doi: 10.17221/283/2014-SWR

Investigation of Soil Water Infiltration at a Scale of Individual Earthworm Channels

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Abstract

Pelíšek I. (2018): Investigation of soil water infiltration at a scale of individual earthworm channels. Soil & Water Res., 13: 1–10.

This study focused on the hydraulic efficiency of vertical earthworm channels (henceforth referred to as macropores or channels). The parameters selected for investigation were the rate of change in hydraulic soil conductivity in the channel walls due to compaction, the rate of this compaction, and the wall stability against running and stagnant water. We preferentially tested the variants for infiltration of water flowing from the soil horizons against gravity (e.g. from the level of installation of tile and controlled drainage). The details of influx and infiltration processes were examined both in the field and more thoroughly in the laboratory using an accurate continuous infiltrometer constructed at the Research Institute for Soil and Water Conservation (RISWC), Czech Republic. Both direct measurements and indirect evidence consisted of tests of individual natural macropores directly in the field, as well as tests of intact collected samples and artificial samples with variants of natural, artificially extruded, and cut out tubular macropores. We studied the processes occurring in macropores with diameters of ca. 5 mm and larger. In these particular conditions, we identified the apparent saturated hydraulic conductivity (K_s') of the soil horizons (including macropore-mediated vertical surface infiltration and preferential flow to soil followed by radial infiltration) most frequent as K_i (apparent saturated hydraulic conductivity affected by preferential flow or influx of water) from 50 to 200 cm/h. In some cases, saturated hydraulic conductivity of earthworm channel walls (K_{sw}) was reduced in the order of tens of percent compared with matrix K_s. The increase of bulk density of soil (ρ_d) in the macropore vicinity reached the maximum of 25%. The intensity of macropore wall erosion (i_{er}) ranged from 0 to 70 mg/min/dm^2.

Keywords: effect of radial compaction; efficiency of earthworm channels; macropore infiltration; preferential flow; soil macropore vicinity

List of abbreviations: C_c – coefficient of compaction; d_{MP} – diameter of macropore; d_z – particle size of soil; Δr_n – rate of radial infiltration, radius change; θ – volumetric soil water content; ic_n – distance of wetting fronts from macropore wall; i_{er} – intensity of erosion; k – unsaturated hydraulic conductivity of soil; K_i – saturated hydraulic conductivity influenced by preferential flow; K_s – saturated hydraulic conductivity of soil; K_s' – apparent saturated hydraulic conductivity; K_{sw} – saturated hydraulic conductivity of macropore wall; pF – soil suction; ρ_d, (ρ_{dR}) – bulk density of soil (relative bulk density); t_n – time; v_i – velocity of water inflow into macropore; v_i' – velocity of water flow front; V_i' – advancing volume of water per time unit; w – mass soil water content by weight; Φ – porosity.

While examining the factors that play a role in soil water infiltration or the effect of drainage irrigation (the processes related to the control of drainage runoff), attention was focused on the selected parameters and functions of vertical tubular earthworm channels (vertical tubular macropores formed primarily by the anecic earthworm species). The objectives of the present paper were to investigate the rate of radial hydraulic soil conductivity in the walls of earthworm channels due to compaction, the rate of this compac-

doi: 10.17221/283/2014-SWR

tion, and the resistance, i.e. the long-term macropore wall stability during the interaction with running and stagnant water in the conditions of agricultural soils of the Czech Republic. The key role in these processes is played by the zooedaphon species, whose number and frequency in agricultural soils displays medium- to macro-scale impact on the variability of preferential flow and rise by macropores in the soil profile and water distribution in the soil matrix. In particular, the effect of earthworms (*Lumbricidae*) is notable to these processes. The meso- and macrozooedaphon in Central Europe has been described e.g. by Novák *et al.* (1959). Concerning macropores, Novák *et al.* (1959) particularly emphasize the effects of the lumbricid species, compared to a relatively lower significance of moles, the periodical effects of rodents and larger insects, social insects, and a marginal effect of larger mammals. The long-term presence and resistance of vertical earthworm macropores is associated with compaction during burrowing, shape-related characteristics of the macropore (morphology), mucus secretion, and wall impregnation and smoothing, and is related to more favourable distribution of soil pressures compared to horizontal burrows (of earthworms or moles). In comparison, the durability of mole drainage used for irrigation was routinely reported as one vegetation season (Mika 1959).

