Acta fytotechn zootechn, 24, 2021(2): 129–136
http://www.acta.fapz.uniag.sk

Original Paper

Soil structure as a significant indirect factor affecting crop yields

Vladimír Šimanský[1]*, Martin Juriga[1], Marcel Golian[2], Miroslav Šlosár[2], Marek Provazník[3]
[1]*Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources, Department of Soil Science, Slovakia*
[2]*Slovak University of Agriculture in Nitra, Faculty of Horticulture and Landscape Engineering, Department of Vegetable Production, Slovakia*
[3]*Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resouces, Department of Agrochemistry and Plant Nutrition, Slovakia*

Article Details: Received: 2021-01-29 | Accepted: 2021-02-22 | Available online: 2021-06-30

https://doi.org/10.15414/afz.2021.24.02.129-136

The use of organic amendments for improving soil properties including soil structure is crucial for sustainable soil management. In this study, two organic materials (1. compost, and 2. farmyard manure) both at a rate of 44 t ha^{-1} as well as their combination were applied to a Hortic Calcaric Fluvisol (Slovakia) to evaluate the soil physical properties to test the potential of these amendments for soil amelioration under gardening conditions. The results showed that the addition of organic amendments did not have any significant effects on bulk density, total porosity, soil moisture and aeration, but their application influenced the total contents of dry-sieved aggregates as well as water-stable aggregates. The highest content of dry-sieved macro-aggregates was in compost > farmyard manure + compost > farmyard manure > control (unfertilized). The stability of aggregates was higher in compost and farmyard manure + compost treatments than in farmyard manure compared to control. Also, better soil structure stability evaluated by vulnerability coefficient was in farmyard manure + compost and compost than in farmyard manure. The highest contents of soil organic carbon and humic substances were found in the farmyard manure + compost treatment and then compost > farmyard manure > control. In compost, farmyard manure and farmyard manure + compost treatments, cabbage yield increased by 52, 22 and 72%, respectively compared to control treatment. Cabbage yields linear also increased as a result of increasing of soil organic carbon and humic substances.

Keywords: aggregate stability, coefficient vulnerability, cabbage yield, compost, farmyard manure, soil organic matter

1 Introduction

Soil physical health is the ability of a given soil to meet plant and ecosystem requirements for water, aeration, and strength over time and to resist and recover from processes that might diminish that ability (McKenzie et al., 2011). Soil structure is often defined as the most important basic physical property of soil and is therefore considered an important indicator of soil quality (Kay et al., 2006). Soil structure refers to the shape, size, and strength of soil aggregates (the basic unit of soil structure) and pores (voids between particles and soil aggregates). These characteristics are differentiated through the capacity of soil pores, and their ability to retain water, organic and inorganic substances in them, allowing them to move, solubility and ability to support the growth and development of soil microorganisms and plant roots (Lal & Shukla, 2004). A change in the condition of the soil structure will usually also induce a change in other soil properties (Kay et al., 2006).

From the above context, soil structure does not directly affect plant growth and development. This is significant as it affects virtually all growth factors. Soil and plant water supply, aeration, availability of plant nutrients, microbial activity, root growth and many physical properties of soil are significantly affected by the soil structure. Therefore, an unfavourable soil structure is a factor that indirectly limits the growth of plants. Conversely, a good water-resistant soil structure allows growth factors to act in optimal performance (Fulajtár, 2006; Nayak & Mishra, 2019). The soil structure is influenced by the whole

***Corresponding Author:** Vladimír Šimanský, Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources, Department of Soil Science, Tr. Andreja Hlinku 2, 949 76 Nitra, Slovakia; e-mail: vladimir.simansky@uniag.sk

complex of external and internal factors, and there are numerous interactions between them (Idowu, 2003; Bronick & Lal, 2005; Šimanský et al., 2013). Organic matter is very important for maintaining structural stability in soils as well as improving the physical, chemical, and biological properties of soils (Iwai et al., 2019). The quantity and quality of organic matter that affects the physical condition of soils, including the soil structure as is known, can be modified through soil management practices (Šimanský et al., 2013; Iwai et al., 2019; Nayak & Mishra, 2019). The application of organic materials for soil amendment, especially the composed manures, plays important roles in reclaiming and improving the physical health, including the soil structure of degraded soils (Are et al., 2017).

The following hypotheses were verified: added organic amendments to the soil would improve the soil physical properties, including the soil structure, and that the intensity of the soil physical properties improvement would primarily depend on the quality of the applied organic amendments, though the quantity may have a lesser bearing. Taken together better soil structure should result in a higher crop yield. Therefore, the aim of this study was to:

1. evaluate the effect and extent of applied organic amendments on the soil physical properties with an emphasis on the soil structure,
2. determine whether there is a linear relationship between the soil structure and crop yield.

