, Lal, 2005). They concluded that aggregate stability is primarily a function of the type and amount of clay. According to the soil aggregate stability measurement, it is evident that effects of soil organic matter content are more important for the final aggregate stability value.

Soil pH values increased in the vineyard soils due to the cultivation measures. Soil pH has a close relationship to soil organic carbon content as it commonly decreases with increasing organic carbon content. The quite apparent impact of soil pH on the soil aggregates stability shown in Table 1 follows from this relationship. Here, the aggregate stability in the forest soils with low pH is much greater than in two cultivated soils with higher pH values. However, cultivation causes increase in soil pH in the vineyard soils. This increased soil pH can result in increased microbial activity and soil organic matter accumulation, which enhance the aggregation processes (Haynes, Naidu, 1998). Such a relationship agrees with the increased aggregate stability in old vineyard soil compared to the deeply ploughed vineyard soil, which have mean aggregate stabilities of 49% and 29%, respectively.

This investigation also suggests that the soil aggregate stability was higher for both forest study sites, and this can also be associated with higher biological activity in the forest study sites. This involves a beneficial effect of fine roots and fungal hyphae on soil aggregate stabilization. The results also suggests that management measures in the Modra surrounds have a significant impact on the soil properties, and that these effects must be investigated with respect to hazardous processes such as surface runoff formation and soil erosion.

Conclusion

Results presented in this paper show that human activities in the viticulture region can have variable impact on the soil aggregate stability. The effect of management measures has a significant impact especially during the early period of vineyard establishment. Properly cultivated vineyard soils have relatively stable aggregates and the old vineyard soils are not at risk of degradation processes such as soil erosion. The most stable soils were found under the forest vegetation. Even in the vineyard soils abandoned due to grape phylloxera at the end of 19th century, the aggregate stabilities were very high and comparable with the original forest soils. Of all the studied soil properties, soil organic matter content was established as the main determining property controlling aggregate stability. The apparent effect of pH on the soil aggregate stability is due to the close correlation between the pH and organic carbon content of the soil. Soil organic matter effects even overlap the effect of increasing clay-fraction content. It can be concluded that land use and soil management can have significant effect on soil aggregate stability and on soil erosion risk. Indeed, correct management decision-making procedures can significantly reduce hazardous processes in the viticulture district of Modra city.

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