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The impact of the permanent grass cover or conventional tillage on hydraulic properties of Haplic Cambisol developed on paragneiss substrate

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Abstract: This study is focused on the comparison of soil structure and soil hydraulic properties of a Haplic Cambisol on paragneiss under two different land managements. Soil samples were taken from all diagnostic horizons (A, Bw and C) of the soil profile under the permanent grass cover (grassland) and under the conventional tillage (arable land). Basic soil properties were measured. Aggregate stability was assessed using the WSA index. Soil composition was evaluated using micromorphological images. Tension disk infiltrometers with two diameters of 2.22 and 10.25 cm (and applied pressure head of –2 cm) and Guelph permeameter were used to measure unsaturated and saturated hydraulic conductivities, respectively. Soil hydraulic properties were measured in the laboratory using the multistep outflow experiment, which was performed on the undisturbed 100 cm^3 soil samples. Results showed that the unsaturated and saturated hydraulic conductivities measured in all horizons were lower at the arable land than conductivities at the grassland. The shapes of the soil water retention curves for A and Bw horizons were also different, indicating that soil below the grass contained larger fraction of the large capillary pores, which also corresponded to measured hydraulic conductivities and soil structure characteristics. Differences between both locations were caused by a negative impact of tillage (inflicting soil degradation) and positive influence of grass (increasing organic matter content and improving soil aggregation).

Key words: aggregate stability; conventional tillage; grassland; hydraulic conductivity; soil micromorphology; soil water retention curve.

Introduction

One of the most important factors that determine soil quality and capability of soil to serve the ecosystem are soil hydraulic properties (Horel et al. 2015). It is well known that chemical and mainly hydro-physical soil properties are variable in space (e.g. Herbst et al. 2006; Sándor et al. 2015; Huang et al. 2016) and time (e.g. Schwen et al. 2011; Jirků et al. 2013). In agricultural soils, cultivation frequently leads to soil degradation and thereby to change the soil structure, porosity and hydraulic properties (e.g. Pagliai & Vignozzi 2002; Lipiec et al. 2006; Kodešová et al. 2009; Bartlová et al. 2015). Permanent vegetation cover usually improves soil chemical, physical and hydraulic conditions of topsoil (Schwartz et al. 2003; Skukla et al. 2003; Bormann & Klassen 2008; Noellemeyer et al. 2008; Bachmair et al. 2010; Kodešová et al. 2011; Kelishadi et al. 2014). On the other hand grass or various trees cover may induce soil water repellency (e.g. Orfánus et al. 2008, 2014, 2016; Lichner et al. 2010, 2011; Lozano et al. 2014; Bachman et al. 2016).

Above mentioned studies dealing with the soil physical quality usually evaluated mainly topsoils or assessed soil quality only from some points of view (i.e. using selected tests). Our previous study (Kodešová et al. 2011) evaluated quality of grassland and arable soils within the entire soil profiles of a Haplic Luvisol using a complex set of methods: analysis of chemical properties, micromorphological analysis, laboratory analysis of soil hydraulic properties using the multistep outflow method and filed measurements of saturated and unsaturated (for pressure head of –2 cm) conductivities using the Guelph permeameter and disk infiltrometers, respectively. We found that the different soil management influenced evaluated soil properties approximately to the depths of 60 cm. The similar study has been performed for the Haplic Cambisol. In this case, an analysis of aggregate stability extended the set of applied methods. The goal was to assess the land use impact on soil quality and to compare the extent of soil properties alternation (i.e. with respect to depth etc.) with those of our previous study.

