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Effects of organic and conventional management on physical properties of soil aggregates

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A b s t r a c t. The aim of this study was to compare the effect of organic and conventional management systems on total porosity, water and ethanol sorptivity, repellency index, and tensile strength of soil aggregates. Two size fractions of soil aggregates (15-20 and 30-35 mm) were collected from the 0-10 and 10-20 cm depths. Data on water and ethanol sorptivities of the initially air-dry soil aggregate fractions were obtained from the steady state flow measurements using an infiltration device. Water repellency was identified by the ethanol/water sorptivity method. The total porosity was higher in aggregates from the conventionally than organically managed soil irrespective of soil layer or aggregate size. Infiltration and sorptivity of ethanol (60 mm^3) were faster under the conventional than organic management irrespective of aggregate size and depth. Infiltration and sorptivity of water in 30-35 mm aggregates were greater under organic than conventional management. The repellency index was mostly higher for the conventional management of soil and for agregates 30-35 than 15-20 mm in each management system. Aggregate crushing strength was in most cases greater under the organic than conventional management and could increase resistance to compaction and carbon sequestration under the former.

K e y w o r d s: soil management systems, water sorptivity, ethanol sorptivity, repellency, tensile strength

INTRODUCTION

Variation in the hydraulic and mechanical properties of soil aggregates is an important factor affecting water storage and infiltration because large inter-aggregate pores are dewatered first and the transport of water and solutes is influenced by the properties of the individual aggregates (Abrishamkesh *et al*., 2011; Peth *et al*., 2010). A high mechanical stability of soil aggregates is fundamental for maintenance of proper tilth and provides stable traction for farm implements, but limits root growth inside aggregates (Turski, 2002). The hydraulic properties of soil aggregates such as infiltration, sorptivity, or wettability help to assess the water flow mechanisms in very conductive pores inside aggregates. Water repellent soil resists water infiltration and leads to surface runoff and erosion (Hallett *et al*., 2001).

The combined effect of the internal aggregate strength and wettability can result in increased soil stability and water infiltration (Eynard *et al*., 2006). The pore development within aggregates determines the spatial distribution of solutes, soil organic carbon, and community of microorganisms which are the factors influencing both the hydraulic (Eynard *et al*., 2006) and the mechanical (Goebel *et al*., 2005) properties of soil aggregates. Moreover, the structure of pores in soil aggregates influences water vapour adsorption (Kharitonova *et al*., 2004) and storage of water and its availability to plants (Witkowska-Walczak, 2000). Specific management practices have responses in hydrologic, retention and aggregate stability information (Park and Smucker, 2005).

Generally, cultivation decreases the organic matter content of soils and corresponds to a decrease in aggregate stability by changing its structure. Conventional agriculture without application of organic manure reduces the soil quality for crop production by worsening its fertility (Schjønning *et al*., 2002) and has contributed to global warming by increasing the atmospheric concentration of CO_2 (Lal and Kimble, 1997). Organic, 'environmentally friendly' farming puts into practice the idea of sustainable development.

To date, the majority of studies on the effects of organic farming and management practices were focused on soil organic matter and biological activity. It was shown that organic farming and management practices can improve soil properties through addition of soil organic matter, increased

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earthworm population and density of burrows, biodiversity, soil fertility *etc*. (Schjønning *et al*., 2002). However, there is scarce information on the effect of organic management practices on the soil structure. The results obtained hitherto indicate that organic management significantly affects the pore structure and enhances biological activity with positive effects to the environment and agriculture (Papadopoulos *et al*., 2006). This supports the view that organic management has a greater potential for soil structural improvement than conventional management. However, more attention should be directed toward the influences of organic farming on the hydraulic and mechanical properties of soil aggregates which determine soil quality. We hypothesized that the soil management system causes significant changes in the hydraulic and mechanical properties of soil aggregates because of significant alterations in porosity.

The objective of study was to compare the effect of organic and conventional soil management on porosity, water and ethanol sorptivity, repellency index, and tensile strength of variously sized aggregates from two soil depths.

