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ASSESSMENT OF RETENTION POTENTIAL AND SOIL ORGANIC CARBON DENSITY OF AGRICULTURALLY USED CHERNOZEMS, CAMBISOLS AND FLUVISOLS

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Abstract

Climate change and the increasing frequency of climatic extremes have led to growing concerns over the sustainability of agriculture during recent years. In this context, soil retention and carbon storage are becoming widely discussed. The aim of this study was to evaluate the retention potential (RP) and soil organic carbon density (SOCD) of Chernozem, Cambisol and Fluvisol topsoil under agricultural management. Despite the different natural assumptions of these soil types, no significant statistical difference was found there. Mean RP values of the soil types varied from 39 to 40 mm and mean SOCD values from 23 to 28 t/ha. This finding may suggest that long-term agricultural management can suppress the naturally diverse potential for water retention and carbon storage of the individual soil types. Comparison of SOCD of the studied soils with agricultural soils in similar studies showed that most of the observed values can be considered as average. Despite this fact, a very strong local degradation has been revealed indicating poor agricultural management. Especially in such cases, there is an urgent need to adjust the management of the agricultural land fund (e.g. increased application of organic fertilizers, change in crop rotation) in order to increase carbon stocks and to improve the water retention capacity of soils.

Keywords: soil retention potential, arable land, climate change, soil organic carbon

INTRODUCTION

Soils are major reservoir of terrestrial organic carbon, and are important in both, sequestering atmospheric CO_2 and emitting CO_2 which contributes to the ‘greenhouse’ effect (Mikhailova *et al.*, 2006; Manojlović *et al.*, 2008). Even small changes in soil organic carbon (SOC) storage can result in large variation in atmospheric CO_2 concentration (Xu *et al.*, 2011; Chen *et al.*, 2014; Minasny *et al.*, 2017). Increasing atmospheric CO_2 levels related to anthropogenic forcing are related to periods of extreme drought (Brázdil *et al.*, 2015). In relation to climate change and increased frequency of climatic extremes, there is observed reduced soil moisture content which negatively affects agriculture (Trnka *et al.*, 2015; Štěpánek *et al.*, 2016). Extreme short-term localized precipitation and possibility of its greater frequency are discussed as well (Hanel *et al.*, 2016; Rulfová *et al.*, 2017; Beranová and Kyselý, 2018). The mentioned facts lead to greater interest in soil retention.

The issue of soil retention is abundantly discussed social and scientific topic, mainly in relation to land-use. The interest is focused mainly on arable land. The retention is one of the most significant hydraulic properties of soil as it affects and partly defines the whole ecosystem (Rawls *et al.*, 2003). It belongs to the key parameters for water flow modelling in the landscape and for transport of solute in soils (Batjes, 1996; Wösten *et al.*, 2001; Rubio *et al*, 2008).

Soil retention largely influences soil management (Rawls *et al.*, 2003) and vice versa (Chen *et al.*, 2015). It is used, for example, in agriculture, hydrology, meteorology, ecology or environmental protection (Rawls *et al.*, 2003). The issue of soil retention, especially in larger areas, is faced with the inherent time and spatial variability. It is necessary to work with a large number of samples there (Pachepsky *et al.*, 2001; Wösten *et al.*, 2001).

Different soil types have different retention potentials (Chen *et al.*, 2015). Focusing more closely on soil properties, water retention is mainly influenced by texture (sand, silt, and clay content), structure (bulk density and porosity), and organic matter content (Hollis *et al.*, 1977; Pachepsky *et al.*, 1996; Pachepsky *et al.*, 2001; Wösten *et al.*, 2001; Otalvaro *et al.*, 2016; Querejeta, 2017).

The soil organic matter content can be influenced by land management practices (Weber *et al.*, 2007; Hagemann *et al.*, 2017; Wong *et al.*, 2017; Kintl *et al.*, 2018). The content and composition of organic matter in the soil affects both, soil structure and adsorption properties (Rawls *et al.*, 2003). For this reason, soil water retention can be easily influenced by changes in soil organic matter, which can be initiated, e.g. by land management (Weber *et al.*, 2007; Ulyett *et al.*, 2014; Elbl *et al.*, 2015; Hagemann *et al.*, 2017) or climate change (Rawls *et al.*, 2003).

