



Evaluation of soil structure and physical properties influenced by weather conditions during autumn-winter-spring season



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ABSTRACT

Physical state of the upper soil layer is susceptible to external factors, including weather conditions. It concerns in particular a soil without plant cover or mulching. Significant soil structure transformations could arise especially due to the globally observed climate change which e.g. increases the possibility of extreme precipitation events. Therefore, we evaluated the seasonal changes of structure of the uncovered 0–5 cm soil layer and their effect on other physical properties in relation to precipitation and air temperature. Both the direct evaluation of soil structure by quantitative image analysis and the measurements of structure-dependent parameters as water and air contents and permeabilities were conducted to describe soil physical state in detail. Soil samples were taken on 4 dates during the 2009/2010 season from a Haplic Luvisol developed from loess-like deposits. The largest alterations of soil structure were detected in spring, after the soil had thawed completely and had been affected by the heavy and long-term precipitation. During the season soil structure transformed from aggregate into non-aggregate one and the rearrangement of soil pore size distribution occurred. Soil showed very high available water capacity and mostly medium saturated hydraulic conductivity, but field air capacity and corresponding air permeability decreased below values required for good plant condition. The total volume of pores correlated negatively with precipitation and temperature. Actual water content was strongly positively correlated with the precipitation amount shortly before sampling. There was no statistically valid correlation between saturated hydraulic conductivity and precipitation or temperature. Furthermore, air permeabilities for selected groups of pores showed contrasting trends with precipitation, dependent on the studied span of time. The temperature influenced the intensity of soil drying and freezing-thawing processes. Most of the identified alterations of soil physical state could be attributed however to mechanical impact of rain which remodelled pores and solid phase in the studied soil layer.

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1. Introduction

Soil structure is defined as the arrangement of primary particles and their aggregates and complementary pores in soils across the size range from nanometres to centimetres (Oades, 1992). In modern understanding of soil structure, pores and solid phase elements are equally important components and the term “structure” is broader than “aggregation”. Soil structure is influenced by physical forces created by wetting and drying, and impact of tillage and traffic. Roots and the larger soil organisms also affect soil structure both directly and indirectly (Oades, 1992). The complete assessment of soil physical status should encompass

the evaluation of soil structure by both direct and indirect methods. The latter involve the measurement of soil physical parameters determined by soil structure, e.g. water and air permeability, water stability of aggregates. According to Paluszek (2011), the proportion of aggregates 1–10 mm in diameter, both air-dry and water-stable, is one of the most important parameters for the evaluation of soil physical quality. The direct examination of soil structure can be accomplished in the field or in the laboratory. The simplest method regards the characterization of the plough-layer cultivation and involves the counting of peds larger than 50 mm in diameter in 1 m² of a field after agricultural measures (Medvedev, 2008). More sophisticated field methods include the assessment of colour, size, stability, compactness, and porosity of solid phase structural elements, and the analysis of fissure and plant root systems (Medvedev, 2008). The authors of many recently published papers indicate the close relation of the visual

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Nomenclature

A_{AP}	Relative area of pore cross-sections, macro-porosity ($\text{cm}^2 \text{cm}^{-2}$)
A_{AS}	Relative area of solid phase element cross-sections ($\text{cm}^2 \text{cm}^{-2}$)
AC_a	Air content at the time of sampling, actual air content ($\text{cm}^3 \text{cm}^{-3}$)
A_{NP}	Mean area of pore cross-section (μm^2)
A_{NS}	Mean area of solid phase element cross-section (μm^2)
$AP_{>d}$	Air permeability ($10^{-8} \text{m}^2 \text{Pa}^{-1} \text{s}^{-1}$) at selected soil water potential corresponding to pore diameter d (μm)
AP_a	Air permeability at the time of sampling, actual air permeability ($10^{-8} \text{m}^2 \text{Pa}^{-1} \text{s}^{-1}$)
c_c	Clay ($<0.002 \text{mm}$) fraction content (g g^{-1})
c_s	Sand ($0.05\text{--}2 \text{mm}$) fraction content (g g^{-1})
c_{si}	Silt ($0.002\text{--}0.05 \text{mm}$) fraction content (g g^{-1})
D_{in}	Number of days in the intervals between samplings
$D_{in_Prc=0}$	Number of days without precipitation in the intervals between samplings
$D_{in_snow-cover}$	Number of days with snow cover in the intervals between samplings
$D_{in_T<0}$	Number of days of daily average temperature below 0°C in the intervals between samplings
$IAC-PV_d$	Pore volume fraction ($\text{cm}^3 \text{cm}^{-3}$) of diameter d (μm) calculated by image analysis from circle-area equation (IAC)
$IAC-SV_d$	Solid phase element volume fraction ($\text{cm}^3 \text{cm}^{-3}$) of diameter d (μm) calculated by image analysis from circle-area equation (IAC)
$IAO-PV_d$	Pore volume fraction ($\text{cm}^3 \text{cm}^{-3}$) of diameter d (μm) calculated by image analysis with iterative morphological openings (IAO)
$IAO-SV_d$	Solid phase element volume fraction ($\text{cm}^3 \text{cm}^{-3}$) of diameter d (μm) calculated by image analysis with iterative morphological openings (IAO)
K_S	Saturated hydraulic conductivity (cm d^{-1})
L_A	Relative length of pore/solid phase element cross-sections' boundary (cm cm^{-2})
N_{AP}	Number of pore cross-sections per 1cm^2 of the sample area (the relative number of pore cross-sections, cm^{-2})
N_{AS}	Number of solid phase element cross-sections per 1cm^2 of the sample area (the relative number of solid phase element cross-sections, cm^{-2})
P_o	Total porosity of the soil ($\text{cm}^3 \text{cm}^{-3}$)
Prc_{in}	Precipitation sum as rain or snow (mm) in the intervals between samplings
Prc_t	Precipitation sum as rain or snow (mm) in the selected time span before sampling, t (days)
$Rain_{in}$	Rainfall sum (mm) in the intervals between samplings
$Rain_t$	Rainfall sum (mm) in the selected time span before sampling, t (days)
$SWC-PV_{<0.2}$	Water unavailable for plants, UW ($\text{cm}^3 \text{cm}^{-3}$)
$SWC-PV_{<20}$	Field water capacity, $WC_{-15.54}$ ($\text{cm}^3 \text{cm}^{-3}$)
$SWC-PV_{<d}$	Water content (WC , $\text{cm}^3 \text{cm}^{-3}$) at selected soil water potential corresponding to pore diameter d (μm)