Earthworms apparently create a pliable soil–mucus composite, which they press into the soil pores outside the burrowed macropore diameter more easily than they would do with dry soil grains (see also e.g. Capowiez *et al.* 2014). This activity is combined with the formation of small cracks in the soil matrix. Another observed factor which plays a role in wall permeability is rooting and introduction of organic litter into the burrows and its gradual consumption, so that some percentage of the macropore length is “lined” with up to several layers.

To quantify the hydrological effectiveness of earthworm channels, we gathered information from the studies by Urbánek and Doležal (1992), Vašků (2008), and others. Numerous results of this article were confirmed by studies performed in similar soil conditions and laboratory tests (e.g. Bastardie *et al.* 2003; Capowiez *et al.* 2014). The presence, parameters, and evolution of earthworm channels cannot be separated from the occurrence of other subsurface canals and caverns, formed namely by the activity of abiotic factors (Conacher & Dalrymple 1977), which display typical properties related to climatic and geo-relief conditions.

The objectives were: (A) to obtain general data on the presence of a lumbricid population (incidence, distribution, tolerance to the environment and spatial distribution) and of the macropores resulting from their activity (e.g. characteristics of shape, direction and topology), (B) to assess the hydraulic functions and efficiency of the preferential routes formed primarily by lumbricids.

The objectives according to (B) were related to the examination of the intensity of infiltration processes and preferential flow from above (namely precipitation water) and infiltration and water rise from below (namely during amelioration or effective manipulation of the groundwater level). In the first step of objective (B), described in more detail below, focus was on the processes at the level of individual vertical earthworm channels, in particular:

– relationships with the parameters of the soil matrix (in drained soils, a backfill of the drainage trench is also an important factor, namely because of different characteristics compared to the surrounding soil),
– permeability of macropore walls and the effects burrowing and mucus secretion have on wall compaction, and the dimensions and roughness of individual macropores.

The second step consisted of determining the rate of macropore flow and infiltration of earthworm channels in the actual conditions of the experiment location. The third step was focused on identifying generalized characteristics of the macropore networks.

In the soils drained by tile drainage, the vertical earthworm channels (in the drainage trench backfill) extend to the hydraulically effective radii of drains (r_{ef}, in general 0.1 m). Data on the water movement from above, particularly on the measured values of the preferential flow, on parameters of the soil matrix, and on the calculations of model laboratory experiments, precised the data on water rise for macropores in the field.

The testing aimed to identify: (1) The (decreasing) effect in the hydraulic conductivity of the compacted walls of natural earthworm macropores compared to the hydraulic conductivity of the soil matrix unaffected by compaction; (2) The extent of earthworm-produced compaction in the macropore vicinity, i.e. the relationship between the diameter of macropores and the rate of soil compaction in the immediate vicinity of macropores; (3) The existence of significant differences between the surface erod-

doi: 10.17221/283/2014-SWR

ibility of natural earthworm macropores compared to artificial macropores (associated with the effects of surface smoothing and mucus impregnation on the hydraulic macropore parameters concerning vertical water flow).

MATERIAL AND METHODS

For objective (A), in order to assess general quantitative parameters of the lumbricid population, after literature research, the method of mechanical analysis directly in the field was selected, namely to investigate the presence and current activity of lumbricids in the examined soil horizon, and the influence of mucus on macropores immediately after secretion. For this study, basic information of lumbricid biology was found in the following studies: Pižl (2002), Vašků (2008), Karaca (2011), and others. Concerning the anthropic impact on lumbricid biology, an important role is played by agrotechnical measures.

For (B), several variants were investigated. We preferentially tested the variants of infiltration and water rise from below in deeper soil horizons occurring above the level of tile drainage deposition (Table 1).

Selected identical macropores were repeatedly tested. This may have led to a bias, but it is not in conflict with natural processes occurring in earthworm channels (repeated rainfall, leaching, consolidation, macropore wall desiccation, etc.). Artificial macropores of various diameters were hollowed out using a wetted steel tip with a continuous, slow motion (aimed at simulating the approximate parameters of a natural earthworm burrow, but without the mucus effect), or cut out with a corkscrew with the edge bevelled inside a tube (aimed at minimizing the macropore wall compaction).