MATERIALS AND METHODS

Experimental fields subjected to long-term (14 years) organic (OM) and conventional (CM) management systems were run at the Institute of Soil Science and Plant Cultivation-National Research Institute in Puławy in the experimental station in Osiny (51°28´ N, 22° 30´ E). Table 1 presents some characteristics of the soil. Information about changes in soil fertility under different farming systems during several years (from 1995 to 2008) can be found in Kuś and Jończyk (2008).

In the organically managed field, potato (one year), spring barley mixed with clover grass (consecutive two years), and winter wheat were planted in rotation. Thirty Mg ha^{-1} of compost and 50 kg ha^{-1} of K_2O (allowed to be used in organic farming) were applied to the organic field in spring before planting potato every four year. Synthetic pesticides, ’Nowodor’ and ‘Perytryna’ were used only to eliminate potato beetle. In the conventional field, winter wheat was planted consecutively. Chemical fertilizers, 120-140 kg ha^{-1} of N, 50 kg ha^{-1} of P_2O_5, and 70 kg ha^{-1} of K_2O were applied. Synthetic pesticides were used. The applied technology was based on intensification of production. The plowing depth was 25 cm in both management systems. Particle size distribution of the soil was determined by sieving and sedimentation. For the pH measurement, a potentiometric method was used. Total carbon and total nitrogen were measured using Tiurin and Kjeldahl methods, respectively.

Soil samples were collected from two soil depths (0-10 and 10-20 cm). After air-drying, two size fractions of soil aggregates (15-20 and 30-35 mm) were manually selected and kept in the dried state in a dessicator in order to provide the same boundary conditions. The aggregate size was chosen due to their relatively high contribution in the soil (Witkowska-Walczak, 2000). The water content of the aggregates was determined in the thermogravimetric way.The porosity (%) of the soil aggregates was determined using the standard wax method (after weighing, for determination of the volume, necessary for calculating bulk density, the aggregates were covered with paraffin and immersed in water). Repellency (hydrophobicity) of soil was calculated by comparison of sorptivity of water (S_W) and ethanol (S_E) using repellency index R (Hallett *et al*., 2001):

$$\mathrm{R} = 1.95\left(\frac{S_E}{S_W}\right), \tag{1}$$

with the coefficient 1.95 taken from the differences in viscosity and surface tension of the two liquids. The repellency index informs about how much sorptivity is reduced by water repellency. When *eg* R =3, it means that water sorptivity was reduced 3 times because of repellency. Infiltration of ethanol is not affected by hydrophobic compounds but only by the soil pore structure, so it easily infiltrates hydrophobic soil. The R value of 1 means no repellency, >1.95 means subcritical repellency, and >50 indicates high repellency (Hallett *et al*., 2001). Cumulative infiltration Q (mm^3 s^{-1}) and sorptivity S (mm $s^{-1/2}$) of water and/or ethanol was determined using a tube with a sponge inserted at the tip (1.9 mm diameter), after Leeds-Harrison *et al*. (1994):

T a b l e 1. Characteristics of the Haplic Luvisol at Puławy

Soil management	Depth (cm)	Particle size (mm) distribution (%)			Total nitrogen (% N)	Total carbon (% C)	pH H_2O
		2-0.02	0.02-0.002	<0.002			
OM*	0-10	85.0	11.5	3.5	0.06	0.90	6.31
	10-20	84.5	11.9	3.6	0.12		6.44
CM*	0-10	85.0	12.0	3.0	0.11	0.81	5.10
	10-20	86.0	11.0	3.0	0.12		6.18

*OM – organic soil management, CM – conventional soil management.

$$S = \sqrt{\frac{Qf}{4br}}, \quad (2)$$

where: Q – the steady rate of flow, cumulative infiltration ($mm^3\ s^{-1}$); f – fillable porosity; b – parameter affected by soil-water diffusivity function (assumed as 0.55); r – radius of infiltration tip (0.95 mm). The tensile strength q (MPa) was determined using a strength testing device (Zwick/Roell) by putting an air-dry aggregate into its most stable position for crushing and calculated as suggested by Dexter and Kroesbergen (1985):

$$q = 0.576\,Fd^{-2}, \quad (3)$$

where: F – the vertical breaking force (N), d – the mean aggregate diameter (taken along the longest, intermediate, and the smallest axis) and 0.576 is the coefficient.

