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Slope position and management practices as factors influencing selected properties of topsoil

Abstract: An interaction between the slope position and type of soil management practices could be one of the most important factor affecting several soil properties including soil structure. Therefore, we evaluated selected soil properties including soil structure parameters in relation to slope gradient and soil management practices between Trakovice and Bučany villages (western Slovakia). The sampling sites were located in two adjacent, gently sloping fields with a NW-SE orientation. The sites also differ in soil management type: Field No. 1 was used as arable land with intensive cultivation (IC) of crops, while a greening system (GS) had been established on Field No. 2. Soil samples were taken from five geomorphological zones at each slope: summit, shoulder, backslope, toe slope and flat terrain under the slope. Results showed that soil pH, content of soil organic matter (SOM) and carbonates depended on land use of the slopes. In GS, the water-stable macro-aggregates (WSA_{ma}) 0.5–3 mm (favourable size fraction) displayed statistical significant quadratic polynomial trend along the slope gradient. In IC the values of mean weight diameter of dry sieved aggregates (MWDd) decreased significantly along the slope gradient, while in GS the opposite trend was observed. In IC significant correlations between carbonates content ($r=-0.775$, $P<0.01$), humic acids (HA) content ($r=0.654$, $P<0.05$), colour quotients of humic substances ($r=-0.706$, $P<0.05$), colour quotients of HA ($r=-0.723$, $P<0.05$) and MWDd were determined. In GS higher content of carbonates was followed by a decrease in content WSA_{ma}, MWDd, mean weight diameter of wet sieved aggregates (MWDw) and stability index of aggregates. At the same time stabile and labile soil organic matter improved soil structure parameters in GS.

Keywords: soil structure, soil organic matter, intensive cultivation, greening system, slope

INTRODUCTION

Soil structure can be defined as the arrangement of different constituents of soil (e.g. Laatsh 1954, Fiedler and Reissing 1964; Mückenhausen 1975, Rząsa and Owczarzak 2004). A soil with good structure has low compaction or bulk density and a large amount of pore space. These soils have high infiltration, quick water movement through the profile, high water retention, high water availability to roots, low crusting on soil surface, high gas exchange, high nutrient availability, easier root penetration, reduced surface runoff and soil erosion (Kay 1998, Shukla 2014). Stability of soil structure is one of the most important indicators of soil quality. Numerous studies suggest that organic matter (OM), sesquioxides, clay minerals, microbial activity and soil management practices play an important role in the formation of aggregates as the basic unit of soil structure (Tisdall and Oades 1982; Bronick and Lal 2005; Gajewski et al. 2016, Polláková et al. 2018, Kobierski et al. 2018). In addition, the stability of aggregates determines soil resistance to erosion (Barthés and Roose 2002).

In Slovakia, the most important degradation processes include water and wind erosion, which have a direct impact on soil structure (Šimanský et al. 2018). Water erosion presents a potential threat to 46% of agricultural land (10 878.39 km^2) and wind erosion processes potentially threaten 9% of agricultural land, which amounts to 2024.29 km^2 (Šimanský et al. 2018). Small particles as well as the micro- and smaller macro-aggregates are being subjected to erosion (Barthés and Roose 2002; Efthimiou 2018), especially on soils that have an adverse soil structure due to their intensive cultivation (Steinhoff-Knopp and Burkhard 2018). Soil erosion have also significant effect on changes in soil properties what results in increased field heterogeneity. For example, the increase in soil organic carbon content (SOC) increases aggregation as well as the water stability of aggregates. Different SOC fractions also influence different macro-aggregate-associated properties. Topographic features such as slope can also influence the SOC distribution in macro-aggregates, since considerable amounts of light SOC fractions can be redistributed and concentrated near the soil surface on

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the toe slope due to water erosion and transport from shoulder or backslope positions (Gregorich et al. 1998). The redistribution of SOC can, in turn, affect the formation, stability and hydrological properties of aggregates (Shukla 2014). Slope gradient and change in land use are known to influence soil quality, and the assessment of soil quality is important in determining sustainable land-use and soil-management practices (Cambardella and Elliot 1992; Tisdall 1996, Chun-Chih et al. 2004, Nabiollahi et al. 2018).

Thus, we hypothesised that creating a greening system on a slope is a factor that improves stability of soil structure in comparison to an intensively cultivated slope. Moreover, a more stable soil structure should be present on the toe slope (or within the accumulation zone of the slope). Therefore, we evaluated soil structure parameters as one of the most important soil quality parameters in relation to slope gradient and soil management practices.

MATERIALS AND METHODS

The study sites were located in the north-western part of the Danube lowland (Fig. 1) between Trakovice and Bučany villages (Trnava Region, western Slovakia). The geological substrate of the studied area is loess of several metres thick. The average monthly temperature is 10°C (9–10°C), while precipitation is 525 mm (450–600 mm, Tarábek 1980).

The soil cover of the study area comprises of a Regosols and Chernozems complex (Societas Pedologica Slovaca 2014). Regosols occurred along both of the studied slopes while buried Chernozems were present at the flat terrain under the slopes. The sampling sites were in two adjacent fields. Both were gently sloping (8°) with a NW-SE orientation. According to the slope forms and surface pathways, Field 1 was located on a concave slope, and Field 2 on a convex-concave slope. The fields also differed in soil management type. Field 1 was used as arable land with intensive cultivation (IC) of crops by standard conventional tillage system. Conventional tillage consisted of mouldboard ploughing to the 0.22–0.25 m depth in autumn, followed by disking/rolling/levelling and planting in dependence to cultivated crops. In the sampling year (2018) the field was planted with maize and the tillage rows were oriented along the slope direction, with spacing of 70 cm. On Field 2, a greening system (GS) had been established in 2012. Plant cover has been cut being and mulched there twice a year.