Macropores parametres investigated. The following parameters of macropores were determined: saturated hydraulic conductivity (K_s) of the soil matrix and influx-influenced K_s' (K_i) of the natural soil environment (based on direct field measurements); velocity of water inflow into soil voids (v_i) and K_i (direct measurements of isolated macropores in the field); infiltration velocity and saturated hydraulic conductivity of macropore walls (K_{sw}) (direct and indirect measurements). An uncertainty was caused by the unknown course and connections of the entire macropore systems. A partial solution was to collect an intact soil sample in the macropore section and perform non-destructive testing and destructive analysis. These activities are sensible to precision with very low volumes of supplied water; such requirements can be satisfied by using accurate pumps (including a diaphragm driven directly by electromagnetic force). Further soil analyses were necessary (measuring bulk density (ρ_d) and other parameters). The detection of the permeability of a surface unit of the macropore wall is influenced by the heterogeneity of the wall surface, and its interpretation requires sample analyses and examination of the morphology of tested macropores. The calculations

Table 1. Summary of infiltration tests variants for soil horizons (successful variants are labelled by points)

Variant No.	Description of variant				Soil horizons and tested variants				
	environment	soil sample	macropore	water flow	A1	A2	B1	B2	C
1	T	n	n	a	●	●	●	●	
2	L	n	n	a	●	●			
3	L	n	n	b			●	●	
4	L	n	a (corkscrew)	a	●	●			
5	L	n	a (corkscrew)	b			●	●	
6	L	a	a (corkscrew)	b			●	●	
7	L	a	a (rod)	b			●	●	
8	L	a	n	b				x	
9	L	a	a (corkscrew)	a		●		●	
10	L	a	a (rod)	a		●		●	
11	L	a	n	a				x	
12	T	n	a (rod)	a				●	

Environment: T – terrain, L – laboratory; soil sample: n – natural, a – artificial; macropore: n – natural, a – artificial (burrowing tool); water flow: a – inflow from above, b – rise from below; x – unsuccessfully tested variants 8 and 11

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of the effect of tubular macropores of lumbricids on the water movement in the soil during wetting mediated by controlled drainage may be limited to the vertical earthworm macropores. Due to the depths of regulated groundwater level (usually ca. 0.5–1.2 m in agricultural land), the dominating type of lumbricid burrows is vertical. During manipulations of groundwater level by irrigation or drainage runoff regulation, the air from macropores can freely escape upwards, if there is no simultaneous infiltration and macropore flow, e.g. from rainfall, or if it is not impeded by a closed macropore section. The calculations of K-values are based on usual solutions according to Philip (1969) included in spreadsheets. The solution of radial or spatial distribution of water infiltration from macropores is based on a simple mathematical model similar to a solution of Edwards *et al.* (1979). Next, the parameter of the rate of compaction of macropore vicinity, i.e. the coefficient of compaction (C_c), was calculated as the increase of relative bulk density of soil (ρ_{dR}) toward values of the soil matrix unaffected by compaction ($\rho_{dR} \approx 1$). We assumed that the compaction rate is associated with the diameter of a macropore. The compressibility rate must be modified for calculations at swelling soils. The last parameters calculated were the rate of changes in porosity (Φ) values due to compaction in the macropore vicinity, and the erosion intensity of the surface unit of a macropore wall, i_{er} (mg/min/dm^2), during the defined duration of the test, flow direction, and intensity of water influx or continuing preferential flow. The investigation of water erosion of macropores was limited by adjustable flow (maximum infiltration velocity ca. 800 cm/h), vessel capacity, and the diaphragm pump capacity (minimum volume ca. 0.06 ml per shot and maximum volume ca. 40 ml/min).