All properties were determined in 15 replicates for each treatment, aggregates size, and depth. Statistical analysis of results comparing the soil management systems and the size of aggregates was done using confidence tests with a one way analysis of variance ANOVA (STATISTICA 9.0). Means were compared by the ANOVA LSD (least significant difference) test.

RESULTS AND DISCUSSION

The soil management had a direct effect on the porosity (derived from bulk density) of soil aggregates. It was generally significantly ($p<0.05$) higher in aggregates from conventionally than organically managed soil irrespective of the soil layer or aggregate size (Fig. 1). Leading to a decrease in the total porosity of soil aggregates and an associated increase in its bulk density, long-term organic farming can result in a greater number of fine pores and contact points between soil particles in a single aggregate (Horn, 2004). This may also explain changes in resistance to crushing of soil aggregates reported in this study. As can be seen from Table 2, the volumetric air-dry water content of all aggregate fractions was greater in the surface (0-10 cm) than subsurface (10-20 cm), irrespective of management practice, and increased with the aggregate size for conventional soil treatment, unlike under organic management where the water content decreased with the increasing aggregate size.

Faster infiltration of the ethanol volume applied (60 mm^3) was observed in aggregates form the conventionally managed soil in both soil layers (Fig. 2). The ethanol uptake increased linearly with time ($R^2>0.99$). The differences between the soil management systems among one aggregate size were significant. The fastest infiltration of the assumed ethanol volume at the end of the infiltration event was noticed for aggregate size of 30-35 mm under CM at 0-10 cm depth (23 s), whereas it was the slowest for aggregate size of 15-20 mm (58 s) under OM at 10-20 depth.

The data in Fig. 3 indicate that water infiltration was the highest for the organic soil management in smaller aggregates (15-20 mm diameter) in both depths (61 and 55 s, respectively), the difference at 0-10 cm depth was significant ($p<0.05$). The opposite effect of soil treatment was observed in larger aggregates, where water infiltration was higher under CM than OM and the difference at 10-20 cm depth was significant ($p<0.05$). The effect of the soil layer on water uptake at comparable soil treatment was not as considerable as the effect of the aggregate size, especially in OM.

As can be seen from Fig. 4 ethanol sorptivity into both aggregate fractions was greater from conventionally managed soil regardless of soil depth ($p<0.05$). It is further worth noting that the ethnol sorptivities at the comparable aggregate sizes were in general lower at the depth of 10-20 than 0-10 cm. The exception was in 15-20 mm aggregates from the conventional system, where ethanol sorptivity was slightly higher in the subsurface layer. Larger aggregates generally

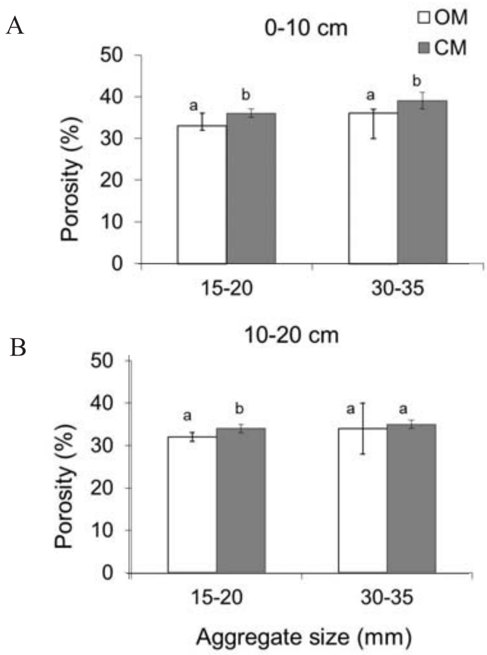

Fig. 1. Porosity of 15-20 and 30-35 mm aggregate fractions from different soil management practices: OM – organic management, CM – conventional management and depths: A – 0-10, B – 10-20 cm. Vertical bars show standard deviation, means with different letters within each aggregate fraction are significantly different at $p<0.05$ (n = 20).