In 2018, both studied slopes (sampling fields) were divided into five zones: summit (S), shoulder (SH), backslope (BS), toe slope (TS) and flat terrain under the slope (F). A total of 10 soils pits were prepared (one per slope zone for both analysed slopes). Soil samples were collected from the cultivated soil layer (upper 20 cm). The following soil properties were determined in the collected samples: pH of the soil-to-solution ratio of 1:2.5 using H_2O as the suspension medium; content of soil organic carbon (SOC) by sample oxidation in the mixture of $K_2Cr_2O_7$ and H_2SO_4 (Dziadowiec and Gonet 1999); and content of carbonates by the volumetric method using a Jankov calcimeter. Particle-size distribution was determined by pipette method (Hrivňaková et al. 2011), texture classes were described according to USDA (Soil Survey Division Staff 1993). The labile carbon content (C_L) was determined using 0.005 mol dm^{-3} $KMnO_4$ (Loginow et al. 1987) and hot water extracted carbon (C_{HWE}) was determined according to the method of Kőrschner et al. (1990). The group and fraction composition of humic substances (HS) was determined by the Belchikova and Kononova method

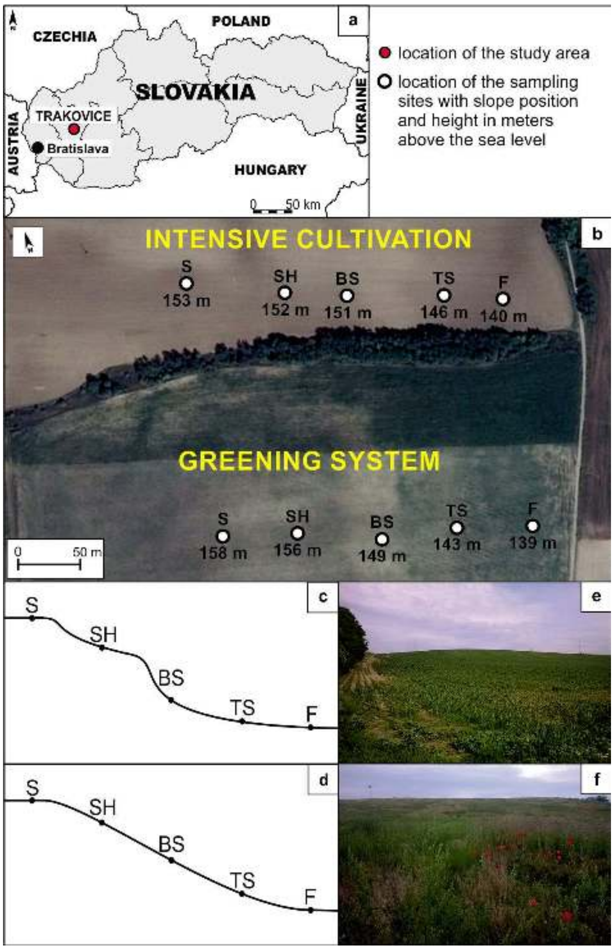

FIGURE 1. Location of the study area within the borders of Slovakia and sampling plots within the analysed slopes

(Dziadowiec and Gonet 1999). The light absorbance of humic substances (HS) and humic acids (HA) was measured at 465 and 650 nm using a Jenway 6400 Spectrophotometer to calculate the colour quotients $Q^{4/6}_{HS}$ and $Q^{4/6}_{HA}$. In undisturbed soil samples, individual size fractions of aggregates were determined by dry sieving of soil through sieves with mesh diameters >7, 7–5, 5–3, 3–1, 1–0.5, 0.5–0.25 mm as dry sieved macro-aggregates (DSA_{ma}) and <0.25 mm as dry sieved micro-aggregates (DSA_{mi}). These fractions of air-dried aggregates were used to determine water-stable macro- (WSA_{ma}) and micro-aggregates (WSA_{mi}) by the Baksheev method (Vadjunina and Korchagina, 1986). Also, the mean weight diameters (MWD: for both dry sieved aggregates, MWDd; and for water-stable aggregates, MWDw), vulnerability coefficient (Kv) by the method of Valla et al. (2000), and the stability index of water-stable aggregates (Sw) by the Henin method (Zaujec and Šimanský, 2006) were calculated.

One-way analysis of variance (ANOVA) and the least significant difference (LSD) method was used to compare treatment means for the two types of managements (IC and GS) at $P < 0.05$. The interrelations between SOM and soil structure parameters were determined through a correlation matrix. For the expression of soil structure parameter dynamics along the slope gradient, linear and quadratic polynomial regression models were used. All the statistical analyses were performed using Statgraphics Centurion XV.I software (Statpoint Technologies, Inc., USA).