2 Material and methods

In 2018, the Department of Vegetable Production of SUA-Nitra established a field experiment in the Botanical Garden at the Slovak University of Agriculture in Nitra. The local climate was warm and dry, with annual rainfall of 539 mm approx. and a long-term an average temperature of 10.2 °C (Špánik et al., 2002). The Botanical Garden is located on the left bank of the river Nitra. Hence, the original soil-forming substrate was Quaternary loamy-clayey alluvial sediments above gravel facies, on which were formed a Hortic Calcaric Fluvisol (Polláková & Šimanský, 2015). The average soil content before the experiment was 9.7% sand, 55.8% silt and 34.5% clay on average. Soil organic carbon content was 2.01% and the average soil pH_{H_2O} was 7.75. More chemical characteristics of soil (such as: sorption parameters, humic substances etc.) in the experimental field are available in Polláková and Šimanský (2015a).

A small-plot experiment at the Botanical Garden was established in spring 2018. The preceding crop was winter squash. Cabbage (*Brassica oleracea* var. *capitata* f. *alba*) was planted in 2018. The area of one plot was 42 m^2 and the plots were divided by protective belts. The experiment was established by using the method of random arrangement with the triple repetition and it consisted of the following treatments:

1. control (non-fertilization),
2. compost at a rate of 44 t ha^{-1},
3. farmyard manure at a rate of 44 t ha^{-1},
4. farmyard manure together with compost at rates of 44 and 44 t ha^{-1}, respectively.

Organic materials (farmyard manure and compost) were applied on the soil surface in autumn 2017 and incorporated at a depth of 15–25 cm. As farmyard manure was used poultry manure which contains in dry matter 55% of organic substances with pH 6–8. Compost contains in dry matter 47% of organic substances and its pH on average was 8.2. Conventional practices were applied at the site. The seedlings of the model variety (Kamienna Glowa) were grown according to the usual methodology in the Botanical Garden greenhouses at the Slovak University of Agriculture in Nitra. Sowing was carried out on April 17th, 2018. The seedlings were planted on the site on May 31st, 2018 in plantation spacing of 60 × 60 cm. Additional irrigation was carried out by spraying in the morning, according to the current water deficit in the soil (saturation to 65% of field water capacity). The soil crust was disturbed by a hand hoe. As production was simulated in an ecological farming system, no pesticides or supplementary fertilizers were applied throughout the vegetation period. Cabbage was harvested on November 7, 2018.

Soil samples were repeatedly taken from a soil depth of 0–20 cm twice a year (in spring and autumn) in 2018. For the determination of physical and hydro-physical properties, 100 cm^3 cylinders were used. The soil analysis was then conducted using standard methods. We determined: the bulk density (BD), total soil porosity (TP), volume of non-capillary pores (Pn), volume of capillary pores (Pc), volume of semi-capillary pores (Psc), gravimetric soil water content (Θ) and aeration (A). The fractions of dry-sieved aggregates – DSA (fractions: >7 mm, 7–5 mm, 5–3 mm, 3–1 mm, 1–0.5 mm, 0.5–0.25 mm and <0.25 mm) and the fractions of water-stable aggregates – WSA (fractions: >5 mm, 5–3 mm, 3–2 mm, 2–1 mm, 1–0.5 mm, 0.5–0.25mm and <0.25 mm) were determined by wet sieving – the Baksheev method (Hrivňáková et al., 2011), respectively.

Based on the contents of DSA, the mean weighted aggregate diameter obtained by dry sieving (MWD_d) was calculated:

$$MWD_d = \sum_{i=1}^{n} x_i w_i \qquad (1)$$

where

x_i – the mean diameter of each size fraction (mm); w_i – the total sample weight within the corresponding size fraction; n – the number of size fractions

Mean weighted aggregate diameter obtained by wet sieving (MWD_w) – based on the contents of WSA:

$$MWD_w = \sum_{i=1}^{n} x_i WSA \tag{2}$$

where:

xi – the mean diameter of each size fraction (mm); *WSA* – the total sample weight within the corresponding size fraction; n – the number of size fractions

Soil structure vulnerability coefficient (K_v) (Valla et al., 2000):

$$K_v = \frac{MWD_d}{MWD_w} \tag{3}$$

The structure coefficient (K) was calculated according to Equation (4):

$$K = \frac{A}{B} \tag{4}$$

where:
A – the weight of air-dried aggregates in size fractions from 0.25 to 7 mm; B – the sum of the weight of air-dried aggregates in size fraction more than 7 mm and less than 0.25 mm

We also determined the soil organic carbon content (C_{org}) – measured using the wet combustion method – oxidation of soil organic matter by a mixture of 0.07 mol dm^{-3} H_2SO_4 and $K_2Cr_2O_7$ with titration using Mohr's salt (Hrivňáková et al., 2011). The labile carbon content (C_L) was determined using 0.005 mol dm^{-3} $KMnO_4$ (Loginow et al., 1987) and the fraction composition of humic substances according to Belchikova and Kononova (Hrivňáková et al., 2011).

The statistical analyses were performed with the statistical package Statgraphics Centurion XVI. programme (Statpoint Technologies, Inc., USA). The effects of organic materials on physical properties were tested using one-way ANOVA and then the least significant difference (LSD) method was used to compare treatment means at the significant level of α = 0.05.

3 Results and discussion

The addition of organic amendments would normally improve soil properties including soil physics (Lal and Shukla, 2004; Belmonte et al., 2018) however, in our experiment organic amendments (compost, farmyard manure and their combination) did not have statistically significant effects on bulk density, total porosity (TP), soil moisture or aeration (Table 1).