Table 2. Volumetric water content (%) of air-dry soil aggregates used in experiment, values in brackets are standard deviations (n=5)

Treatment	Depth (cm) 0-10		10-20	
	Aggregate size (mm)			
	15-20	30-35	15-20	30-35
OM*	0.78 (0.17)	0.66 (0.02)	0.67 (0.20)	0.60 (0.03)
CM	0.71 (0.27)	0.86 (0.11)	0.53 (0.22)	0.57 (0.04)

*Explanations as in Table 1.

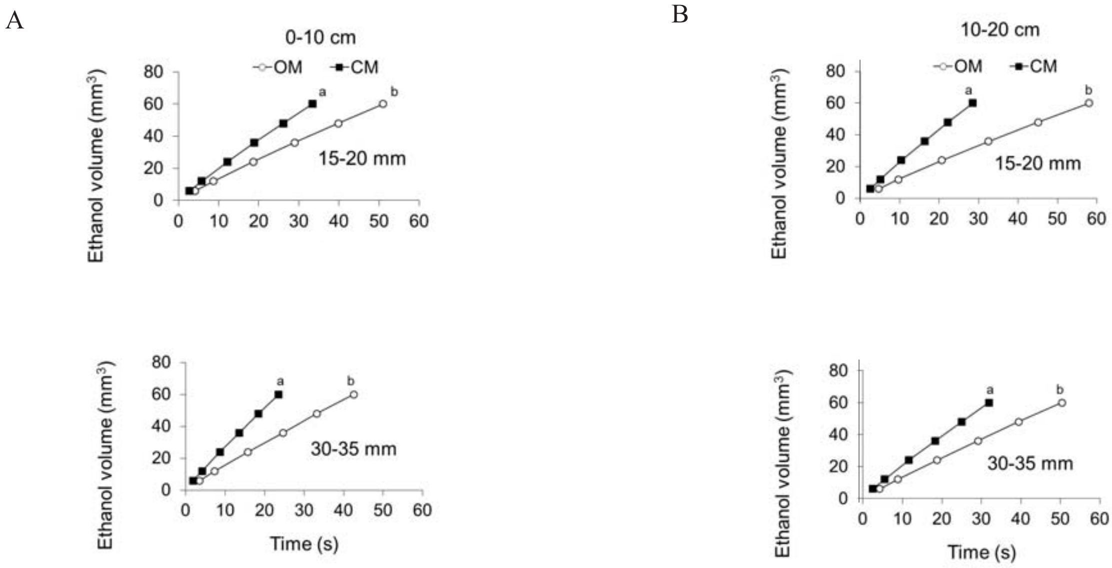

Fig. 2. Cumulative infiltration of ethanol (mm^3) as a function of time for 15-20 and 30-35 mm aggregate fractions from different soil management practices: OM – organic management, CM – conventional management and depths: A – 0-10, B – 10-20 cm. Means at the end of infiltration time with different letters within each aggregate fraction are significantly different at $p < 0.05$ ($n = 20$).