RESULTS AND DISCUSSION

Basic soil properties are presented in Table 1. In both types of management, the soils were weakly alkaline, and the pH ranged from 7.70–7.94. Similarly, rather low and medium SOC content (from 11.5 to 14.4 g kg^{-1} on the IC and from 7.90 to 15.9 g kg^{-1} on the GS) and high and relatively high content of hot water extracted carbon (from 0.492 to 0.702 g kg^{-1} on the IC and from 0.378 to 0.767 g kg^{-1} on the GS) were determined for both parts of the analysed slope. The content of labile carbon ranged from 1.09 to 1.45 g kg^{-1} (8.9 to 10.1% of SOC) and from 0.674 to 1.54 g kg^{-1} (8.13 to 9.72 % of SOC) in the intensively cultivated slope and in the greening system, respectively. Contents of carbonates depended on – land use and slope form (Table 1). The highest content of carbonates was determined for the soil sample in the summit in IC (180 g kg^{-1}) and the lowest for the flat part of the GS (50 g kg^{-1}). Soil texture was silt loam, with the clay content ranging from 14 to 22%. In IC and GS, the content of carbon in extracted humic substances (CHS, Table 2.) ranged from 4.17 to 5.2 and from 2.82 to 6.37 g kg^{-1} which comprises 34–37% and 35–40% of SOC, respectively. The average

TABLE 1. Basic soil properties with results of ANOVA and LSD analyses results showing the difference between studied slopes

Land use	Slope position	pH H_2O	SOC	C_L	C_{HWE}	$CaCO_3$	Percentage share of fraction [mm]		
			[g kg^{-1}]				2–0.05	0.05–0.002	<0.002
IC	S	7.73	12.2	1.086	0.681	180	32	54	15
	SH	7.81	11.5	1.160	0.581	170	23	63	14
	BS	7.75	14.3	1.447	0.635	120	26	57	17
	TS	7.73	14.4	1.354	0.702	100	26	58	16
	F	7.70	14.1	1.140	0.492	100	23	58	19
GS	S	7.86	13.7	1.228	0.537	60	23	57	20
	SH	7.94	7.90	0.674	0.378	120	19	61	20
	BS	7.86	11.7	0.955	0.475	80	25	55	20
	TS	7.78	15.5	1.320	0.588	40	28	55	17
	F	7.85	15.9	1.543	0.767	50	30	51	19
ANOVA and LSD analyses results									
IC		$7.74{\pm}0.04^a$	$13.3{\pm}1.30^a$	$1.237{\pm}0.15^a$	$0.608{\pm}0.08^a$	$133{\pm}35.2^b$	$25.9{\pm}3.28^a$	$58.0{\pm}3.03^a$	$16.1{\pm}1.79^a$
GS		$7.86{\pm}0.05^b$	$13.0{\pm}3.10^a$	$1.144{\pm}0.32^a$	$0.549{\pm}0.14^a$	$72{\pm}29.7^a$	$25.1{\pm}4.09^a$	$55.9{\pm}3.22^a$	$19.0{\pm}1.36^b$
p-value		0.0000	0.7381	0.4098	0.2560	0.0232	0.6353	0.1396	0.0006

Land use: IC – intensive cultivation, GS – reening system; Slope position: S – summit, SH – shoulder, BS – back slope, S – toe slope, F – flat; SOC – soil organic carbon, C_L – labile carbon, C_{HWE} – hot water extracted carbon, $CaCO_3$ – content of carbonates; Different letters (a, b) indicate significant differences between studied slopes at P<0.05 according to LSD test

TABLE 2. Soil organic matter properties with results of ANOVA and LSD analyses results showing the difference between studied slopes

Land use	Slope position	CHS	CHA	CFA	CHS	CHA	CFA	CHA:CFA	$Q^{4/6}$	
		[g kg^{-1}]			as % of the SOC				HS	HA
IC	S	4.61	2.45	2.16	37.76	20.07	17.69	1.13	5.54	4.12
	SH	4.17	2.45	1.72	36.29	21.32	14.97	1.42	6.47	4.44
	BS	5.20	2.75	2.45	36.39	19,24	17.14	1.12	4.81	3.85
	TS	5.16	2.86	2.30	35.86	19,87	15.98	1.24	4.31	3.61
	F	4.82	2.72	2.10	34.28	19,35	14.94	1.30	4.70	3.82
GS	S	5.20	2.89	2.31	38.10	21.17	16.93	1.25	4.56	3.77
	SH	2.82	1.44	1.38	35.70	18.23	17.47	1.04	5.55	3.87
	BS	4.58	2.72	1.86	39.01	23.17	15.84	1.46	4.58	3.76
	TS	5.99	3.68	2.31	38.67	23.76	14.91	1.59	3.71	3.38
	F	6.37	3.75	2.62	40.14	23.63	16.51	1.43	3.90	3.45
ANOVA and LSD analyses results										
IC		4.79±0.40^{a}	2.64±0.20^{a}	2.15±0.20^{a}	36.1±0.52^{a}	19.9±0.78^{a}	16.2±0.48^{a}	1.24±0.14^{a}	5.17±0.81^{a}	3.97±0.0^{a}
GS		4.99±1.30^{a}	2.90±0.90^{a}	2.09±0.50^{a}	38.3±1.28^{b}	22.0±2.21^{b}	16.3±0.28^{a}	1.36±0.23^{a}	4.46±0.68^{a}	3.64±0.20^{a}
P-value		0.6554	0,3876	0.7573	0.0075	0.0184	0.8008	0.1645	0.1946	0.0960