Study area. For a detailed field experimental testing the relationship between earthworm channels and hydro-physical soil characteristics, namely in association with rainfall infiltration and drainage water distribution during drainage irrigation, the location selected for the experiment was the Research Institute for Soil and Water Conservation (RISWC) Pokřikov (Eastern Bohemia, Czech Republic, www.hydromeliorace.cz/povodi). The location comes under a moderately warm humid region (average monthly air temperature 8.8°C, average annual rainfall 711 mm) and possesses a complete set of detailed hydrometeorological, hydrological, and hydro-physical measurements related to a functional drainage system situated in parcels of arable soils and grassland. The studied parcels are situated at altitudes of ca. 500–510 m a.s.l., in the Kotelský Brook catchment, and occupy an area of 2.5 ha, which is dewatered by systematic tile drainage, with a pipe at the depth of 0.8–1.1 m. The primary soil types are Dystric and Gleyic Cambisols (FAO 2014) on phylite slates, fluvial sandy loam, and gravel. The depth of the soil profile ranges from 0.7 m (on hillslopes) to 1.1 m (along thalwegs). This study was primarily focused on soil horizons (A, B) within the expected range of regulation of the groundwater level by manipulation of the regulation element in the drainage well. Characteristics of the soil horizons are given as a short summary of data. Soil horizons (A and B) display certain differences in the fine earth and skeleton content (skeleton ca. 25 or 6%), organic matter (2 or 1%), porosity (Φ = 0.43–0.52), and mean K_s values (most frequently 0.7–20 cm/h). The normalized histogram in Figure 1 shows the frequency of

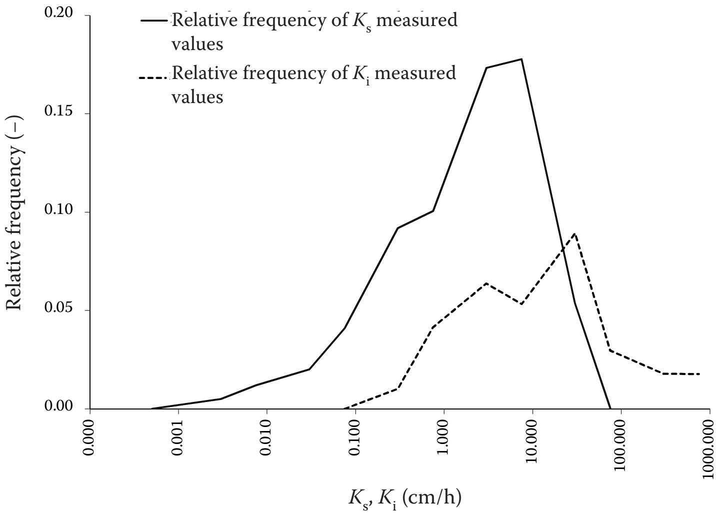

Figure 1. Histogram of measured values of apparent saturated hydraulic conductivity K_s and K_i for studied soil horizons

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Figure 2. Excavation and measurement of the influx capacity of individual macropores and saturated and unsaturated hydraulic soil conductivity in horizon B (a meadow east of the village of Pokřikov, clover–grass mixture, March 2014); the intact block between two excavations contains (in the lower part) the filling of the drainage trench above a functional collector drain; the block was transported to the laboratory for further testing

about sixty measured values of K_s (apparent saturated hydraulic conductivity) where K_i (apparent saturated hydraulic conductivity affected by preferential flow or influx of water) represents other ca. thirty measurements with the confirmed presence of an earthworm channel. Extremely high K_i values are unreliable due to a water flow into the mole burrows.

Field and laboratory measurements. Field measurements were done both at the surface and at selected depths (excavations of ca. 1.5 m^2 surface and max. depth of 0.7 m). The field tests were performed during 2014 (Figures 2–4). Intact samples with macropores for laboratory tests were collected in the field from individual soil horizons. A diagram of the laboratory testing setup is in Figure 5.

Artificial fine earth samples of particles of size d_z < 1.25 mm were prepared by the dry sieving of soil blocks collected in individual horizons at the experiment location. The fine earth was placed into plastic containers, and then (applying the formerly tested number of blows, layers, and vibration after the modified Proctor compaction test) was compacted to the bulk density ρ_d = 1.30–1.52 g/cm^3, corresponding to ρ_d of the soil in natural conditions of the sampling location.