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Material and methods

Site description and soil sampling

The study area is at the Humpolec experimental station of the Crop Research Institute in Prague (Czech Republic). The elevation of the location above the sea level is 523 m. The average annual temperature and average annual precipitation (for 30 yr) is 7.4℃ and 660 mm, respectively. Two places in distance of 200 meters from each other were chosen to study different land use and management impact on the soil properties: 1. grassland and 2. arable land (with 5-yr rotation system and conventional tillage, tillage depth of 25 cm). The soil type at both places determined according WRB (2014) was the Haplic Cambisol on paragneiss. However, the thickness of three diagnostic horizons A, Bw and C differed from each other (Table 1). Soil sampling and field tests at both sites were carried out in the same time (July 2009) immediately after the harvest of winter barley planted at the arable land. The soil properties of the arable land were from various points of view studied before by Kodešová et al. (2008, 2012). Disturbed, undisturbed (volume 100 cm^3) soil samples and soil blocks (3 cm × 3 cm × 10 cm) were taken from all horizons to analyze soil chemical, physical and hydraulic properties. Disk infiltrometer and Guelph permeameter measurements were performed at both sites in each horizon to obtain unsaturated and saturated hydraulic conductivities, respectively.

Basic physical and chemical properties

The basic physical and chemical properties of the A, Bw and C diagnostic horizons were determined in three replicates using the standardized laboratory techniques. Disturbed soil samples were used for measuring particle density (Flint & Flint 2002), particle size distribution (Gee & Or 2002), oxidable organic carbon content (Skjemstad & Baldock 2008), pH_{KCl}, pH_{H2O} (ISO 10390:1994).

Soil aggregate stability

Aggregate stability was assessed using the WSA index proposed by Nimmo & Perkins (2002). Four grams of air dry soil aggregates (segregates) of the size of 2–5 mm was sieved for 3 min in distilled water (sieve 0.25 mm). Aggregates remaining on the sieve were next sieved in sodium hexametaphoshate until only sand particles remained on the sieve. The index of water-stable aggregates, *WSA* [–], was then determined as:

$$WSA = \frac{W_{\text{ds}}}{W_{\text{ds}} + W_{\text{dw}}} \tag{1}$$

where W_{ds} [M] is the weight of aggregates dispersed in dispersing solution and W_{dw} [M] is the weight of aggregates dispersed in distilled water.

Micromorphological images

Micromorphological properties characterizing the soil composition of the A, Bw and C diagnostic horizons were studied in thin soil sections prepared from soil blocks. These thin sections were prepared according to methods presented by Stoops (2003). Two soil sections were made for each horizon. The final thin section size was 1.5 by 2 cm. Images were taken with the polarization microscope OLYMPUS BX51 with the digital camera OLYMPUS DP70 (using software Deep Focus 3.0) at a magnification 2× and a resolution of 300 dpi.

Multistep outflow test

Laboratory multistep outflow test was used to gain soil hydraulic properties. Three undisturbed soil samples of volume 100 cm^3 (soil core on height of 5.1 cm and cross-sectional area of 19.60 cm^2) were taken and analyzed from each horizon (A, Bw, C). Samples were placed into Tempe cells. Fully saturated soil samples in Tempe cells were slowly drained for 3 weeks. Nine pressure head steps were used as follows, –10, –30, –50, –100, –170, –250, –350, –500 and –1000 cm. Program HYDRUS 1-D (Šimůnek et al. 2008) with the single-porosity model was applied to simulate water flow in the soil samples, and to optimize parameters of the van Genuchten (1980) soil hydraulic function, the soil water retention curve, $\theta(h)$, and the hydraulic conductivity function, $K(\theta)$:

$$\theta_{\text{e}} = \frac{\theta - \theta_{\text{r}}}{\theta_{\text{s}} - \theta_{\text{r}}} \quad \theta_{\text{e}} = \frac{1}{(1 + (\alpha \mid h \mid)^n)^m}, \ \text{for } h < 0$$
$$\theta_{\text{e}} = 1 \text{ for } h \geq 0 \tag{2}$$

$$K(\theta) = K_{\text{s}} \theta_{\text{e}}^{l} \left[1 - \left(1 - \theta_{\text{e}}^{1/m}\right)\right]^2, \ \text{for } h < 0$$
$$K(\theta) = K_{\text{S}}, \ \text{for } h \geq 0 \tag{3}$$

where θ_{e} is the effective soil water content (dimensionless), θ_{r} is the residual soil water content [L^{3}L^{-3}], θ_{s} is the saturated water content [L^{3}L^{-3}], h is the pressure head [L], α is the reciprocal of the air-entry pressure head [L^{-1}], l is the pore-connectivity parameter equal here 0.5 (dimensionless), n (dimensionless) is related to the slope of the retention curve at the inflection point (dimensionless), m = 1–1/n (dimensionless), and K_{s} is the saturated hydraulic conductivity [LT^{-1}].