There were expected that a finding to be consistent with Iwai et al. (2019) and show the addition of compost in soil resulted in physical properties such as bulk density, TP, moisture in soil were improved. However, applied compost decreased bulk density and increased TP, moisture, and aeration but the changes were not significant compared to the control, the exception being the quantity of added organic matter to the soil, a key factor in the quality of organic amendments. Manure improves cation exchange capacity (CEC), a nutrient regime in the soils and physical properties through added humic substances (Vachalová et al., 2016). The quality of humic substances depends on their maturity. Besides, younger humic substances are responsible for CEC and nutrient regime in the soils, and mature (old) humic substances are responsible for improvements of physical properties in the soils. In this context, it is evident that organic amendments applied to the soils occur due to the production process (because of the conditions employed in the production process) and maturity of organic matter used. If the results of TP were evaluated there should not be any significant differences between organic amendments applied to the soil. However, when TP was evaluated to ascertain the volumes of an individual energetic category of soil pores (capillary, non-capillary and semi-capillary pores), the

Table 1 Effect of organic amendments on physical properties of soil

Treatments	BD	TP	Θ	A
	t m^{-3}	%		
C	1.35 ±0.09^a	47.0 ±3.14^a	32.5 ±2.65^a	14.5 ±4.53^a
Com	1.29 ±0.07^a	49.0 ±3.43^a	32.7 ±4.46^a	16.7 ±7.41^a
FYM	1.30 ±0.10^a	46.2 ±4.25^a	31.0 ±6.30^a	15.2 ±8.50^a
FYM + Com	1.36 ±0.09^a	46.3 ±3.39^a	30.7 ±3.90^a	15.6 ±6.00^a

C – control, Com – compost, FYM –farmyard manure, BD – bulk density, TP – total porosity, Θ – soil moisture, A – aeration
different letters (a, b) between lines indicate that treatment means are significantly different at p <0.05 according to the LSD test

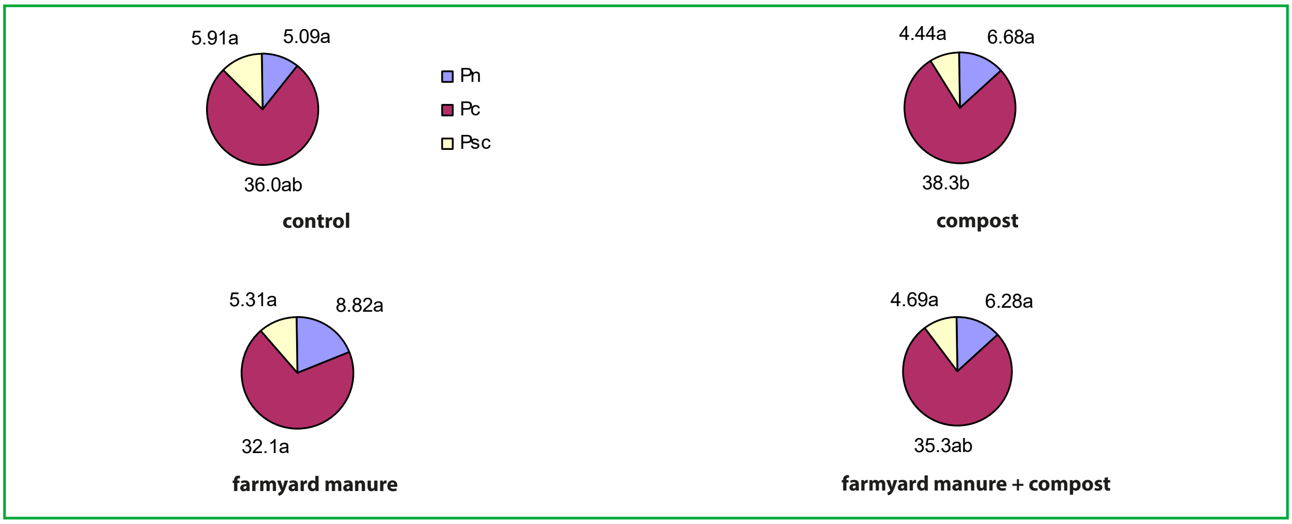

Figure 1 Effect of organic amendments on volumes individual energetic pore categories
the values with different letters are significantly different from each other
Pn – volume of non-capillary pores, Pc – volume of capillary pores, Psc – volume of semi-capillary pores

one-way ANOVA analysis showed significant differences between treatments, for a volume of capillary pores (Figure 1). The highest average volume of capillary pores was found in the compost treatment and then in control > farmyard manure + compost > farmyard manure, however statistically significant differences between compost vs. farmyard manure were also observed. This indicates that the quality of applied farmyard manure was poorer compared to applied compost. Volumes of non-capillary and semi-capillary pores were not changed significantly due to organic amendments application (Figure 1).