Land use: IC – intensive cultivation, GS – greening system

Slope position: S – summit, SH – shoulder, BS – back slope, TS – toe slope, F – flat

CHS – humic substances carbon, CHA – humic acids carbon, CFA – fulvic acids carbon, $Q^{4/6}$ – color quotient 465 to 650 nm

HS – humic substances, HA – humic acids

Different letters (a, b) between lines indicate that treatment means are significantly different at P<0.05 according to LSD test

content of extracted humic acid carbon (CHA) was lower in IC (2.65 g kg^{-1}) than in GS (2.90 g kg^{-1}). The opposite was observed for the fulvic acids (FA), as the average content of extracted fulvic acids carbon (CFA) was slightly higher in IC (2.15 g kg^{-1}) than in GS (2.09 g kg^{-1}). We evaluated the humus quality with regard to the soil managements on carbon of HA and FA ratio (CHA:CFA) as well as with regard to the optical parameters of humic substances ($Q^{4/6}_{HS}$) and HA ($Q^{4/6}_{HA}$). In GS, the average values of the CHA:CFA ratio were wider than in IC. The average values of $Q^{4/6}_{HS}$ and $Q^{4/6}_{HA}$ and the degree of humification – DH (expressed as CHA from SOC) were also more favourable in GS than in IC (Table 2).

Intensive soil management practices, which are very often incorrect, accelerate soil erosion, which was reflected in the differences between the soil profiles on the two slopes. Loss of soil material from the surface horizon at the summit position and its delivery to the accumulation zone (toe slope and flat terrain under the slope) was clearly visibly due to the human induced erosion. This phenomenon affected and changed the original soil cover on the analysed slopes. Nowadays arable horizon material is mixed with the parent material mainly on the intensively cultivated (IC) slope, while this situation took place on the both analysed slopes (IC and GS) in the past due to its former cultivation. Moreover, eroded material accumulating on the toe slope and under the slope resulted in the burial of the original mollic surface horizon, which is present at the depth of more than 50 cm (Šimanský et al. 2014). Therefore, the soil properties along the slope gradient were affected. Slope gradient is considered to be one of the most important factors influencing soil quality because of its effects on variations in several soil properties, and thus on crop yield (Paz-Kagan et al. 2016). The loss and degradation of soils have negative impacts on nutrient cycling and carbon stocks mainly in shoulder and backslope positions (Dominati et al. 2010).

The one-way ANOVA analysis showed significant differences between both management types (IC vs GS) for soil pH, $CaCO_3$, CHS as % of the SOC (expressed also as degree of humification) and CHA as % of the SOC (Tables 1 and 2).

Types of managements had statistically significant influence on soil structure parameters (Table 3) and their values in greening system (GS) were better in comparison to intensive cultivation (IC).

Content of DSAmi and DSAma ranged from 35 to 54% and from 16 to 42% in the IC and GS, respectively. Transfer (transport) of soil aggregates down slope via erosion can increase content of DSA_{mi} while decrease the DSA_{ma} in lower parts of the slopes. This arrangement was much more demonstrable in the IC (Fig. 2A). Nevertheless, content of DSA_{mi} and DSA_{ma} did not significantly correlate with slope forms, as the

TABLE 3. Statistical evaluation (ANOVA and LSD) showing the difference in soil structure parameters between studied slopes

Land use	DSA_{mi}	DSA_{ma}	DSA_{ma} 0.5–3	WSA_{mi}	WSA_{ma}	WSA_{ma} 0.5–3	MWDd	MWDw	Kv	Sw
IC	24.7 ± 5.20^{b}	75.3 ± 5.20^{a}	29.0 ± 3.03^{a}	45.7 ± 7.91^{b}	54.3 ± 7.91^{a}	30.3 ± 11.3^{a}	2.36 ± 1.32^{b}	0.37 ± 0.24^{a}	6.67 ± 2.07^{b}	0.70 ± 0.10^{a}
GS	19.4 ± 2.62^{a}	80.57 ± 2.62^{b}	40.0 ± 3.41^{b}	30.7 ± 12.3^{a}	69.3 ± 12.3^{b}	42.5 ± 12.9^{b}	1.93 ± 0.24^{a}	0.84 ± 0.26^{b}	2.45 ± 0.58^{a}	0.90 ± 0.19^{b}
P-value	0.0106	0.0106	0.0000	0.0044	0.0044	0.0385	0.0007	0.0000	0.0000	0.0110

Land use: IC – intensive cultivation, GS – greening system

DSA_{mi} – dry sieved micro-aggregates, DSA_{ma} – dry sieved macro-aggregates, DSA_{ma} 0.5-3 – dry sieved macro-aggregates from 0.5 to 3.0 mm, WSA_{mi} – water-stable micro-aggregates, WSA_{ma} – water-stable macro-aggregates, WSA_{ma} 0.5-3 – water-stable macro-aggregates from 0.5 to 3.0 mm, MWDd – mean weight diameters for dry sieved aggregates, MWDw – mean weight diameters for wet sieved aggregates, Kv – vulnerability coefficient, Sw – stability index of water-stable aggregates