Tension disk infiltrometer

Unsaturated hydraulic conductivities were evaluated at the depths of 5 (A), 30 (Bw grassland) and 45 (Bw, arable land), 63 (C, grassland) and 85 (C, arable land) cm. Cumulative water infiltrations were measured with two tension disk infiltrometers with different disk radiuses (2.22 and 10.25 cm, 12 and 4 replicates, respectively). Pressure head was always set at value of –2 cm as proposed by Watson & Luxmoore (1986) as limit between gravitational and capillary pores. The soil surface was carefully leveled using knife before the tension disk infiltrometer test. Then 1 mm layer from the same soil, sieved through a 2-mm sieve, was formed to ensure close contact between the soil and disk (Kodešová et al. 2010, 2011). The tension disk infiltration test lasted at least 60 min. The unsaturated hydraulic conductivity $K(h_0)$ for h_0 = –2 cm was calculated according to Zhang (1997). Cumulative infiltration I [L] in time t [T] was fitted using the following equation:

$$I = C_1 t + C_2 t^{1/2} \tag{4}$$

C_1 [LT^{-1}] a C_2 [LT^{-1}] are parameters related to the hydraulic conductivity $K(h_0)$ and sorptivity $S(h_0)$:

$$C_1(h_0) = A_1 K(h_0) \text{ and } C_2(h_0) = A_2 S(h_0) \tag{5}$$

where A_1 [LT^{-1}] and A_2 [LT^{-1}] are dimensionless constants. The $K(h_0)$ value was calculated using Eq. (5) and following expressions for A_1 constant:

$$A_1 = \frac{11.65(n^{0.1} - 1) \exp\left[2.92(n - 1.9)\alpha h_0\right]}{(\alpha r_0)^{0.91}} \text{ for } n \geq 1.9 \tag{6}$$

Table 1. The average values of measured physical and chemical properties obtained from 3 replicates: the particle density (ρ_S), bulk density (ρ_D), porosity (P), active (pH_{H2O}) and potential (pH_{KCl}) soil reaction, oxidable organic carbon content (C_{OX}), soil texture and WSA index.

Soil profile	Horizont	Depth (cm)	ρ_S (g cm^{-3})	ρ_D (g cm^{-3})	P (–)	pH_{H2O} (–)	pH_{KCl} (–)	C_{OX}) (%)	Clay (%)	Silt (%)	Sand) (%)	WSA (–)
Grassland	A	0 – 20	2.60	1.16	0.55	5.17	4.24	2.34	10	42	48	0.977
	Bw	20 – 55	2.62	1.34	0.49	5.58	4.46	1.33	10	36	54	0.873
	C	55 – 94	2.57	1.48	0.42	5.60	4.82	0.58	10	26	65	0.488
Arable land	A	0 – 28	2.57	1.49	0.42	5.76	4.71	1.77	15	43	42	0.576
	Bw	28 – 61	2.61	1.50	0.44	5.78	4.47	0.43	28	36	36	0.305
	C	61 – 118	2.57	1.46	0.43	5.02	3.93	0.98	15	37	48	0.362

$$A_1 = \frac{11.65(n^{0.1}-1)\exp[7.5(n-1.9)\alpha h_0]}{(\alpha r_0)^{0.91}}$$
$$\text{for } 1.35 < n < 1.9 \quad (7)$$

or using modified expression by Dohnal et al. (2011):

$$A_1 = \frac{11.65(n^{0.82}-1)\exp[34.65(n-1.19)\alpha h_0]}{(\alpha r_0)^{0.6}} \text{ for } n < 1.35 \quad (8)$$

where α and n are the van Genuchten parameters (parameters obtained from the multistep outflow experiment), r_0 is the disk radius (2.22 or 10.25 cm) and h_0 is the applied pressure head (–2 cm).