The artificial and compacted samples were then saturated with water to the optimal range of moisture values (θ = 0.35–0.39). The goal was to unify the conditions of the laboratory tests with the field measurements and at the same time provide a sufficient reserve for examined sample pore saturation, allowing accurate sampling of the defined soil volumes. The samples were saturated to the soil suction (*pF*) corresponding to pressure head of –10 hPa, presuming saturation of all capillary pores.

The soil moisture was determined by gravimetry, *in situ* as volumetric moisture (θ), and in collected and artificial samples with macropores as the mass soil water content by weight (*w*) from damaged samples. Due to the small sample sizes and to avoid the formation of preferential routes, sampling instead of time domain reflectometry (TDR) sensor installation

Figure 3. Measurement in natural conditions using a continuous infiltrometer with accurate metering pump (accuracy of volume ca. 0.063 ml per 1 pulse)

Figure 4. Preparation of artificial macropores with various diameters in natural soil

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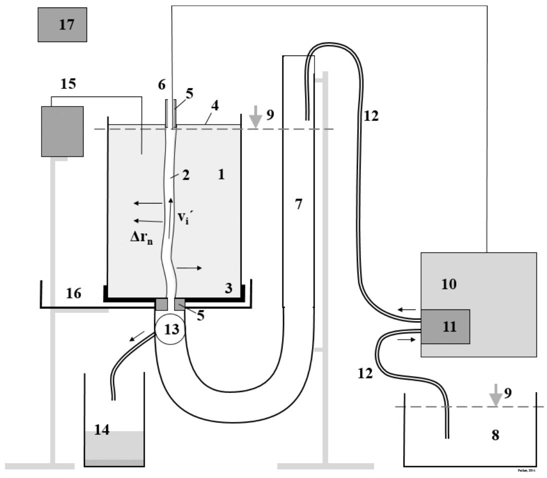

1 – soil sample (diameter 10–20 cm)
2 – tested macropore
3 – sample bottom and isolation
4 – upper parafin cover (if applied)
5 – adjusting clutch
6 – sensor of water level
7 – equilibrating container
8 – source water tank
9 – constant water levels
10 – continuous infiltrometer, incl. microprocessor
11 – accurate dosage pump
12 – tubing
13 – valve
14 – sediment trapping
15 – soil moisture control
16 – control of potential water leaks
17 – air temperature and humidity control
v_i' – (velocity of) water inflow in a macropore
Δr_n – (velocity of) radial infiltration

Figure 5. Scheme of the laboratory testing: a continuous infiltrometer (with an accurate metering pump), a tool for sample saturation from below mediated by an equilibrating container, and the tested macropore (natural intact or artificial) in a soil sample

was used. To minimize effects of evapotranspiration and redistribution of soil moisture, respectively, the measurements were performed off the periods of maximal insolation.

The intensity of water infiltration into macropore walls was expressed as a cumulative volume per unit surface area (ml/mm^2) during the inflow and infiltration testing. Factors for correction of the final curves are water leaks (recorded amounts), soil moisture, soil porosity, soil particle size, air resistance, and erosion.

We also observed the effect of air entrapped in some samples and its pneumatic effect on infiltration velocity and moisture change. The infiltration tests were followed by testing macropore sections (longitudinal and lateral). Selected macropores were processed in paraffin castings to allow more precise examination of the macropore morphology.

Creating high quality natural macropores in an artificial substrate (variants No. 8 and 11 according to Table 1 for comparative testing) proved to be problematic, especially due to keeping the most direct and shortest burrows routes, and location close to the centre of the soil samples.

Using the instrument setups designed and tested at the RISWC, we were able to effectively conduct the experiments. Specifically, the instruments were a ponding infiltrometer (according to patent No. 300463, using Mariott bottle principle, an adjustable water ponding depth, and automatic data record), and a continuous infiltrometer (according to patent No. 305517 and UV23245 (Kulhavý *et al*. 2014), using a microprocessor, accurate diaphragm metering pumps, and a special software and infiltration regimes). The continuous infiltrometer requires calibration after the actual hydraulic configuration of the metering set and achieves the accuracy of ca. 0.063 ml volume per 1 pulse.

The rate of compaction of the natural and artificial macropores was examined in separate experiments, with subsequent evaluation (for more see the Discussion section).