In particular, soil water retention can be reduced by intensive agricultural practices (Ulyett *et al.*, 2014). Regular removal of vegetation leads to rapid deterioration of the physical and hydraulic properties of the soil. It is caused mainly due to a sharp decline in infiltration capacity and increase in bulk density associated with a rapid drop in organic matter content (Ulyett *et al.*, 2014; Querejeta, 2017). Such soil degradation can lead, e.g. to higher risk of flooding (Chen *et al.*, 2015; Collentine and Futter, 2018), water erosion (Querejeta, 2017) or reduced agricultural production (Batjes, 1996; Weber *et al.*, 2007; Manojlovic *et al.*, 2008; Ulyett *et al.*, 2014).

Aims of the study were:

1) to determine retention potential (RP) and soil organic carbon density (SOCD) of agricultural topsoil in the Czech Republic (Moravia region);
2) to compare RP and SOCD of Chernozems, Cambisols and Fluvisos;
3) to assess effect of soil organic matter on RP;
4) to propose adjustment of the management on arable land with respect to climate change.

MATERIALS AND METHODS

Soil Sampling

All sampling sites are located in Moravia, Czech Republic. There were taken 55 samples from topsoil (0–10 cm). The topsoil was chosen because effects of agricultural management are usually the greatest on the surface and they decrease with depth (Ogle *et al.*, 2003). Soil samples intended for analysis of physical properties were collected using 100 cm^3 soil column cylinders (Kopecký's cylinders) in three replications. Samples for further analyses were put into plastic bags. There were investigated 3 soil types: Cambisol (26 samples), Chernozem (21 samples) and Fluvisol (8 samples). There was taken different number of samples of the particular soil types as it reflects their abundancy within the arable land.

Sample Analysis

Physical properties (bulk density, porosity, full water capacity) were determined and evaluated using standard methods according to Zbíral *et al.* (2016). Soil pH was measured in 1M of KCl (ISO 10390, 2005). The C_{ox} (oxidizable carbon) was determined by means of oxidation using chromosulphuric mixture (ISO 14235,1998) to characterize SOC (Kubát *et al.*, 2004).

Soil Retention Assessment

Direct soil retention measurement is quite time-consuming and expensive. Thus, a number of indirect methods to determine soil retention has been developed (Rubio *et al.*, 2008). The methods are based on different soil properties that are measured more easily (Pachepsky *et al.*, 2001). In our study, the soil retention potential (RP, in mm) was calculated on the basis of the formula (Vlček *et al.*, 2012):

$$RP = H \times FWC \times (1 - S), \quad (1)$$

where H is thickness of the soil layer (mm), FWC full water capacity (%) and S is soil skeleton estimate (%) (in agricultural soil is this value close to zero).

SOC Evaluation

The SOC density (SOCD) (in t/ha) was calculated on the basis of the formula (Chen *et al.*, 2014; Xia *et al.*, 2016; Liu *et al.*, 2018):

$$\mathrm{SOCD} = SOC \times \rho \times H \times 10^{-1}, \quad (2)$$

where SOC is soil organic carbon (g/kg), ρ is bulk density (g/cm^3) and H represents thickness of soil horizon (cm).

I: *Soil retention potential (RP) and soil organic carbon density (SOCD) of individual soil types (in 0–10 cm)*

Soil type	RP (mm)				SOCD (t/ha)			
	min	median	max	average	min	median	max	average
Chernozems	27.29	40.30	48.66	40.17	17.26	27.28	38.68	26.98
Cambisols	11.85	39.60	46.25	38.69	16.77	27.54	46.82	27.83
Fluvisols	34.59	38.84	46.72	39.81	15.81	21.14	31.85	23.29

Statistical Analyses

Basic raw data processing was performed using Excel (Microsoft Corporation, USA) program. The programme Statistica 12 (StatSoft, Dell Software, USA) was used for statistical analyses. The potential differences in RP and SOCD were analysed using one-way analysis of variance together with post-hoc Tukey´s HSD test. Above all, the strength of a relationship between selected parameters was evaluated by correlation analysis. All analysis were performed at the level of significance $P < 0.05$.

RESULTS AND DISCUSSION

The results of the RP and SOCD in topsoil of arable land (Chernozems, Cambisols and Fluvisols) are stated in Tab. I.

The highest average RP of the study soils was found in Chernozems (40.17 mm). Nevertheless, the difference between the soil types is minimal and statistically insignificant ($P > 0.05$). Although different soil types have different retention preconditions (Vlček *et al.*, 2012; Chen *et al.*, 2015), the significant difference was not confirmed. The result may point to the fact that intensive agricultural practices suppresses natural potential of the individual soil types in water retention and it leads to uniformity of this property.