Another method to evaluate the unsaturated hydraulic conductivity from disk infiltrometer measurements has been proposed by Wooding (1968). Wooding proposed the following algebraic approximation of steady state unconfined infiltration rates into soil from a circular source of radius r [L]:

$$Q = \pi r_0^2 K(h_0)\left(1 + \frac{4}{\pi r_0 \alpha_G}\right) \quad (9)$$

where Q is the steady water flux [L^3T^{-1}], r_0 is the disk diameter (2.22 or 10.25 cm), h_0 is the applied pressure head (–2 cm), α_G [L^{-1}] is the constant in Gardner equation (1958) describing relationship between the unsaturated hydraulic conductivity and the pressure head.

$$K(h) = K_S \exp(\alpha_G h) \quad (10)$$

value α_G characterizing soil structure was measured by Reynolds & Elrick (1991) for sand 0.36 cm^{-1}, loam 0.12 cm^{-1} and clay 0.04 cm^{-1}. The value for loam was applied in this study to evaluate the $K(h_0)$ values.

Guelph permeameter

A Guelph permeameter was used to measure in the field cumulative water flux under well ponding condition. The tests with the Guelph permeameter were performed in each horizon, lasted at least 30 minutes and they were done in four replications. The depth of the drilled well was 10 (A), 35 (Bw grassland), 50 (Bw, arable land), 68 (C, grassland) and 90 (C, arable land) cm, the well radius was 3 cm, and the well ponding depth was 5 cm. The standard procedure recommended in the Guelph permeameter manual (Soil Equipment Corp. 2008) was used to prepare the infiltration well. Well with the radius 3 cm was drilled using a soil auger, than for final well shaping a size auger was used and finally well brush was applied to remove the smear layer on the well sides. From these measurements the results of the saturated hydraulic conductivity K_s were calculated according to Elrick et al. (1989) and Reynolds et al. (2002):

$$K_s = \frac{CQ}{2\pi H^2 + \pi a^2 C + 2\pi H/\alpha_G} \quad (11)$$

where K_s is the saturated hydraulic conductivity, Q is steady water flux [L^3T^{-1}], H is ponding depth [L] (5 cm), a is well radius [L] (3 cm), α_G is the constant characterizing soil structure [L^{-1}] (Equation 10) and C is dimensionless constant calculated for α_G = 0.12 cm^{-1} according to the following equation (Zhang et al. 1998):

$$C = \left(\frac{H/a}{2.074 + 0.093(H/a)}\right) \quad (12)$$

Results and discussion

The basic soil properties and soil structure characteristics

The basic soil properties of all diagnostic horizons for both soil profiles are shown in Table 1. There are no differences between particle densities of grassland and arable land. However resulting values of the bulk densities from of soil samples taken from A and Bw horizons of grassland soil profile are lower when compared with the values for the same horizons in arable land. Thus average porosities are considerably higher in the A and Bw horizons of grassland in comparison with arable field. Similar results were obtained also by Borman & Klarsen (2008) for a Podzol and Stagnosol (except of subsoil of Stagnosol) and Kodešová et al. (2011) for the Luvisol. Oxidable carbon content (Cox) was higher in A and Bw horizons of grassland but lower in the C horizon than those at the arable land, which is again consistent with other studies (e.g. Kodešová et al. 2011; Noellemeyer et al. 2008). Moderately different soil textures were probably again obtained due to soil destruction by periodical tillage and also due to increased weathering processes induced by the soil management, for instance by agrochemicals (e.g. Matocha et al. 2016), periodical root growth and decay etc. That is also documented by the fact that cordierite (that is usually more easy weathered) was found in samples from grassland (Žigová et al. 2013). Soil pH of different horizons slightly varied due to different Cox content and agricultural practice at both locations. The almost 2-times higher soil aggregate stability (WSA index) was at the grassland than at arable land, which can be attributed to the higher organic content, positive impact of roots and no affect of tillage at grassland in comparison to that of the arable land (Jirků et al. 2013). The largest WSA index was always found in the A horizon