In this study, the results of soil structure parameters are summarized in Table 2. The ratio between dry-sieved macro- (DSA_{ma}) and micro-aggregates (DSA_{mi}) is a sensitive indicator of soil compaction and it indicates how much of the macro-pores are being altered concerning the volume of micro-pores. This ratio can be called the structure coefficient (K). A higher value of K results in optimal soil structure and better overall soil physical properties. No significant effects of organic amendments on changes in K values were observed. Based on the one-way ANOVA results, no significant differences in MWD_d were between the following treatments: compost > farmyard manure + compost > control > farmyard manure. It is estimated that for proper soil aeration and plant development, the relationship between DSA_{ma} and DSA_{mi} within TP should be 67% DSA_{mi} and 33% DSA_{ma} (Oliveira et al., 2015). In the present study, the content of DSA_{mi} and DSA_{ma} was lower than 67% and higher than 33%, respectively for all treatments (Table 2). Higher content of DSA_{mi} and reversely a lower content of DSA_{ma} can induce aeration deficiency in soil and reduce gas exchange processes (Colombi et al., 2017). In this study, the contents of DSA_{ma} and DSA_{mi} ranged from 85.9 to 96.5% and from 3.52 to 14.13%, respectively. The application of organic amendments had a statistically significant influence on the total contents of DSA_{ma} and DSA_{mi} (Table 2). The highest content of DSA_{ma} was in compost > farmyard manure + compost > farmyard manure > control. The effects of organic amendments were dependent on size fractions of DSA_{ma}. No significant effect of organic amendments in higher size fractions of DSA_{ma} (>1 mm) on one and statistically significant effect in smaller size fractions of DSA_{ma} (<1 mm) were observed on the other (only between fertilized treatments; no between control vs. fertilized treatments).

From a structural stability point of view, the content of WSA is crucial. The total contents of WSA, contents of agronomically favourable macro-aggregates (WSA_{ma}) in size fractions 0.5–3 mm (Šimanský & Bajčan, 2014), MWD_w and coefficient vulnerability (Valla et al., 2000) are summarized in Table 2. Content of water-stable micro-aggregates (WSA_{mi}) and water-stable macro-aggregates (WSA_{ma}) ranged from 1.47 to 23.47% and from 76.56 to 98.53%, respectively. According to the Dolginov classification of WSA (Šimanský et al., 2017), the content of WSA_{ma} >70% represents excellent water-resistant soil structure. The addition of organic amendments had a statistically significant influence on the increase of total contents of WSA_{ma} and the decrease of WSA_{mi}. The average value of WSA_{ma} was higher by 10 and 11% in compost and farmyard manure + compost treatments, respectively compared to control. In WSA_{ma} size fractions 2–1 and 1–0.5 mm, statistically significant differences between fertilizer treatments were observed. Fertilization of organic manures did not have any significant effects on changes in higher size fractions of WSA_{ma} as well as in agronomical favourable size fraction of WSA_{ma} 0.5–3 mm

Table 2 Effect of organic amendments on soil structure parameters

Treatments	Individual size fractions in mm of dry-sieved aggregates (mass%)						
	>7	7–5	5–3	3–1	1–0.5	0.5–0.25	<0.25
C	41.4 ±9.83^{a}	9.13 ±2.25^{a}	9.61 ±0.73^{a}	18.7 ±1.53^{a}	8.61 ±1.21^{ab}	3.96 ±0.54^{ab}	8.50 ±2.15^{b}
Com	47.3 ±3.72^{a}	9.59 ±0.91^{a}	10.4 ±0.84^{a}	18.1 ±4.81^{a}	7.21 ±2.24^{a}	3.55 ±0.72^{a}	3.99 ±0.48^{a}
FYM	39.9 ±4.99^{a}	10.1 ±1.68^{a}	9.33 ±3.03^{a}	20.6 ±2.33^{a}	10.1 ±2.32^{b}	5.33 ±1.49^{b}	4.69 ±0.73^{a}
FYM + Com	41.3 ±7.55^{a}	11.4 ±2.34^{a}	11.2 ±2.06^{a}	20.2 ±2.37^{a}	7.53 ±1.35^{ab}	3.65 ±0.66^{a}	4.73 ±0.71^{a}
	Individual size fractions in mm of water-stable aggregates (mass%)						
	>5	5–3	3–2	2–1	1–0.5	0.5–0.25	<0.25
C	10.4 ±5.72^{a}	9.85 ±3.70^{a}	13.1 ±1.48^{a}	14.3 ±0.97^{a}	21.6 ±6.64^{ab}	11.9 ±1.48^{a}	18.9 ±1.44^{b}
Com	18.3 ±8.90^{a}	16.4 ±8.19^{a}	15.4 ±1.49^{a}	16.1 ±3.83^{ab}	13.8 ±5.02^{a}	9.58 ±5.02^{a}	10.4 ±4.16^{b}
FYM	8.06 ±3.18^{a}	9.71 ±0.45^{a}	13.2 ±3.12^{a}	14.4 ±0.72^{a}	24.7 ±2.43^{b}	14.0 ±1.68^{a}	16.0 ±6.79^{b}
FYM + Com	12.9 ±5.52^{a}	15.2 ±5.69^{a}	20.7 ±1.32^{b}	18.9 ±3.05^{b}	13.8 ±5.56^{a}	8.94 ±6.88^{a}	9.45 ±5.83^{a}
	DSA_{ma}	WSA_{ma}	$WSA_{ma\ 3–0.5}$	MWD_d	MWD_w	K_v	K
	mass%			mm			
C	91.5 ±2.15^{a}	81.1 ±1.44^{a}	49.0 ±6.48^{a}	3.88 ±0.19^{a}	1.36 ±0.45^{a}	3.08 ±0.88^{ab}	1.01 ±0.11^{a}
Com	96.0 ±0.48^{b}	89.6 ±4.16^{a}	45.3 ±7.60^{a}	4.32 ±0.56^{a}	1.97 ±0.38^{b}	2.53 ±0.68^{a}	1.00 ±0.38^{a}
FYM	95.3 ±0.73^{b}	84.0 ±6.79^{a}	52.2 ±2.68^{a}	3.85 ±0.30^{a}	1.26 ±0.21^{a}	3.13 ±0.30^{b}	1.27 ±0.27^{a}
FYM + Com	95.2 ±0.71^{b}	90.5 ±5.83^{b}	53.4 ±5.78^{a}	4.05 ±0.38^{a}	1.80 ±0.20^{b}	2.38 ±0.18^{a}	1.21 ±0.36^{a}