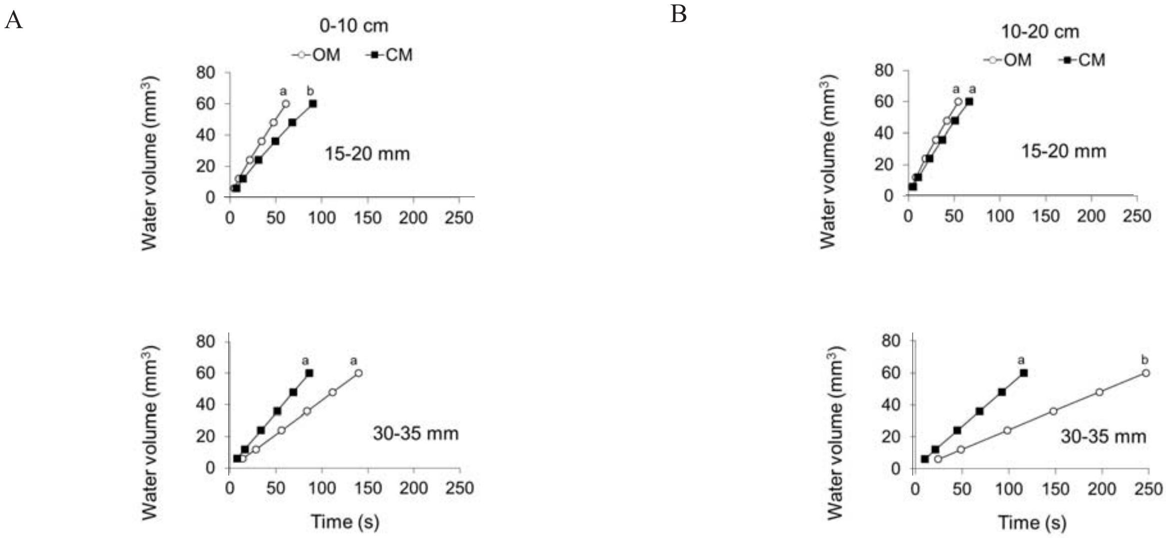

Fig. 3. Cumulative infiltration of water (mm^3) as a function of time for different soil aggregate fractions, soil management practices and depths: A – 0-10, B – 10-20 cm. Explanations as in Fig. 2.

revealed a greater potential for the sorptivity of ethanol, except those from the depth of 10-20 cm in CM, however, the difference was small and not significant (data not shown).

The effect of soil management on water sorptivity was related to aggregate size and depth. At 0-10 cm depth, the sorptivity of 15-20 mm aggregates was greater under OM than CM ($p<0.05$), whereas at 10-20 cm depth it was greater under CM than OM for 30-35 mm aggregates ($p<0.05$). Generally, among one soil management and aggregate fraction, the sorptivity of water decreased with the depth. An increased aggregate size had a negative influence on water sorptivity in most cases (except CM at 0-10 cm depth, Fig. 3).

All aggregates exhibited repellent or almost repellent behaviour. The values of R ranged from 1.92 to 4.14 in OM soil aggregates and from 2.94 to 3.69 in CM (Fig. 5). The repellency index was significantly ($p<0.05$) higher under CM (3.20 and 2.94 at 0-10 cm and 10-20 cm depth) than OM for 15-20 mm aggregates (2.12 and 1.92, respectively). As to