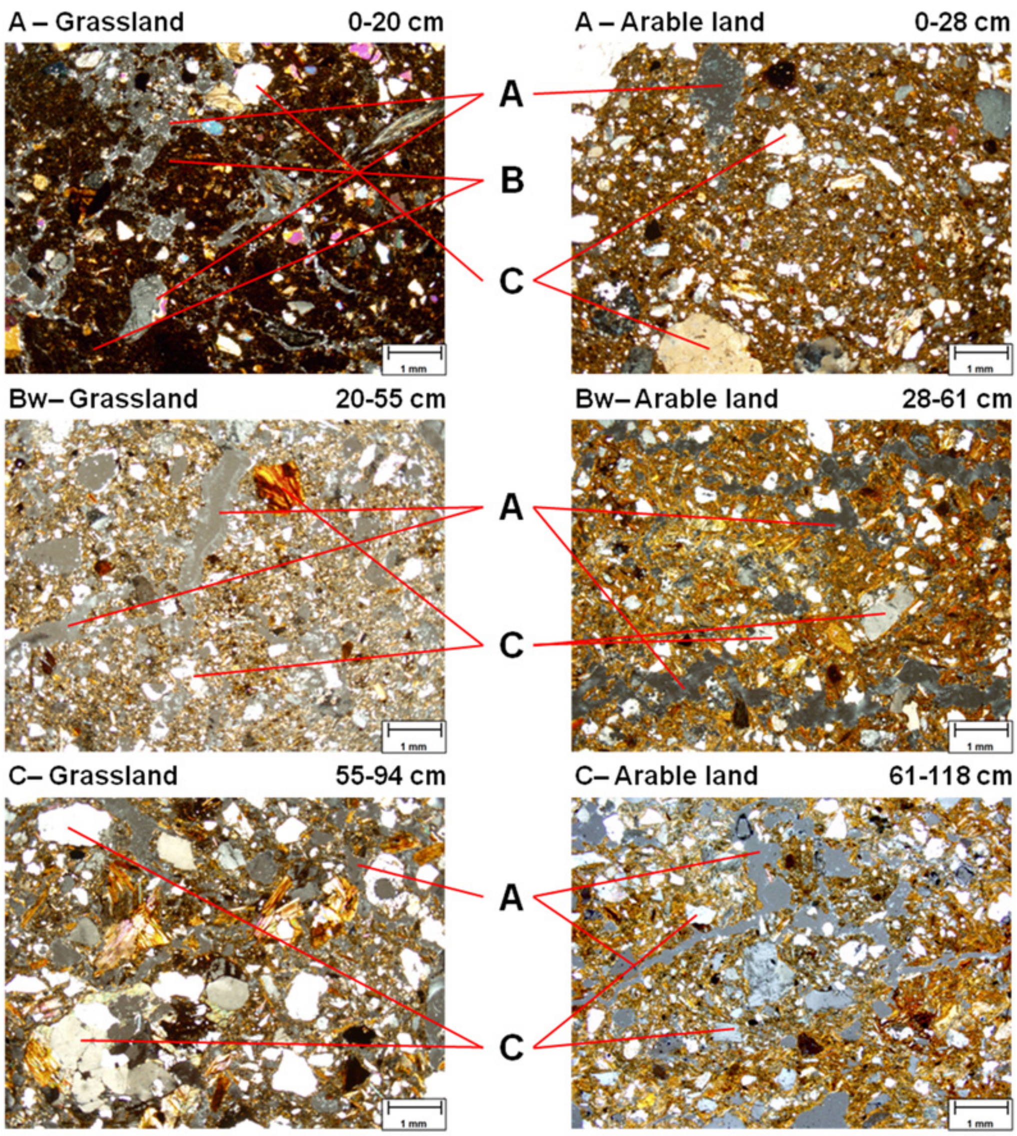

Fig. 1. Images of thin soil sections at grassland (left) and arable land (right) taken in polarized light: A – voids; B – organic matter, and C – large grains.

and decreased with depth. Positive correlation between oxidable carbon content and WSA index was described for example in Jakšík et al. (2015), Jirků et al. (2013), Kodešová et al. (2009) or Zádorová et al. (2011).