C – control, Com – compost, FYM –farmyard manure, DSA_{ma} – the content of dry-sieved macro-aggregates, WSA_{ma} – the content of water-stable macro-aggregates, $WSA_{ma\ 3–0.5}$ – the content of water-stable macro-aggregates in size fractions 3–0.5 mm, MWD_d – mean weight diameter for dry-sieved aggregates, MWD_w – mean weight diameter for water-stable aggregates, K_v – vulnerability coefficient, K – structure coefficient
Different letters (a, b) between lines indicate that treatment means are significantly different at p <0.05 according to the LSD test

Table 3 Effect of organic amendments on soil organic matter and humus parameters

Treatments	C_{org}	C_L	HS	HA	FA	HS	HA	FA	$C_{HA} : C_{FA}$
	g kg^{-1}					% share in C_{org}			
C	19.5	2.24	6.04	3.08	2.96	30.9	15.7	11.8	1.06
Com	32.4	4.08	9.23	5.44	3.80	28.3	16.6	15.2	1.42
FYM	23.6	2.77	7.09	3.49	3.60	30.0	14.7	15.2	0.97
FYM + Com	32.0	3.97	9.97	5.83	4.14	31.0	17.8	13.1	1.38

C – control, Com – compost, FYM – farmyard manure, C_{org} – soil organic carbon, C_L – labile carbon, HS – humic substances, HA – humic acids, FA – fulvic acids

(Table 2). The stability of aggregates was higher in compost and farmyard manure + compost than in farmyard manure treatment compared to control. Also, better soil structure stability evaluated by vulnerability coefficient (K_v) was in farmyard manure + compost (2.38 ±0.38) and compost (2.53 ±0.68) than in farmyard manure treatment (3.13 ±0.30).

The addition of organic amendments to the soils has been suggested for improving structural stability by many researchers (Šimanský et al., 2018; Nayak & Mishra, 2019). Šimanský et al. (2013) reported that the addition of manure improved the stability of soil aggregates due to the increased organic matter. Organic matter is the main agent for binding mineral and organic particles together to soil aggregates (Bronick & Lal, 2005) and the application of organic amendments also improves the water-resistance of the soil structure (Gosling et al., 2013) through soil organic matter (Dörner et al., 2010). Soil organic matter affects WSA by decreasing their wettability and increasing their mechanical strength (Idowu, 2003; Onweremadu et al., 2007). This positive effect of applied organic amendments was also confirmed (Table 3). The highest content of soil organic carbon and humic substances were found in the farmyard manure + compost treatment and then in compost > farmyard manure > control. In this study, added farmyard manure

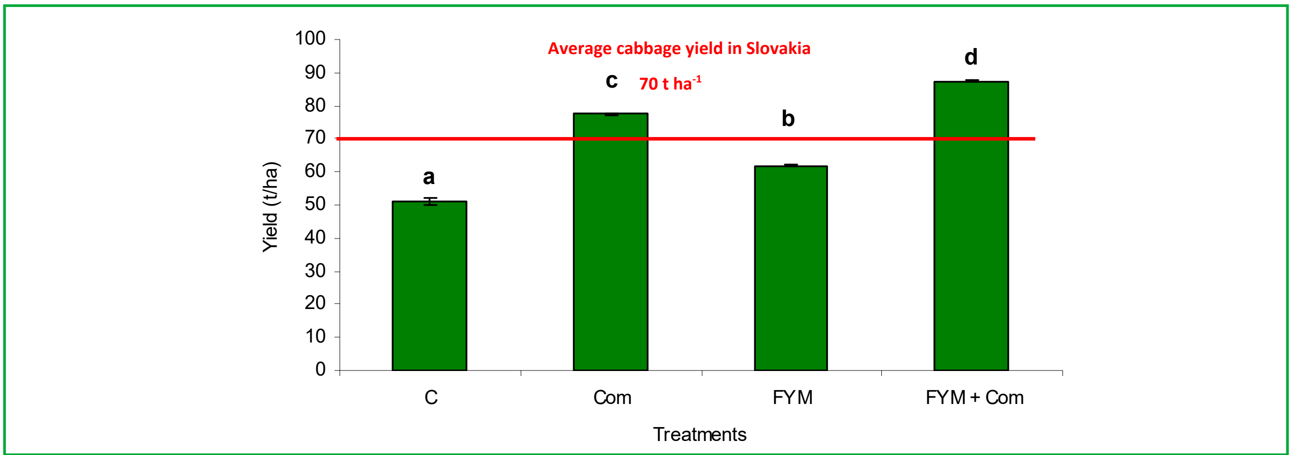

Figure 2 Effect of organic amendments on the cabbage yields in 2019 in comparison to average cabbage yields in Slovakia (red line)
different letters (a, b) between columns indicate that treatment means are significantly different at p <0.05 according to LSD test