RESULTS

The experiment resulted in the specification of the relative permeability of earthworm channels for the soil matrix apart from the compaction effect. The experiments showed that the surfaces of natural earthworm macropores are more resistant to erosion than those of the artificial macropores. This issue is discussed in more detail in the next section (Table 2).

Testing the impact of the mucus effect, some preliminary conclusions can be deduced, based on the comparison of the measured values (infiltration velocity and wall erosion in natural earthworm and artificial macropores) (Table 2).

Data on the influx-infiltration soil capacity found in the literature had to be complemented and verified in the field (the catchment of the Kotelský Brook). Traces of the stay on the soil surface revealed the existence of earthworm macropores and targeted measurements of hydraulic conductivity (K_s, K_i, and k) were performed. In addition, intact soil blocks and further samples were collected for laboratory analyses.

doi: 10.17221/283/2014-SWR

Table 2. Intensity of macropore wall erosion due to experimental water rise from below

	Intensity of macropore wall erosion (mg/min/dm^2)			Coefficient of erosion	
	artificial (corkscrew)	artificial (rod)	natural (earthworm)	natural/artificial (corkscrew)	natural/artificial (rod)
Min	0.310	0.110	0.064	0.208	0.585
Max	72.150	61.843	1.142	0.016	0.018
Mean	17.266	14.652	0.353	0.020	0.024

Macropore abundance at various depths exposed by excavations on the area of ca. 1.5 m^2 was established in a generalized form. Defining the probable distribution of earthworm channels in the actual field pedon enables the comparison with data of other authors (e.g. Urbánek & Doležal 1992 or Vašků 2008 examined the abundance of earthworm macropores of 10–200/m^2 for d_{MP} = 3 mm in similar soils).

The velocity of inflow into vertical macropores with circular profiles was calculated based on the values obtained by measuring the infiltration velocity and inflow volumes. These values were obtained from the measurement at the paraffin-isolated macropore inlet as well as by the measurement on the open soil surface and the subsequent separation of macropore flow based on the known K_s value. The values of the velocity of inflow into the macropore (v_i) for macropore diameter $d_{MP} \geq 5$ mm in the given conditions ranged from 4 to 12 cm/s. The inflow velocity measured at the inlet (v_i) represents the velocity of water flow front at h_0 height. The advancing volume of water per time unit V_i' gradually decreased with a growing distance, i.e. at time points t_1 to t_n, due to the infiltration to macropore walls. The above-mentioned inflow values cannot be directly generalized for the entire process of water infiltration e.g. during the rainfall, or for all variants of the infiltration process, because the participating factors have various intensities.

Figure 6 shows 1D sections with wetting fronts of water infiltration through the wall of the model tubular vertical macropores at constant infiltration velocities assuming tubular water-filled pores. For illustration, theoretical examples of hypothetical