Images of soil structure (Fig. 1) show large differences between soil compositions of the A and Bw horizons at both locations. In the case of the grass land, soil was not long time affected by tillage. Thus soil from the A horizon contained a large among of organic matter (which is present in the image in clumps). Another reason may be slower mineralization process taking place in Cambisols in comparison to other soil types (e.g. Kodešová et al. 2011). Similar organic matter features were observed in overlaying organic matter horizon and topsoils of Cambisols and Podzols at grassland sites by Kodešová et al. (2007) and Nikodem et al. (2013). Soils samples from the A and Bw horizons of the arable land contained large amount of fine particles in comparison to those from grassland. The images from C horizons show similar difference (but less significant).

The soil hydraulic properties

The resulting average van Genuchten soil hydraulic parameters (θ_S, θ_R, α, n,K_s) obtained using the multistep outflow experiment and their standard deviations from both soil types and all horizons are shown in Table 2. The shapes of the soil water retention curves are presented in Fig. 2. While very similar results were obtained for the C horizons of grassland and arable land, considerably different curves were measured in the A and Bw horizons at both locations. These results are consistent with results of Kodešová et al. (2011) and Schwartz et al. (2003), who also documented that land use practices had a greater effect on the water retention. As discussed above, repeated agricultural management mainly soil tillage on the arable land led to destruction of soil texture and structure in topsoil and had influence also on the Bw horizons probably due to increased weathering induced by the soil management.

Soil hydraulic conductivity curves obtained from the multistep outflow experiments (Fig. 2) and val-

Table 2. Average values obtained from 3 replicates of van Genuchten soil hydraulic parameters obtained using the multistep outflow experiment in the Tempe cells and numerical inversion using the HYDRUS-1D program of saturated water content (θ_S), residual water content (θ_R), parameters (α, n) and hydraulic conductivity (K_s) and their standard deviations.

Soil type	Horizon	θ_S (cm^3cm^{-3})	θ_R (cm^3cm^{-3})	α (cm^{-1})	n (–)	K_s (cm h^{-1})
Grassland	A	0.553 ± 0.015	0.344 ± 0.048	0.031 ± 0.007	1.44 ± 0.16	0.132 ± 0.076
	Bw	0.486 ± 0.011	0.253 ± 0.021	0.042 ± 0.005	1.50 ± 0.13	0.574 ± 0.342
	C	0.416 ± 0.046	0.228 ± 0.037	0.076 ± 0.026	1.55 ± 0.21	0.904 ± 0.690
Arable land	A	0.418 ± 0.041	0.295 ± 0.037	0.047 ± 0.014	1.50 ± 0.09	0.083 ± 0.061
	Bw	0.433 ± 0.011	0.248 ± 0.008	0.037 ± 0.024	1.37 ± 0.02	0.147 ± 0.141
	C	0.428 ± 0.078	0.198 ± 0.171	0.053 ± 0.032	1.35 ± 0.21	0.151 ± 0.073

Table 3. Average values and standard deviations of unsaturated hydraulic conductivities obtained from disk infiltrometer (K TDI, radius = 10.25 cm), minidisk infiltrometer (K TDI, radius = 2.22 cm) evaluated according to Zhang ([a]) and Wooding ([b]) and saturated hydraulic conductivity ($K_s GP$) measured using the Guelph permeameter.

Soil type	Horizon	$K(h_0 = -2$ cm$)^a$ TDI r_0 = 10.25 cm cm h^{-1}	$K(h_0 = -2$ cm$)^a$ TDI r_0 = 2.22 cm cm h^{-1}	$K(h_0 = -2$ cm$)^b$ TDI r_0 = 10.25 cm cm h^{-1}	$K(h_0 = -2$ cm$)^b$ TDI, r_0 = 2.22 cm cm h^{-1}	$K_s GP$ cm h^{-1}
Grassland	A	0.125 (3)[c] 0.114[d]	0.420 (7)[c] 0.334[d]	0.225 (3)[c] 0.160[d]	0.636 (7) 0.554[d]	0.256 (3)[c] 0.193[d]
	Bw	0.218 (3)[c] 0.055[d]	0.668 (8)[c] 0.530[d]	0.132 (3)[c] 0.016[d]	0.678 (7) 0.584[d]	0.162 (3)[c] 0.089[d]
	C	2.573 (6)[c] 2.71[d]	5.760 (2)[c] 3.783[d]	1.283 (3)[c] 1.128[d]	0.952 (8) 0.852[d]	1.962 (3)[c] 1.093[d]
Arable land	A	0.665 (1)[c] –	0.028 (4)[c] 0.021[d]	0.450 (3)[c] 0.029[d]	0.057 (7) 0.029[d]	0.149 (3)[c] 0.106[d]
	Bw	–	0.058 (7)[c] 0.041[d]	0.032 (3)[c] 0.012[d]	0.115 (4) 0.056[d]	0.063 (1)[c] –
	C	–	0.248 (6)[c] 0.107[d]	0.435 (2)[c] 0.557[d]	0.338 (6) 0.146[d]	0.069 (3)[c] 0.051[d]