did not have any significant effect on changes in the quality of humic substances compared to compost and farmyard manure + compost treatments (Table 3). Riffaldi et al. (1998) stated that farmyard manure is a source of unstable organic matter and its application to the soil leads to more intense changes in organic matter content and a robust release of carbon from the soil supply, making the organic matter more unstable (Shein et al., 2001). Labile components of organic matter can affect the stability of the soil structure. After the addition of organic materials, the content of labile carbon (C_L) increased the most in compost and the least in farmyard manure treatments. However, as stated by Harris et al. (1966) supplying organic amendments with higher instability will result in a temporary reduction in the stability of the soil structure, but in the long-term it is beneficial (Zaujec & Šimanský, 2006). As mentioned above, except for quantity, the quality of added organic amendments to the soil is crucial.

The cabbage yields after the addition of organic amendments are shown in Figure 2. In this study, in the control treatment, the average yield of cabbage was 50.9 t ha^{-1} and the addition of organic amendments to the soil increased the yield statistically significantly. In compost, farmyard manure and farmyard manure + compost treatments cabbage yield increased by 52, 22 and 72%, respectively compared to the control treatment. Significant differences were observed between organic amendments treatments too. The highest cabbage yield was in farmyard manure + compost probably because of the highest content of organic materials and nutrition. In compost treatment, the cabbage yield was higher than in farmyard manure. In these treatments, the same rates have been added, however, there were probably differences in the contents of other components and this could be the reason for differences in yields. The addition of compost to the soil has shown to have a more beneficial effect on soil physical properties (Tables 1–3 and Figure 1) compared to farmyard manure. The results of Iwai et al. (2019) also showed the beneficial effects of compost in increasing maize growth and the yield of Cassava. Also, the study of Nayak and Mishra (2019) confirmed that farmyard manure, composts, poultry manure and bio-fertilizers in various combinations along with a recommended dose of mineral fertilizers were applied to impacted soils to evaluate their effect on plant biomass. In this study, the final yields of cabbage in 2019 were also compared to the average cabbage yields

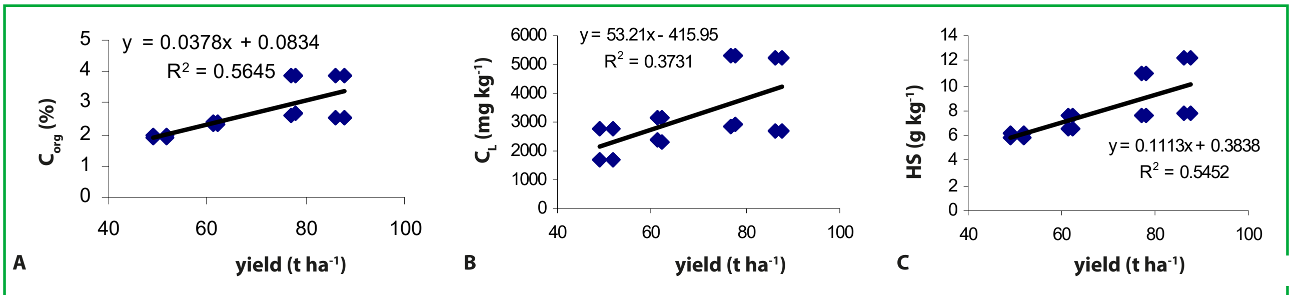

Figure 3 Linear relationships between A) soil organic carbon, B) labile carbon, C) humic substances and cabbage yields