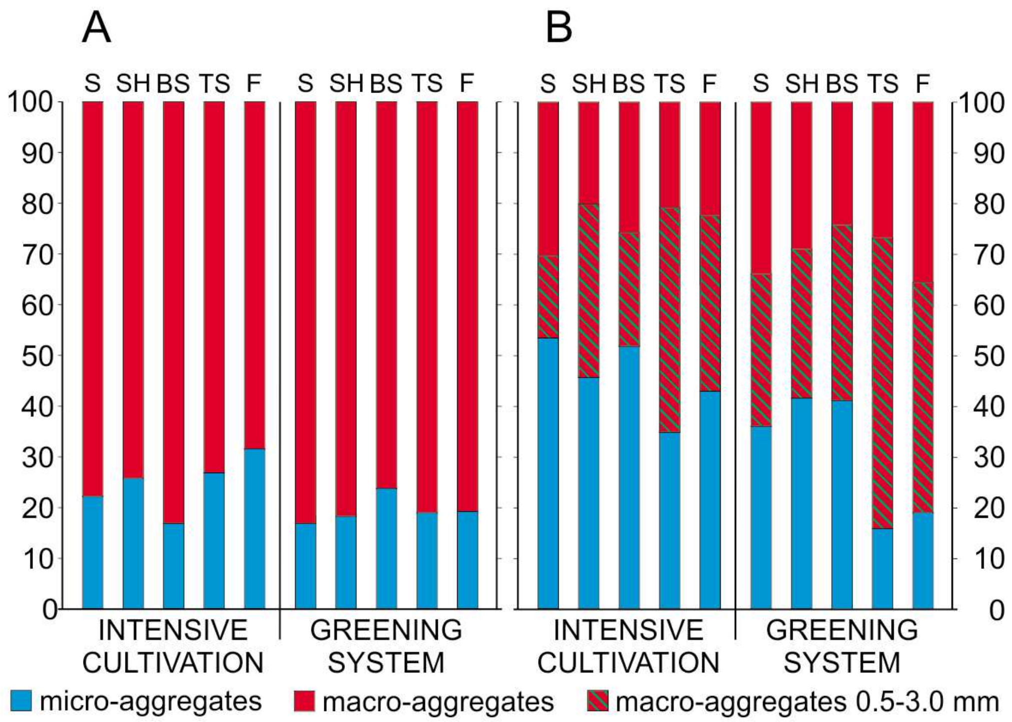

FIGURE 2. Percentage share (by weight) of dry sieved (A) and water-stable (B) aggregates along the slope gradient

dynamics of DSA_{mi} and DSA_{ma} content revealed no trend in either slope's gradient. Despite this fact, the quadratic polynomial trend expressed changes in contents of DSA_{mi} and DSA_{ma} along the slope in the best way (Table 4). Soil structure can be modified by soil management practices (Bronick and Lal 2005), while significant deterioration of soil structure and increase in soil erosion is observed in intensive land use activity (Steinhoff-Knopp and Burkhard 2018), which our findings confirmed. Content of WSA_{mi} and WSA_{ma} are very important indicators of soil structure (stability, vulnerability or water resistance; Šimanský et al. 2018). Similarly the dry sieved aggregates, content of WSA_{mi} decreased and content of WSA_{ma} increased from the upper to the lower parts of the slope (Fig. 2B). Since the contribution of macro-aggregates of size 0.5–3 mm is important from the agronomical point of view (Demo et al. 1995) we evaluated the content of these aggregates additionally. The content of favourable size fraction of WSA_{ma} 0.5–3 mm increased along the slope, while the highest content of these aggregates was observed in flat terrain under the slope for both management types (Fig. 2B). Although only in the GS did the WSA_{ma} 0.5–3 mm show a statistically significant quadratic polynomial trend along the slope gradient. There is a linear increase in WSA_{ma} 0.5–3 mm content by 8% every 80–120 m along the slope (upper to lower slope). In the IC, the values of MWDd decreased significantly in the same direction (Fig. 3A), which was clearly explained with the quadratic polynomial model (Table 3). Based on the linear model, the MWDd decreased by 0.15 mm during every 80–120 m along the slope gradient. On the other hand, the values of MWDd increased significantly in GS along the slope (Fig. 3A) and the quadratic polynomial trend was significant (Table 3). The MWDw values were significantly lower on the backslope as compared to the summit and the accumulation zone of the slope (TS and F parts) indicating more intense erosion (Fig. 3A). Probably it was the reason why no statistically proven decreasing or increasing trends of MWDw were observed both along the IC and GS parts of the slope. In the case of soil structure vulnerability (Kv) and MWDw, similar effects were observed (Fig. 3B). In GS, the aggregate stability (Sw) increased down the slope without any statistical significance. On the IC it was not possible to determine any trend along the slope (Fig. 3C). The arrangement of the soil structure parameter values, as well as the statistical results discussed above, is fully in line with our assumptions. Soil erosion is the well-known result of incorrect soil management practices (Zhang et al. 2008, Liang et al. 2010). This is especially true in the case of inappropriate crop cultivation, as on the intensively cultivated part of the analysed slope. As mentioned before, maize was cultivated with an inter-line spacing of 70 cm and the direction of the lines was oriented along the slope, which obviously accelerated soil erosion. Since this process was more explicit on the intensively cultivated slope, the soil structure was unable to stabilise, in contrast to the greening system.

Under both type of soil management types, carbonates content was relatively high, but on average in the IC, their content was almost double (133 g kg^{-1}) than in the GS (72 g kg^{-1}). Apart from the negative correlation between carbonates content and MWDd, no significant relations were determined in the IC (Table 5). Intensive cultivation can be the main reason for the negative effect of carbonates in decreasing MWDd and can have an insufficient effect on other parameters of soil structure, because IC favours the surface runoff and impedes the formation of secondary carbonates.