a, calculated according to Zhang (1997); b, calculated according to Wooding (1968); c, measurement replicates; d, standard deviation.

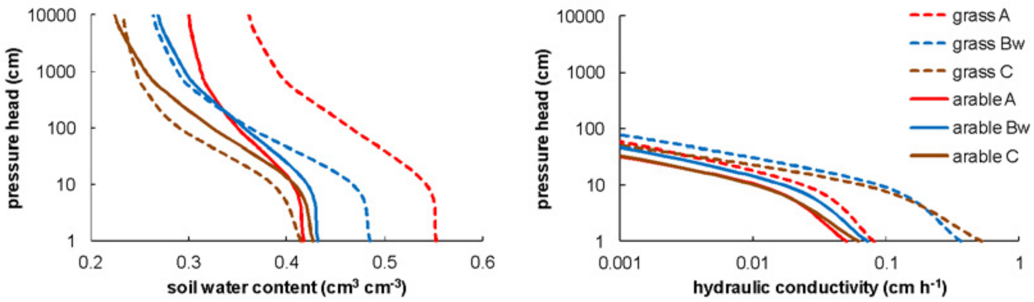

Fig. 2. Soil-water retention and hydraulic conductivity curves at grassland and arable land obtained by the multistep outflow experiment and numerical inversion using HYDRUS-1D program.

ues of unsaturated and saturated hydraulic conductivities (Table 3) resulted from the tension disk and Guelph permeameter tests, respectively, for grassland were mostly higher than those for arable land. This may be again explained by the soil aggregate destruction and accelerated weathering process. It should be noticed that despite the similar shape of the soil water retention curves and almost the same porosities (Table 1) obtained for the C horizons of both soil profiles, large K values were obtained in the grassland in comparison to those in arable land. In some cases the K_S values obtained using the Guelph permeameter were lower than unsaturated hydraulic properties obtained using both disk infiltrometers. Similar results (but in fewer cases) were observed by Kodešová et al. (2011) for the Haplic Luvisol. These lower values were possibly caused by smearing of the soil in the well, and by the well preparation or due to experimental and mathematical procedures, and selection or calculation of used parameters α_G, α and n (Kodešová et al. 2011).

Our previous study (Kodešová et al. 2011) showed that land use mostly impacted the A1, A2 and Bt1 horizons but not the Bt2 and C horizons of the Haplic Luvisol on loess. Results in present study indicate large differences between the A and Bw horizons but also slight modification of the C horizon. The main reasons are: 1. The depth of the Cambisol was smaller than the Luvisol. 2. Soil types were developed on different substrates (i.e. spatially homogeneous stable loess versus weathered paragneiss of the larger areal variability). 3. Different soil forming process took place in both soil types (i.e. iluviation/eluviation process resulted in well developed aggregates in the Bt horizons versus process altering under-laying soil substrate resulted in poor soil structure in the Bw horizon).

Conclusion

Study showed how different management of soils impacted the soil structure and consequently soil hydraulic properties. While soil water retention curves in the C horizons of both soil profiles were relatively similar, soil water retention curves in the A and Bw horizons were considerably different. Despite of the soil water retention curve similarity in the C horizons, the larger values of soil hydraulic conductivities were always obtained at the grassland than those at the arable land, which was attributed to the soil structure and even particle destruction due to periodical tillage and probably more intensive weathering processes taking place at the arable land.

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