Cambisols have the highest average value of SOCD (27.83 t/ha) and the biggest variation range. The difference between the individual soil types is minimal and statistically insignificant ($P > 0.05$) there as well. However, according to FAO and CMCC (2017), the highest SOCDs (in 0–30 cm) should have been found in Chernozem (81.66 t/ha) followed by Cambisols (61.04 t/ha) and Fluvisols (39.34 t/ha). Therefore, it can be stated that long-term intensive agriculture and ploughing have led to oxidation of organic matter and poor diversity in the carbon stock of the individual soil types and to the disruption of the natural potential of the soil. It is similar as in the case of RP results. This finding is supported by the results of earlier studies where they state that SOC is greatly affected by agronomic practices (Xia *et al.*, 2016) and intensive agronomic practices leads to a reduction in soil carbon (Manojlović *et al.*, 2008).

Several studies may be used to compare the SOCD with other world agricultural soils. For example, Pan *et al.* (2003) reported a similar value for plow layer (about 15 cm) in China, specifically 29.48 t/ha. Xu *et al.* (2011) reported a value of 47 t/ha in the depth of 0–10 cm of arable land in Ireland, which is twice higher than the average value of the studied Fluvisols. Such high value is related to a high rainfall and poor drainage. Chen *et al.* (2014) report SOCD 33.3 t/ha at cropland in China at the depth of 0–20 cm. Arrouays *et al.* (2002) state SOCD <45 t/ha in French soils (0–30 cm) of land under annual crops and perennial crops with bare soil. SOCD 32 t/ha in vineyards and crops with a very low organic return, and SOCD 43 t/ha in arable land have been found. SOCD less than 30 t/ha at a depth of 0–30 cm is considered as a low value for the croplands (Minasny *et al.*, 2017). Since the depth of the studied profile is usually greater in the literature, and with increasing depth, the SOC decreases (Pan *et al.*, 2003; FAO and CMCC, 2017), the mean values found in this study can be considered as average compared to the research studies.

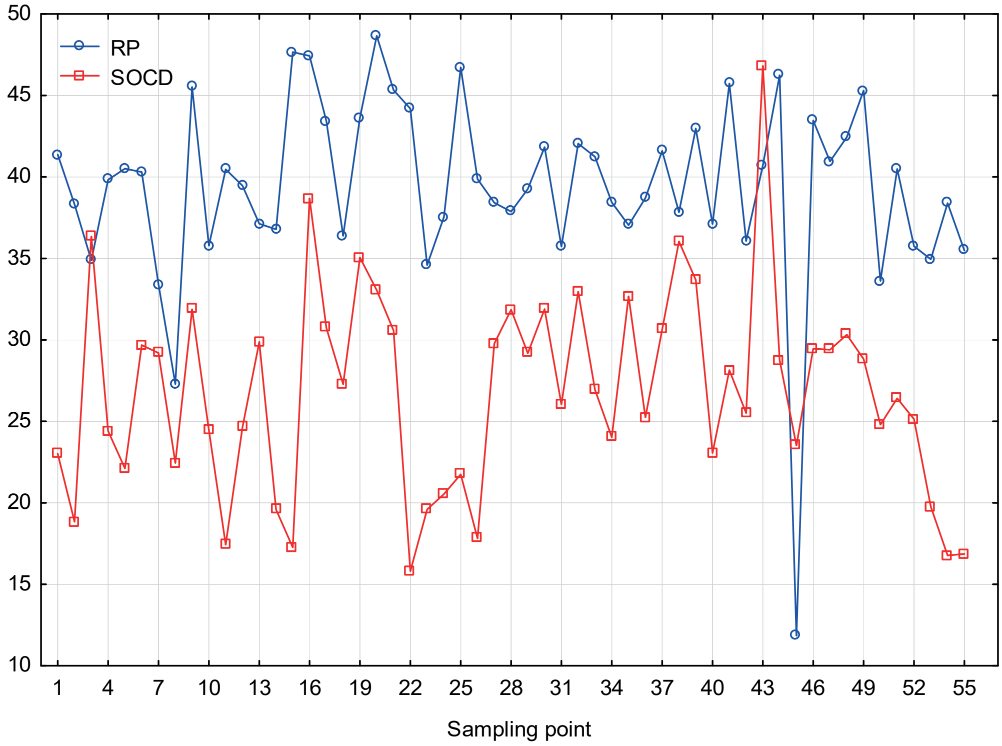
The RP values (Tab. I) show a significant dispersion of data within individual soil types, which reflects the current state of arable land in Moravia. The RP minimal values of Cambisol and Chernozem are especially alarming. They were significantly below the average and indicate strong local degradation of the topsoil RP.