$SWC-PV_{>20}$	Gravitational water, GW , or field air capacity, $AC_{-15.54}$ ($\text{cm}^3 \text{cm}^{-3}$)
$SWC-PV_{>d}$	Air content (AC , $\text{cm}^3 \text{cm}^{-3}$) at selected soil water potential corresponding to pore diameter d (μm)
$SWC-PV_{0.2-20}$	Water available for plants, AW ($\text{cm}^3 \text{cm}^{-3}$)
$SWC-PV_d$	Pore volume fraction ($\text{cm}^3 \text{cm}^{-3}$) of diameter d (μm) calculated from soil water characteristic (SWC) curve
T_{in}	Average temperature ($^\circ\text{C}$) in the intervals between samplings
TOC	Total organic carbon (mg g^{-1})
WC_a	Water content at the time of sampling, actual water content ($\text{cm}^3 \text{cm}^{-3}$)
ρ	Soil bulk density (g cm^{-3})
ρ_s	Particle density (g cm^{-3})

evaluation of soil structure (VESS) performed in the field to physical, chemical, and biochemical soil properties (Askari et al., 2015; Cui and Holden, 2015; Guimarães et al., 2013; Murphy et al., 2013; Newell-Price et al., 2013). In the laboratory, the system of phases (solid and voids) inherently interacting in nature can be directly studied via image analysis which bases on soil thin sections or opaque soil blocks. In this approach the combination of morphographic and morphological (structure description and interpretation) with morphometric analysis which enables the quantification of parameters characterizing both solid phase elements and soil pores is particularly valuable (Bryk, 2016; Cucci et al., 2015). In fact, soil, apart from extreme conditions, is not a two- but a three-component system comprised of solid, liquid, and gas phases. The optimum composition of the three soil phases should correspond to the most favourable soil structure in a generalized sense. The comprehensive study on the soil physical status should undoubtedly comprise the interactions between these three phases, however the attention should be paid not only to soil water and air proportions but also their movement. Medvedev (2008) observed that in some cases even the soil with favourable aggregate structure could have shortcomings – dominating large pores may cause preferential flow and superfluous aeration, promoting evaporative loss of plant available water. The correct interpretation of the data characterizing water and air movement requires the incorporation of image-analysis measurements which give insight into the direction of pores, the way they connect, and the presence of macropores of different genesis (Bryk and Kołodziej, 2014; Lipiec et al., 2006; Zhang et al., 2015).

As stated above, the main factors influencing soil physical status are human, soil faunal and floral activity and weather conditions. The impact of crops, tillage measures and weather conditions on selected aspects of soil physical status was evaluated in field experiments. Schwen et al. (2011a, 2011b) studied soil hydraulic properties for different tillage methods in the growing season of winter wheat while measuring air temperature and rainfall at the same time. Boizard et al. (2013) evaluated the effect of cropping systems and compaction intensities in connection to weather conditions on soil structure. Siczek et al. (2015) investigated the effects of soil compaction and surface mulching on selected soil physical properties and soybean productivity mediated by weather conditions. In the laboratory, on the other hand, the effects of simulated rainfall (e.g. Fan et al., 2008; Vermang et al., 2009; Croft et al., 2013) and controlled freeze/thaw cycles (e.g. Asare et al., 1997; Bryk et al., 2002; Wang et al., 2012) on soil crust formation, aggregate stability, and structure were studied. However, in both the field and laboratory experiments only few authors applied a morphological (direct) structure characterization using opaque

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