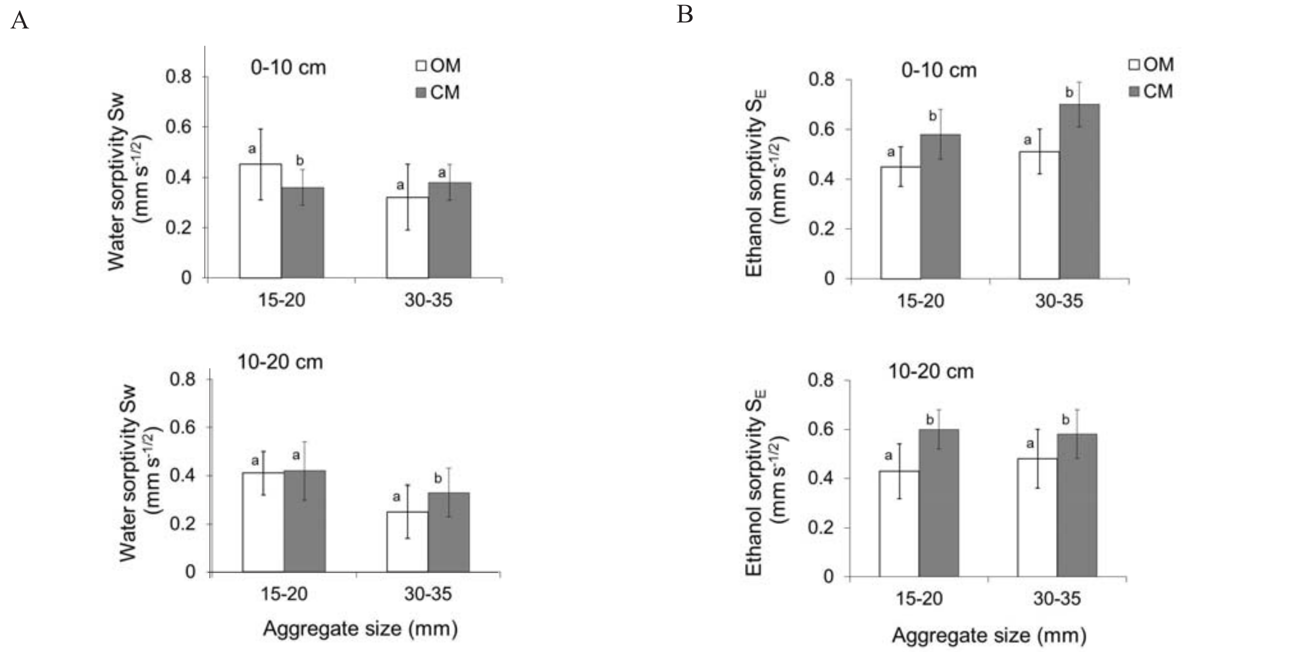

Fig. 4. Water sorptivity – A, and ethanol sorptivity – B for different aggregate fractions, soil managements practices and depths. Explanations as in Fig. 1.

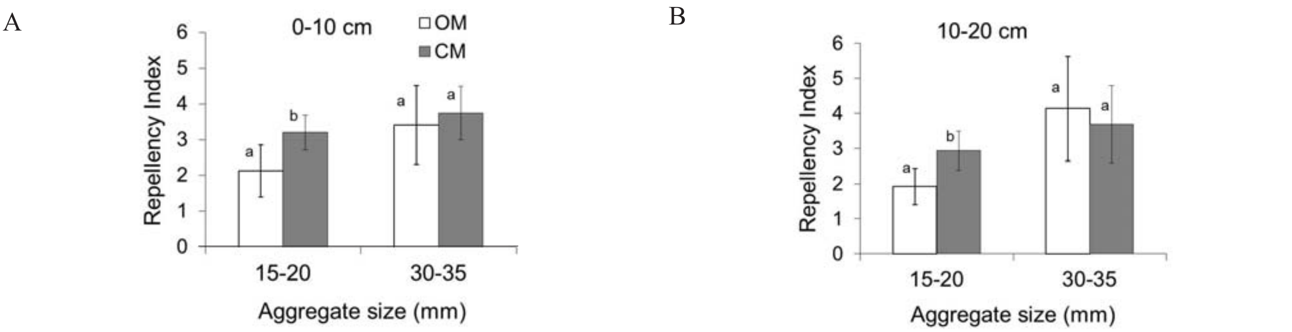

Fig. 5. Repellency index for different aggregate fractions, soil management practices and depths: A – 0-10, B – 10-20 cm. Explanations as in Fig. 1.

30-35 mm aggregates, the repellency index was not different among the management systems ($p<0.05$). At 0-10 cm depth, the R values equaled 3.41 and 3.74 in OM and CM. The R values at 10-20 cm were 4.14 and 3.69 respectively. Under both management systems and depths, the repellency index increased with the increasing aggregate size. This can be due to the descending ratio of the surface area and volume and also to the increasing content of hydrophobic compounds as a result of microbial activity (Peng *et al*., 2003).

Organic carbon may also be responsible for the differences in repellency of soil aggregates. It may stabilize aggregates during fast wetting and increase wettability (opposite to repellency) of soil (Eynard *et al*., 2006; Raut *et al.*, 2012). The greater organic carbon content along with higher pH, in which the solubility of humid acids increases and reduces the surface tension of water (Hurraß and Schaumann, 2006), under organically than conventionally managed soil (Table 1) would explain mostly the smaller R index in OM aggregates (Fig. 5). Additionally, the effect of soil management on repellency to water might be affected by the N level, which was higher in the conventionally managed soil (Table 1). Roberson *et al*. (1995) reported the importance of N in the production of polysaccharides which, as was found by Piccolo and Mbagwu (1999), are generally hydrophilic; however, drying may enhance their water repellency (Czarnes *et al*., 2000). Hallett and Young (1999) confirm that a higher nitrogen level induces repellency.