A similar situation is also observed at SOCD results. When focusing on individual soil types, the impact of different management is evident from the data dispersion (Fig. 1). For example, local application of ash in management have led to an above-average SOCD in Cambisols (46.82 t/ha).

The relation between RP and content of organic matter, SOCD respectively, is unusual in the framework of the monitored data. Although the literature frequently reports on significance of SOC for water retention (Hollis *et al.*, 1977; Querejeta, 2017), its significant effect could not be confirmed in this study (Tab. II). Weak positive correlation between SOC and RP has been found only in Chernozems (0.57).

II: *Correlation among soil retention potential, soil organic carbon and soil organic carbon density*

	RP	SOC	SOCD
RP	1		
SOC	0.449	1	
SOCD	0.233	0.909	1



1: *Comparison of RP and SOCD of the individual sampling sites*

The finding is not entirely exceptional in scientific literature. Rawls *et al.* (2003) state in their review, that studies about the relationship between organic carbon content and soil water retention are often contradictory. They report on number of papers where amount of organic matter did not affect soil water retention significantly. Similarly, Minasny and McBratney (2018) state the increase in soil organic carbon has only a small effect on soil water retention.

Although, there is not confirmed statistically significant relation (Tab. II; $R < 0.5$) between RP and SOCD, Fig. 1 showed apparent similar trend of curves reflecting their very weak positive correlation. Insignificancy of their relation may be caused by agricultural practices leading to affection of other soil characteristics, which have not been studied but can have great effect on their relation. Such characteristics may be texture, which is a significant factor affecting relationship of soil water retention to organic carbon content (Rawls *et al.*, 2003). No significant effect may point to possible unsuitability of the used formula to calculate potential retention (Vlček *et al.*, 2012) as it is based on full water capacity.

Management of Arable Land in Context of Climate Change

The actual intensive agriculture can lead to increasing degradation of soil properties (Ulyett *et al.*, 2014). It can be assumed that soil retention potential and carbon stock will be continuously reducing in future if the agricultural management does not change. In context of growing frequency of climatic extremes connected to climate change, mainly drought (Brázdil *et al.*, 2015; Trnka *et al.*, 2015; Štěpánek *et al.*, 2016), the current agriculture production is unsustainable in long-term. More frequent and intense up to extreme precipitation, which is predicted for the future climate in the Czech Republic, will pose another risk of flash floods and landslides (Rulfová *et al.*, 2017). Thus, agricultural management must change leading to increase retention potential and carbon stock, mainly in degraded soils (Minasny *et al.*, 2017).

Increase of arable land carbon stock may be carried out by a range of procedures which can include atmospheric CO_2 sequestration. These comprise, e.g. reduction in tillage disturbance, crop rotations, using cover crops, replacement of annual crops with perennial vegetation and growing deep-rooted crops (Ogle *et al.*, 2003; Manojlović *et al.*, 2008; Minasny *et al.*, 2017). One of the possible solutions is also biochar application (Ulyett *et al.*, 2014; Wong *et al.*, 2017). Increasing amount of soil organic matter combined with increased carbon stock (Ogle *et al.*, 2003) will lead to reduction of atmospheric carbon and in degraded soil also to better retention potential which can mitigate climate change and its negative impacts (Hagemann *et al.*, 2017; Minasny *et al.*, 2017; Minasny and McBratney, 2018).

Although a number of the mentioned procedures has been applied to the studied arable lands, there is very strong decrease in RP and SOCD locally.

Thus, it would be suitable to determine compulsory minimum limits of these parameters and to introduce them into the legislative. Adjustment of the agricultural practices will contribute to better non-production functions of soil. When principles of sustainable agriculture are complied, preserving of future production potential can be expected at simultaneous fulfilling non-production functions of the arable land.

CONCLUSION

The confirmed absence of difference between the studied Chernozems, Cambisols and Fluvisols in RP and SOCD points to the fact that long-term agriculture fades differences in particular soil types, in their water retention and carbon storage. SOCD of the studied soils is average in comparison to other agricultural lands.

Statistically significant correlation between the carbon stock and RP at the studied soils was not confirmed. It points to possibility, that their relationship is not on so high level and to possible strong effect of agricultural practices or to unsuitability of the retention potential formula.

In context of growing manifestation of the climate change, management of the arable land must be adjusted in order to increase carbon stock and soil water retention.

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