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Temporal variability of structure and hydraulic properties of topsoil of three soil types

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ABSTRACT

The soil structure and hydraulic properties of arable soils considerably vary during the year due to the periodical tillage, fertilization, plant and root grow, climate impact etc. The knowledge of these soil properties is essential when assessing water regime and associated dissolved substance transport in soils. Temporal variability of soil properties measured in surface horizons of three soil types (Haplic Cambisol, Greyic Phaeozem, Haplic Luvisol) was studied in years from 2007 to 2010. Undisturbed soil samples were taken every month to evaluate the actual field soil-water content, bulk density, porosity and hydraulic properties. The grab soil samples were taken every month to evaluate aggregate stability using the WSA (water stable aggregates) index, pH_{H2O} and pH_{KCl}, soil organic matter content and quality. Unsaturated hydraulic conductivity for pressure head of −2 cm was measured directly in the field using the minidisk tension infiltrometer. In addition soil structure was documented on micromorphological images.

In some cases, the similar seasonal trends of the soil pH_{H2O}, pH_{KCl}, organic matter quality, bulk density, porosity or aggregate stability were observed in different soils. Parameters characterizing soil hydraulic properties were highly variable and did not show similar trends for different soils. This study showed different trends during different years. Thus data, which were obtained during one year period, could not be used to generalize soil properties development in particular soil and crop. The soil structure, aggregate stability and soil hydraulic properties were interrelated and depended on plant growth, rainfall and tillage. The drier conditions in some soils positively influenced the soil aggregate stability, slope of the retention curve at the inflection point and hydraulic conductivity. Probably due to the high variation of soil hydraulic properties no closer correlation between them and other properties was detected. The slope of the retention curve at the inflection point (e.g. indicator of soil physical quality) in many cases increased (decreased) when also the soil aggregate stability and hydraulic conductivity values increased (decreased). No closer correlation was revealed when analyzing these relationships for the entire observation period.

1. Introduction

Knowledge of water regime of arable soils and associated dissolved substances transport is important when assessing potential crop production, soil and groundwater contamination, catchment water balance, designing water and agrochemical management within the area etc. Agricultural management considerably affects all soil properties and may lead to soil degradation. Soil structure and consequently soil hydraulic properties of tilled soil vary in space and time (Strudley et al., 2008). In general there are 3 major processes, which modify soil structure (e.g. also soil porous system) after the tillage (Cassel, 1983): a) soil consolidation; b) biophysical root activities; and c) wetting and drying cycles. Soil consolidation is caused by any external pressure or rainfall impact. Root activities compress soil aggregates (Hillel, 2004). Root water uptake increases the bulk density near the roots due to soil adhesion (Young, 1998). Roots enhance aggregate stability due to exudation, death and decay, which stimulate microbial activities and production of humic cements (Hillel, 2004). Wetting and drying cycles cause soil particle/aggregate rearrangement. Frequent drying and wetting cycle can induce aggregate stabilization rather than aggregate disruption (Denef et al., 2001). The aggregate disintegration due to wet event may allow creating more packed particle configuration, resulting in greater cohesion upon the next drying event (Kemper and Rosenau, 1984).

Soil aggregation is under the control of different mechanisms in different soil types. Flocculated clay particles, or their complexes with humus (organo-mineral complexes) and soil organic matter, act as the main cementing agents in soil aggregates. The cementing effect of free Fe and Al oxides is important in soils with low organic matter content (Six et al., 2002). Generally, the level of aggregation and the stability of aggregates increase with increasing organic matter content, surface area of clay minerals, and cation exchange capacity (Bronick and Lal, 2005). The temporal variability of the soil aggregate stability was

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shown for instance by Perfect et al. (1990), Chan et al. (1994), and Yang and Wander (1998). Chan et al. (1994) documented that while the mean (temporal) aggregate stability of the different treatment was significantly related to the mean organic carbon content and polysaccharide content, the temporal changes of aggregate stability were not related to the organic carbon content nor the living root length density. They also observed that seasonal fluctuation in aggregate stability was significantly related to the soil water content at the time of sampling. Perfect et al. (1990) presented that soil aggregate stability decreased with increase in soil-water content and found that variation in soil-water content during the season was the most significant factor determining fluctuation in aggregate stability. Negative correlation of aggregate stability and soil-water content was proven also by Coote et al. (1988). Yang and Wander (1998) did not found consistent effect of soil-water content on soil aggregate size and stability. They suggested that the higher aggregate stability was found due to crop roots, exudates microbial by-products and wet/dry cycles.