TABLE 4. Trends of soil structure parameters along the slope gradient

Land use	Soil structure parameter	Linear model	R^2	Quadratic polynomial model	R^2
IC	DSA_{mi}	y = 2.00x + 18.66	0.3293	y = 1.52x2 - 7.09x + 29.27	0.5935
	DSA_{ma}	y = -2.00x + 81.34	0.3293	y = -1.52x2 + 7.09x + 70.73	0.5935
	WSA_{mi}	y = -3.21x + 55.37	0.4576	y = 0.65x2 - 7.13x + 59.94	0.4841
	WSA_{ma}	y = 3.21x + 44.64	0.4579	y = -0.65x2 + 7.13x + 40.07	0.4843
	WSA_{ma} 0.5–3	y = 4.67x + 16.34	0.4458	y = -1.56x2 + 14.03x + 5.42	0.5156
	MWDd	y = -0.15x + 2.81	0.9277	y = -0.01x2 - 0.12x + 2.78	0.9291
	MWDw	y = 0.01x + 0.36	0.0177	y = 0.02x2 - 0.12x + 0.51	0.3341
	Kv	y = -0.49x + 8.18	0.1328	y = -0.56x2 + 2.87x + 4.25	0.3754
	Sw	y = 0.03x + 0.60	0.3183	y = -0.01x2 + 0.06x + 0.57	0.3254
GS	DSA_{mi}	y = 0.52x + 17.87	0.0987	y = -0.91x2 + 5.95x + 11.53	0.5209
	DSA_{ma}	y = -0.52x + 82.13	0.0987	y = 0.91x2 - 5.95x + 88.47	0.5209
	WSA_{mi}	y = -5.98x + 48.64	0.5812	y = -2.12x2 + 6.72x + 33.82	0.6833
	WSA_{ma}	y = 5.97x + 51.37	0.5809	y = 2.12x2 - 6.73x + 66.19	0.6831
	WSA_{ma} 0.5–3	y = 7.89x + 17.65	0.8064	y = 1.07x2 + 1.45x + 25.17	0.8273
	MWDd	y = 0.07x + 1.71	0.1938	y = 0.12x2 - 0.64x + 2.54	0.9414
	MWDw	y = 0.05x + 0.70	0.0852	y = 0.07x2 - 0.38x + 1.20	0.3726
	Kv	y = -0.04x + 2.59	0.0190	y = -0.12x2 + 0.69x + 1.73	0.2264
	Sw	y = 0.10x + 0.59	0.6388	y = 0.03x2 - 0.10x + 0.83	0.7360

Land use: IC – intensive cultivation, GS – greening system; Slope position: S – summit, SH – shoulder, BS – back slope, TS – toe slope, F – flat; Soil structure parameters: DSAmi – dry sieved micro-aggregates, DSA_{ma} – dry sieved macro-aggregates, WSA_{mi} – water-stable micro-aggregates, WSA_{ma} – water-stable macro-aggregates, WSA_{ma} 0.5–3 – water-stable macro-aggregates from 0.5 to 3.0 mm, MWDd – mean weight diameters for dry sieved aggregtes, MWDw – mean weight diameters for water-stable aggregates, Kv – vulnerability coefficient, Sw – stability index of water-stable aggregates

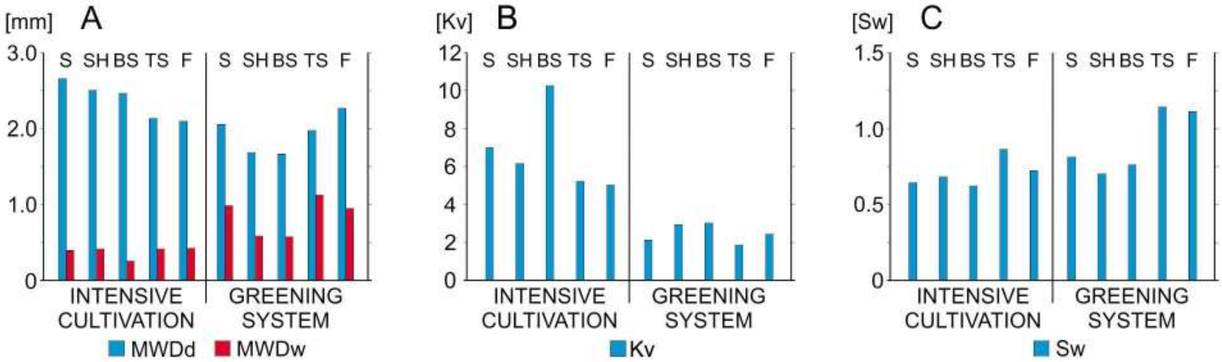

FIGURE 3. Values of mean weight diameter of dry sieved (MDWd) and water-stable aggregates (MDWw; A), vulnerability coefficients (Kv; B) and of stability index of water-stable aggregates (Sw; C) along the slope gradient