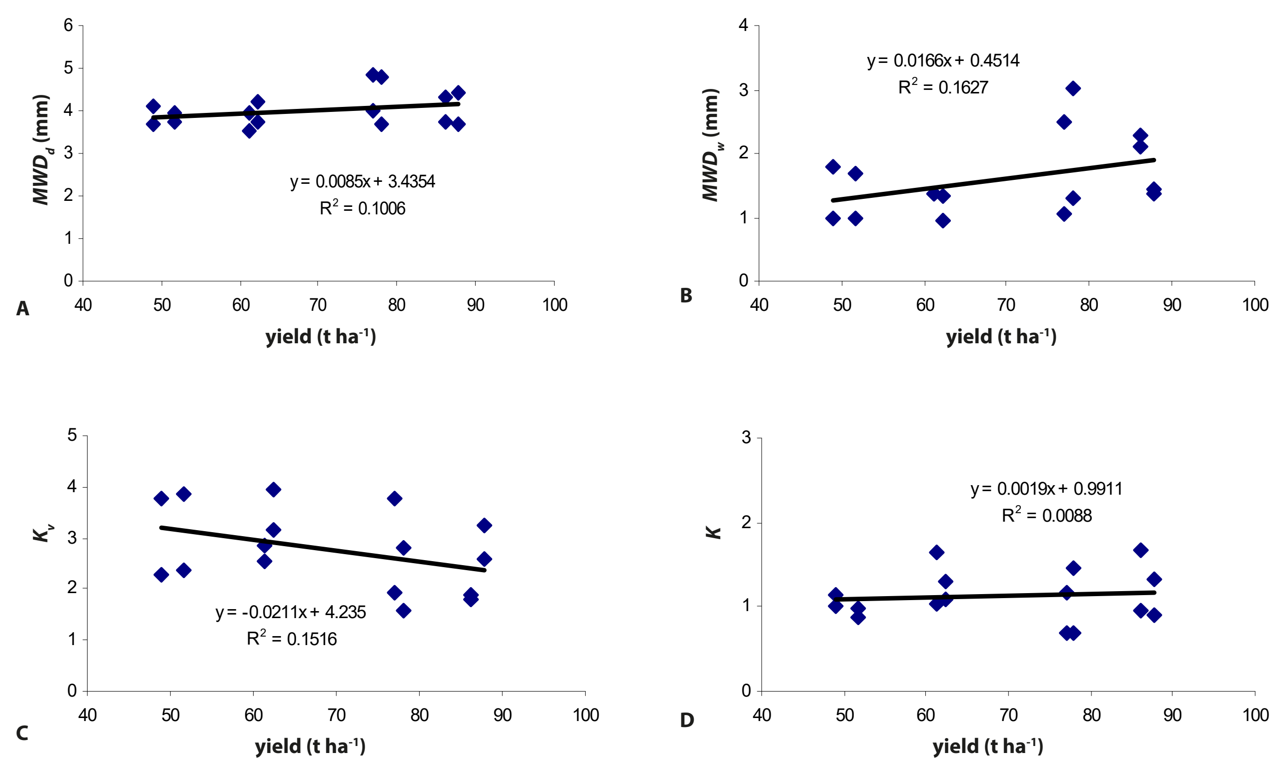

Figure 4 Linear relationships between A) mean weight diameters for dry-sieved aggregates, B) mean weight diameter for wet-sieved aggregates, C) vulnerability coefficient, D) structure coefficient and cabbage yields

in Slovakia (Figure 2). The average yield of cabbage in Slovakia was reported 70 t ha^{-1} (Vaněk et al., 2013). 70 t of cabbage yield per hectare was reached in compost and farmyard manure + compost treatments and the yield of cabbage in control and farmyard manure treatments was observed to be below the country's average.

Since organic amendments are a significant source of carbon, we assumed their application to the soil would increase its content in the soil, which increase in crop yields. The linear relationships between total, labile carbon and crop yields are shown in Figure 3. It is evident from the data that the higher content of soil organic carbon, labile carbon but as humic substances in the soil resulted in higher crop yields, with a statistically significant effect. Conversely, the soil structure parameter had no direct effect on increasing the cabbage yield (Figure 4). We found no statistically significant linear relationships between mean weigh diameters, structure coefficient, vulnerability coefficient and cabbage yields.

4 Conclusions

All in all, the highest cabbage yields and the most significant improvement in soil physical properties including soil structure were produced using the combination of farmyard manure and compost. Adding compost significantly increased cabbage yield and improved physical properties than using farmyard manure.

It is evident that soil structure is an important soil quality parameter but results in this study show; it does not have a direct effect on crop yield even after its improvement with organic amendments. Yield linear increased after organic amendments were introduced due to an increase in soil organic carbon and humic substances and indirectly through an improvement of the physical properties. The increase in yield and improvement of soil properties depends not only on the quantity but also on the quality of the organic amendments incorporated into the soil.

References

Are, K. S. et al. (2017). Improving physical properties of degraded soil: Potential of poultry manure and biochar. *Agriculture and Natural Resources*, 51, 454–462. https://doi.org/10.1016/j.anres.2018.03.009

Belmonte, S. A. et al. (2018). Effect of Long-Term Soil Management on the Mutual Interaction Among Soil Organic Matter, Microbial Activity and Aggregate Stability in a Vineyard. *Pedosphere*, 28(2), 288–298. https://doi.org/10.1016/S1002-0160(18)60015-3

Bronick, C. J. & Lal, R. (2005). Soil structure and management: a review. *Geoderma*, 124, 3–22. https://doi.org/10.1016/j.geoderma.2004.03.005

Colombi, T. et al. (2017). Artificial macropores attract crop roots and enhance plant productivity on compacted soils. *Science Total Environment*, 574, 1283–1293. https://doi.org/10.1016/j.scitotenv.2016.07.194

Dörner, J. et al. (2010). The role of soil structure on the pore functionality of an Ultisol. *Journal of Soil Science and Plant Nutrition*, 10, 495–508. http://dx.doi.org/10.4067/S0718-95162010000200009

Fulajtár, E. (2006). *Physical Properties of Soil*. VÚPOP, Bratislava. In Slovak.

Gosling, P. et al. (2013). What are the primary factors controlling the light fraction and particulate soil organic matter content of agricultural soils? *Biology and Fertility of Soils*, 49, 1001–1014.