Soil pore system and consequently physical and hydraulic properties change due to soil deformation (Alaoui et al., 2011). Suwardji and Eberbach (1998) studied both, aggregate stability and saturated and unsaturated (tension of 4 cm) hydraulic conductivities (*K*). They documented the lowest aggregate stability during the winter and increased in spring. The *K* values decreased during the growing season. Murphy et al. (1993) showed that *K* values at tensions of 1 and 4 cm varied temporally due to the tillage, wetting/drying, and plant growth. Messing and Jarvis (1993) presented that the *K* values (tensions from 0 to 11 cm) decreased during the growing season due to the structural breakdown by rain and surface sealing. Somaratne and Smettem (1993) documented that while the *K* values at tension of 2 cm were reduced due to the raindrop impact, the *K* values at tension of 4 cm were not influenced. Azevado et al. (1998) measured tension infiltration from 0 to 9 cm and showed that macropore flow decreased from 69% in July to 44% in September. Farkas et al. (2006) showed that saturated and near-saturated hydraulic conductivities considerably (4-times and 2-times, respectively) decreased during the vegetation period. Hum et al. (2009) also observed decreasing trends of *K* values measured at 4 tensions (0–15 cm) from May to August. They also showed decreasing fractions of macropores and mesopores and increasing fraction of micropores. Bamberg et al. (2011) observed increasing bulk densities (e.g. decreasing total porosity), decreasing macroporosity, increasing microporosity and increasing field capacity. Alletto and Coquet (2009) also documented increase of bulk density during the growing season and changes of hydraulic conductivities measured at variable tensions (0–15 cm). Decreasing values of hydraulic conductivities were mostly measured at sites under conventional tillage. Bormann and Klaasen (2008) found contradictory development of bulk density (e.g. decrease between spring and summer). Saturated hydraulic conductivities increased due to a decreasing bulk density, due to an increasing soil aggregation and increasing density of continuous macropores. This could be attributed to root grow and other biological activities taking place in soil, which was initially more compacted than for instance soil in study by Alletto and Coquet (2009). Bormann and Klaasen (2008) also documented decreasing values of a field capacity, which was explained by increasing fraction of macropores (e.g. increasing activity of macrofauna due to a convenient weather condition). Zeinalzadeh et al. (2011) observed increasing trends (from June to August) of *K* values measured at 6 tensions (0–15 cm) at the barley, orchard and bare land and decreasing trends of *K* values at the corn field. Bodner et al. (2008) studied changes of near-saturated hydraulic conductivity during two winters (e.g. the impact of the rainfall, soil drying and frost on the seasonal changes of soil hydraulic properties in the structure-related range). They found a significant increase of hydraulic conductivity values and reduction in the flow-weighted mean pore radius. Sacco et al. (2012) documented a progressive compaction of the soil and consequent reduction of near-saturated hydraulic conductivity due to submersion (at the rise field). Macro- and meso-porosity decreased while micro-porosity increased. The non-submerged field showed bulk density deduction due to the rainfall. Angulo-Jaramillo et al. (1997) discovered that only the more homogeneous sandy soil under furrow irrigation exhibited significant decrease in sorptivity. Dörner et al. (2010) presented dynamic development of structural properties of Andisol, which were impacted mainly by wetting and drying cycles. They showed that the saturated hydraulic conductivity decrease due to water infiltration, which caused a particle release, transport and re-sedimentation. Dynamic of hydraulic and mechanical properties influenced by grazing events (soil compaction) and wetting and drying cycles (soil-pore recovery) was documented for an Andosol (Dec et al., 2012) and for a volcanic ash soil (Dec et al., 2011).

Mubarak et al. (2009a,b) documented changes of both hydraulic properties (e.g. soil water retention and hydraulic conductivity) due to the impact of drip irrigation during the short term period (2 weeks before, and 1 and 3 weeks after irrigation started). Schwen et al. (2011a,b) studied also both hydraulic properties but during the three year period. They showed that saturated hydraulic conductivity and saturated soil water content strongly decreased after tillage during winter, which occurred due to rainfall-induced pore sealing and settling. The decrease of both properties was followed by their gradual incensed in spring and summer due to biological activity, root development and wetting/drying cycles. While parameter *n* of the van Genuchten model describing shape of the retention curve showed only small temporal dynamic, parameter α showed high variability.

Finally, there have been some attempts to predict the temporal variation of soil properties. Among others Pare et al. (2011) evaluated prediction models of temporal variation of soil surface characteristics after tillage at the catchment scale. They studied the rainfall impact on a bare soil.

The goal of this study was to assess the temporal variability of the soil structure, aggregate stability and hydraulic properties with respect to each other and to varying soil physical and chemical properties, soil management and climatic conditions. The advance of the approach (in comparison to previous studies) was in studying greater amount of soil parameters (e.g. studying soil conditions from different points of view) during the long period. The main tasks were: a) to compare general trends of soil properties in three different soil types, b) to assess seasonal and annual trends of soil properties during the long term (four years) period, c) to evaluate relationships between studied variables.

2. Material and methods

2.1. Sites description and basic physical and chemical properties

The study was performed at the experimental stations of the Crop Research Institute in Hněvčeves, Čáslav and Humpolec in the Czech Republic. The studied soils were the Haplic Luvisol (parent material loess), the Greyic Phaeozem (parent material loess) and the Haplic Cambisol (parent material orthogneiss). Five soil horizons were identified in the Haplic Luvisol, three horizons in the Greyic Phaeozem, and three horizons in the Haplic Cambisol (Kodešová et al., 2008) (Table 1). Table 1 also shows the soil texture and the specific density. Studies by Kodešová et al. (2009a,b) reported in the case of the Haplic Luvisol well developed soil aggregates of the low stability in the A1 horizon, a compact structure of the A2 horizon (plow pan), intensively developed prismatic structure (impacted by clay and organic matter coating and infilling) of very high aggregate stability in the Bt1 and Bt2 horizons (horizons differed in size and shape of aggregates: small and short prismatic aggregates in the Bt1 horizon, large and long prismatic aggregates in the Bt2 horizon), and compact matrix structure with isolated large capillary pores in the Ck horizon. In the case of the Greyic Phaeozem, the relatively homogeneous matrix structures with many isolated pores were observed in all 3 horizons. Stability of aggregates in the Ap and Bth horizons was high probably