TABLE 5. Correlation coefficients between soil parameters on the analysed slopes

	DSA_{mi}	DSA_{ma}	DSA_{ma} 0.5–3	WSA_{mi}	WSA_{ma}	WSA_{ma} 0.5–3	MWDd	MWDw	Kv	Sw
INTENSIVE CULTIVATION										
$CaCO_3$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.775**	n.s.	n.s.	n.s.
SOC	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C_L	n.s.	n.s.	0.774**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C_{HWE}	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
CHS	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
CHA	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.654*	n.s.	n.s.	n.s.
CFA	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s
CHA:CFA	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
$Q^{4/6}_{HS}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.706*	n.s.	n.s.	n.s.
$Q^{4/6}_{HA}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.723*	n.s.	n.s.	n.s.
GREENING SYSTEM										
$CaCO_3$	n.s.	n.s.	0.807**	0.736*	-0.736*	n.s.	-0.701*	-0.715*	n.s.	-0.785**
SOC	n.s.	n.s.	-0.810**	-0.802**	0.802**	n.s.	0.826**	0.752*	n.s.	0.845**
C_L	n.s.	n.s.	-0.787**	-0.795**	0.795**	0.632*	0.921***	0.722*	n.s.	0.834**
C_{HWE}	n.s.	n.s.	-0.758*	-0.799**	0.799**	0.710*	0.899***	n.s.	n.s.	0.836**
CHS	n.s.	n.s.	-0.849**	-0.786**	0.786**	0.638*	0.822**	0.709*	n.s.	0.838**
CHA	n.s.	n.s.	-0.838**	-0.802**	0.802**	0.673*	0.754*	0.689*	n.s.	0.856**
CFA	n.s.	n.s.	-0.814**	-0.706*	0.706*	n.s.	0.896***	0.701*	n.s.	0.750*
DH	n.s.	n.s.	-0.877***	-0.642*	0.642*	n.s.	n.s.	n.s.	n.s.	0.719*
CHA:CFA	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.638*
$Q^{4/6}_{HS}$	n.s.	n.s.	0.791**	0.833**	-0.833**	-0.720*	-0.687*	-0.699*	n.s.	-0.882**
$Q^{4/6}_{HA}$	n.s.	n.s.	0.618	0.934***	-0.934***	-0.887***	-0.658*	-0.678*	n.s.	-0.963***

SOC – soil organic carbon, C_L – labile carbon, C_{HWE} – hot water extracted carbon, $CaCO_3$ – content of carbonates, CHS – humic substances carbon, CHA – humic acids carbon, CFA – fulvic acids carbon, $Q^{4/6}$ – colour quotient 465 to 650 nm, DSA_{mi} – dry sieved micro-aggregates, DSA_{ma} – dry sieved macro-aggregates, DSA_{ma} 0.5–3 – dry sieved macro-aggregates from 0.5 to 3.0 mm, WSA_{mi} – water-stable micro-aggregates, WSA_{ma} – water-stable macro-aggregates, WSA_{ma} 0.5–3 – water-stable macro-aggregates from 0.5 to 3.0 mm, MWDd – mean weight diameters for dry sieved aggregates, MWDw – mean weight diameters for wet sieved aggregates, Kv – vulnerability coefficient, Sw – stability index of water-stable aggregates

n.s. – non-significant, $^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$

Many studies (Kassam et al. 2015, Blanco-Canqui and Ruis 2018; Zhang et al. 2018) reported negative tillage effects on soil structure. Tillage could result in the reduction of SOM stock, cation exchange capacity (CEC), nutrients content, and microbial and faunal activity, all of which contribute to soil aggregation (Plante and McGill 2002). However, carbonates were reported as a factor in decreasing the stability of micro-aggregates (Boix-Fayos et al. 2001), which is in opposition to our results obtained in the GS. Higher content of carbonates came together with a decrease in WSA_{ma}, MWDd, MWDw and Sw. The effect of carbonates content on soil structure could be moderated by SOC (Chan and Heenan 1999) as an increase in Sw in limed soils suggests the formation of strong bonding, involving Ca^{2+} bridges between primary soil particles and SOM (Kobierski et al. 2018) and it promotes the formation of coarse aggregate fractions (Wang et al. 2013). Higher SOC content could be followed by an increase in dissolution and re-precipitation of carbonates in soil. At low SOC concentration, macro – aggregate stability is enhanced by carbonates (Boix-Fayos et al. 2001) which may explain the positive correlation between content of agronomically favourable size fraction of aggregates (0.5–3.0 mm) and carbonates content in the GS (Table 4). The results presented by Šimanský et al. (2014) showed that a more intense aggregation process in loamy soils (Bučany and Trakovice district) is related to high content of basic exchangeable cations, and high value of CEC and the stabile organic matter content in water-stable aggregates. Generally, the SOM has been linked to improved Sw (Nouwakpo et al. 2018) because the SOM is one of the most important binding agents (Bronick and Lal 2005; Rabbi et al. 2014). In the IC, a higher content of HA resulted in higher values of MWDd, and a higher stability of HS and HA ($Q^{4/6}{}_{HS}$ and $Q^{4/6}{}_{HA}$) resulted in higher values of MWDd. In the GS, a higher SOC resulted in increased content of WSA_{ma}, MWDd, MWDw and Sw, but, by contrast, we observe a decrease in content of agronomically favourable size fractions of dry sieved aggregates and content of WSA_{mi}. Labile fractions of SOM can be a factor in transforming micro-aggregates into macro-aggregates (Six et al. 2004), which is confirmed by our results in the GS. Higher contents of C_L and C_{HWE} result in a decrease in WSA_{mi} content, most probably due to the aggregation of smaller aggregates into bigger aggregates with labile carbon fraction. A positive link between size of aggregates and labile SOM has also been described by other researchers (Six et al. 2004, Polláková et al. 2018, Kobierski et al. 2018), indicating a greater role of C_L in the formation of macro-aggregates than of micro-aggregates. In GS, statistically significant positive correlations were observed between C_L and WSA_{ma}, WSA_{ma} 0.5–3 mm, MWDd, MWDw and Sw. The aggregate binding effect of C_L is rapid but transient (Kay 1998) while decomposing SOC fractions with lower decomposing rates have milder effects on aggregation, but its effects may last longer (Martens 2000). Higher contents of HS, HA and FA was followed by an increase of content WSA_{ma} and WSA_{ma} 0.5–3 mm, MWDd, MWDw and Sw in GS. A higher degree of humification of SOM also had a positive effect in increasing WSA_{ma} ($r=0.642$, $P<0.05$) and Sw ($r=0.719$, $P<0.05$). Based on the negative correlation of $Q^{4/6}{}_{HS}$ and $Q^{4/6}{}_{HA}$ with WSA_{ma}, WSA_{ma} 0.5–3 mm, MWDd, MWDw and Sw values, we can conclude that more condensed (humified) fractions of humus dominated in the formation of favourable soil structure. Optimal soil structure as reported by Kimura et al. (2017) and Polláková et al. (2018) is formed through more humified humus fractions.