Harris, R. F. G. et al. (1966). Dynamics of soil aggregation. *Advantages in Agronomy*, 18, 107–169.

Hrivňáková, K. et al. (2011). *The uniform methods of soil analysis*. VÚPOP, Bratislava. In Slovak.

Idowu, O. J. (2003). Relationships between aggregate stability and selected soil properties in humid tropical environment. *Communications in soil science and plant analysis*, 34(5–6), 695–708. https://doi.org/10.1081/CSS-120018969

Iwai, Ch. B. et al. (2019). Vermicompost as soil amendment for sustainable land and environment in Thailand. In Rakshit, A. et al. (eds.) *Soil amendments for sustainability, challenges and perspectives.* CRP Press, Taylor & Francis Group (pp. 321–348).

Kay, B. D. et al. (2006). Optimum versus non-limiting water contents for root growth, biomass accumulation, gas Exchange and the rate of development of maize (*Zea mays* L.). *Soil & Tillage Research*, 88, 42–54. https://doi.org/10.1016/j.still.2005.04.005

Lal, R. & Shukla, M. K. (2004). *Principles of soil physics*. Marcel Dekker, New York. https://doi.org/10.1111/j.1365-2389.2005.0756c.x

Łoginow, W. et al. (1987). Fractionation of organic carbon based on susceptibility to oxidation. *Polish Journal of Soil Science*, 20, 47–52.

McKenzie, B. M. et al. (2011). Soil physical quality. In Gliński, J. et al. (eds.) *Encyclopedia of Agrophysics*. Springer Science, Coppenhagen (pp. 770–777).

Nayak, S. & Mishra, C. S. K. (2019). Nutrient enrichment of mine spoil with suitable organic and bio-fertilizer amendments as a sustainable technology for eco restoration. In Rakshit, A. et al. (eds.) *Soil amendments for sustainability, challenges and perspectives*. CRP Press, Taylor & Francis Group (pp. 349–361).

Oliveira, D. et al. (2015). Physical soil quality under different management systems and swine slurry application. *Agriambi*, 19, 280–285. https://doi.org/10.1590/1807-1929/agriambi.v19n3p280-285

Onweremadu, E. U. et al. (2007). Carbon and nitrogen distribution in water-stable aggregates under two tillage techniques in Fluvisols of Owerriarea, southeastern Nigeria. *Soil & Tillage Research*, 97, 195–206. https://doi.org/10.1016/j.still.2007.09.011

Polláková, N. & Šimanský, V. (2015). Physical properties of Urban soil in the campus of Slovak University of Agriculture Nitra. *Acta fytotechnica et zootechnica*, 18(2), 30–35. https://doi.org/10.15414/afz.2015.18.02.30-35

Polláková, N. & Šimanský, V. (2015a) Selected soil chemical properties in the campus of Slovak University of Agriculture in Nitra. *Acta fytotechnica et zootechnica*, 18(3), 66–70. https://doi.org/0.15414/afz.2015.18.03.66-70

Riffaldi, R. et al. (1998). Adsorption on soil of dissolved organic carbon from farmyard manure. Agriculture. *Ecosystems and Environment*, 69, 113–119. https://doi.org/10.1016/S0167-8809(98)00097-8

Shen, H. et al. (2001). Effect of fertilization on oxidizible carbon, microbial biomass carbon and mineralizable carbon under different agroecosystems. *Communications in soil science and plant analysis*, 32(2), 1575–1588. https://doi.org/10.1081/CSS-100104214

Šimanský, V. et al. (2013). The effect of organic matter on aggregation under different soil management practices in a vineyard in an extremely humid year. *Catena*, 101, 108–113. https://doi.org/10.1016/j.catena.2012.10.011

Šimanský, V. & Bajčan, D. (2014). The stability of soil aggregates and their ability of carbon sequestration. *Soil & Water Research,* 9(3), 111–118. https://doi.org/10.17221/106/2013-SWR

Šimanský, V. et al. (2018). Response of soil organic matter and water-stable aggregates to different biochar treatments including nitrogen fertilization. *Journal of Hydrology and Hydromechanics*, 66(4), 429–436. https://doi.org/10.2478/johh-2018-0033

Šimanský, V. et al. (2017). *Guide for soil science*. Slovak University of Agriculture, Nitra. In Slovak.

Špánik, F. et al. (2002). *Agroclimatic and phenological characteristics of the town of Nitra (1999–2000).* Slovak University of Agriculture, Nitra. In Slovak.

Váchalová, R. et al. (2016). *Primary soil organic matter and humus, two components of soil organic matter.* Slovak University of Agriculture, Nitra. In Czech.

Valla, M. et al. (2000). Vulnerability of aggregates separated from selected Anthrosols developed on reclaimed dumpsites. *Rostlinná výroba*, 46, 563–568. https://doi.org/10.17221/4376-PSE

Vaněk, V. et al. (2013). *Nutrition of field and garden crops.* Profi Press, Nitra. In Czech and Slovak.

Zaujec, A. & Šimanský, V. (2006). *Influence of biostimulators of plant residue decomposition on soil structure and soil organic matter.* Slovak University of Agriculture, Nitra. In Slovak.