Subcritical repellency is observed to be a common feature of many agricultural soils (Hallett *et al*., 2001). It is worth underlining that low repellency in soil may have positive aspects. It can stabilize soil organic matter (Bachmann *et al*., 2008) and protect it against microbial decomposition

A B

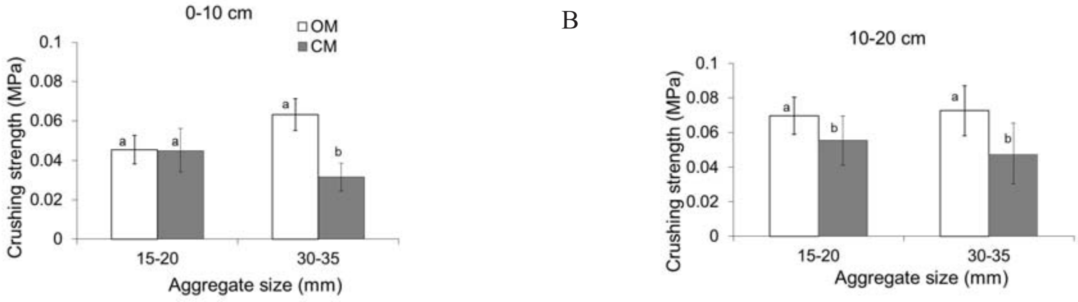

Fig. 6. Crushing (tensile) strength (MPa) for different aggregate fractions, soil management practices and depths: A – 0-10, B – 10-20 cm. Explanations as in Fig. 1.

(Goebel *et al*., 2005). To some extent, repellency buffers water uptake by soil and in that way may enhance structural stability. The presented studies also revealed general tendency for decreasing repellency with depth when comparing one aggregate size and the type of soil management, but the effect was not significant (not shown) (Fig. 5).

As can be seen from Fig. 6 the aggregates from OM compared to CM had higher and in most cases significant ($p<0.05$) resistance for crushing. Comparison of Fig. 6 indicates that at each soil management system and comparable aggregate size the aggregate crushing strength increased with depth ($p<0.05$). The depth-effect on the crushing strength was more meaningful than the effect of the aggregate size. However, it is worth adding that for CM the larger aggregates had smaller tensile strength in both soil layers, the opposite was true for OM.

Recent studies of Papadopoulos *et al*. (2006) using image analysis reveal that increased stability of aggregates form organically compared to conventionally managed soil can be due to the greater contribution of fine pores and also to greater roughness of pores. Moreover, the aggregate stability under OM in the present study can be enhanced by the greater carbon content (Table 1) which becomes a bonding agent between soil particles and in that way may increase tensile strength of soil aggregates and stabilize them (Goebel *et al*., 2005). On the other hand, a greater stability of soil aggregates may better protect C from microbial decomposition and affect soil capability of carbon sequestration (Kęsik *et al*., 2010). This interrelation of the organic carbon content was clearly observed in the present study. Additionally, some scientists pointed out the positive effect of organic soil management on earthworm populations *eg* Pffifner and Luka, 2007, that highly stimulate water flow through the earthworm channels under ponded conditions (preferential flow) (Schjønning *et al*., 2002; Lipiec *et al*., 2011). Earthworm activity may further lead to an increase in C_{org} and aggregate stability.

CONCLUSIONS

1. Total aggregate porosity and infiltration and sorptivity of ethanol were in most cases greater under the conventional than organic soil management irrespective of aggregate size and depth. However, there was an inconsistent effect of the management systems on water infiltration and sorptivity. The water infiltration was highest under the organic management for 15-20 mm aggregates and under the conventional management for 30-35 mm aggregates.

2. The aggregate wettability, as shown by the index of water repellency, was mostly lower under the conventionally than organically managed soil irrespective of aggregate size and depth. In each management system, the wettability was lower for aggregates 30-35 than 15-20 mm. A majority of the aggregates exhibited subcritical water repellency (index of water repellency >1.95).

3. Aggregate crushing strength was in most cases greater under the organically than conventionally managed soil.

4. The results supported our hypothesis since the hydraulic and mechanical properties of the aggregates were significantly influenced by the soil management system.

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