CONCLUSIONS

Even though parameters of soil structure parameters differed according to the morphological parts of analysed slopes (S, SH, BS, TS, F) and between both types of soil management (IC vs. GS), not all of them changed significantly along the slope. Only in greening system did the favourable size fraction of water-stable macro-aggregates show a statistically significant quadratic polynomial trend along the slope. In the intensively cultivated slope the values of mean weight diameter of aggregates decreased in a statistically significant way down the slope, while in the greening system the mean weight diameter of aggregates increased, and this trend was expressed with the quadratic polynomial model. Between inorganic carbon ($CaCO_3$) and organic C forms and soil structure parameters significantly more relationships were found in the greening system. We can conclude that more labile SOM fractions and more humified fractions of humus together dominated the formation of favourable soil structure in the greening system. The results indicate that soil management practices can significantly affect the relationship between SOM quality and soil structure development.

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Wpływ pozycji na stoku i sposobu użytkowania na wybrane właściwości w przypowierzchniowej warstwie gleby

Streszczenie: Celem badań była ocena wybranych parametrów (w tym jakości struktury agregatowej) w przypowierzchniowej warstwie gleby w odniesieniu do nachylenia stoku (pozycji na zboczu) i sposobu użytkowania gleby w Trakovicach (kraj trnawski, Słowacja). Obszar badań obejmował dwa sąsiadujące ze sobą pola położone na stoku o orientacji NW-SE, nachylonym pod kątem około 8°. Pole nr 1 było intensywnie użytkowane jako grunt orny, podczas gdy na polu nr 2 znajdował się tzw. zielony ugór (przez okres 6 lat poprzedzających pobór próbek). Próbki gleby pobierano z poziomów próchnicznych w pięciu wyznaczonych strefach geomorfologicznych (szczyt, górna część stoku, środkowa część stoku, dolna część stoku i podnóże stoku) na każdym zboczu. Wyniki jednoczynnikowej analizy wariancji (ANOVA) wykazały istotny statystycznie wpływ sposobu użytkowania stoku na pH gleby, zawartość $CaCO_3$, zawartość węgla w substancjach humusowych i węgla kwasów huminowych (wyrażonych jako udział wyżej wymienionych w ogóle węgla glebowej materii organicznej) oraz badane parametry struktury gleb. Udział procentowy WSA_{ma} 0,5–3 mm (water stable macro-aggregates) na ugorowanej części stoku wykazywał istotny statystycznie trend (wielomian kwadratowy) wzdłuż nachylenia zbocza. Wartości średniej ważonej średnicy agregatów przesiewanych na sucho (MWDd) na intensywnie użytkowanym stoku zmniejszyły się istotnie wzdłuż gradientu nachylenia, podczas gdy na stoku ugorowanym zaobserwowano przeciwną tendencję. Jednocześnie stwierdzono istotną statystycznie korelację pomiędzy wartościami tego parametru a zawartością węglanów ($r = -0,775$, $p < 0,01$), zawartością kwasów huminowych ($r = 0,654$, $p < 0,05$), indeksem $Q^{4/6}$ określonym dla substancji humusowych ($Q^{4/6}_{HS}$; $r = -0,706$, $p < 0,05$) oraz dla kwasówhuminowe ($Q^{4/6}_{HA}$; $r = -0,723$, $p < 0,05$). Na stoku ugorowanym wraz z wyższą zawartością węglanów obniżał się udział makro agregatów stabilnych w wodzie, oraz średniaważona średnica agregatów przesiewanych na sucho i na mokro oraz wartości indeksu stabilności agregatów (Sw). Jednocześnie wyższe zawartości materii organicznej (zarówno form stabilnych i labilnych) wpływały na poprawienie struktury powierzchniowych poziomów glebowych.

Słowa kluczowe (for Polish authors only): struktura gleby, glebowa materia organiczna, intensywne użytkowanie, ugór, stok