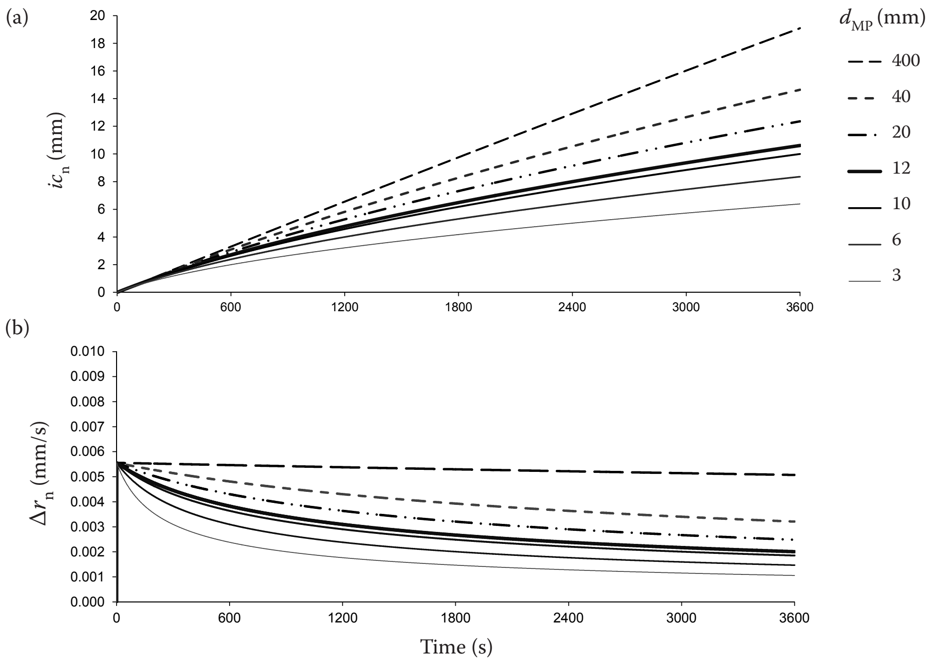

Figure 6. Simulated data for wetting fronts for model tubular macropores; data are shown as (a) the distance of wetting front from the macropore wall (ic_n) at time t_n (growing curves), and (b) the rate of radial infiltration in the soil environment (Δr_n, declining curves); the diameters of the model macropores (d_{MP}) ranged from 3 to 12 mm for vertical channels of earthworms and from 20 to 400 mm for other hypothetical macropores

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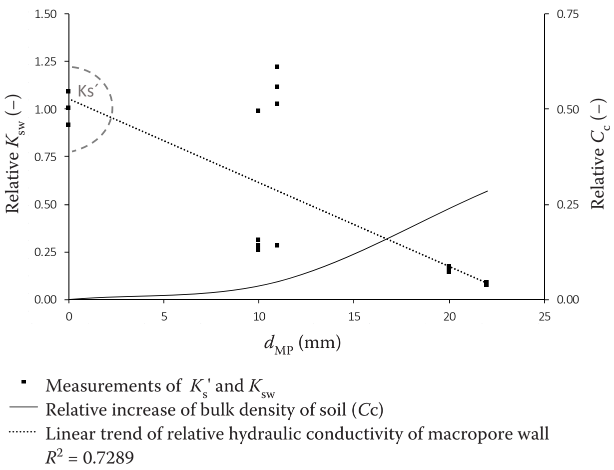

Figure 7. Simplified trend of saturated hydraulic conductivity of macropore walls (K_{sw}) vs increasing macropore diameter (d_{MP}) and related increasing soil compaction (C_c): (a) parameters K_{sw} and C_c are expressed in relative values toward values of the soil matrix unaffected by compaction, (b) K_s' values are used for soil matrix measurements ($d_{MP} \approx 0$, $\rho_{dR} \approx 1$)

macropores of 20, 40, and 400 mm diameters are provided.

Most frequently the apparent saturated hydraulic conductivity affected by preferential flow (K_i) varied from 50 to 200 cm/h. In some cases, the saturated hydraulic conductivity of earthworm macropore walls (K_{sw}) was reduced in the order of tens of percent compared with matrix K_s, and the increase of bulk density of soil in the macropore vicinity achieved 25%. The intensity of macropore wall erosion (i_{er}) was in the range 0–70 mg/min/dm^2.

The effect of radial compaction (in the close vicinity of tubular macropores) on the hydraulic conductivity of soil is illustrated in Figure 7. The graph presents the observed trends of K_{sw} change vs the radial compaction rate. The trend of soil compaction in the close vicinity of the tested vertical tubular macropores is expressed as the increase of relative bulk density ρ_{dR} vs macropore diameter d_{MP} (the soil without compaction is denoted ρ_{dR} = 1, so in Figure 7 it is displayed as 0 value). Data for Figure 7 were collected during testing the artificial macropores made by a metal rod.

The erosion rate differed for the three macropore variants (natural, hollowed out with a steel tip, cut out with a corkscrew) in the natural and the artificial sample. The tests showed that the surface of the natural earthworm macropores is more resistant to erosion than that of the artificial macropores (Table 2). For further interpretation, however, we must take into account the age and consolidation of the macropores by capillary wetting and subsequent desiccation.

The intensity of water infiltration into macropore walls, expressed as a cumulative volume value per surface unit (ml/mm^2) vs the square root of time is shown in Figure 8.

We recorded an interruption in the starting phase of the natural macropore wall infiltration (for ca. 10–120 s).

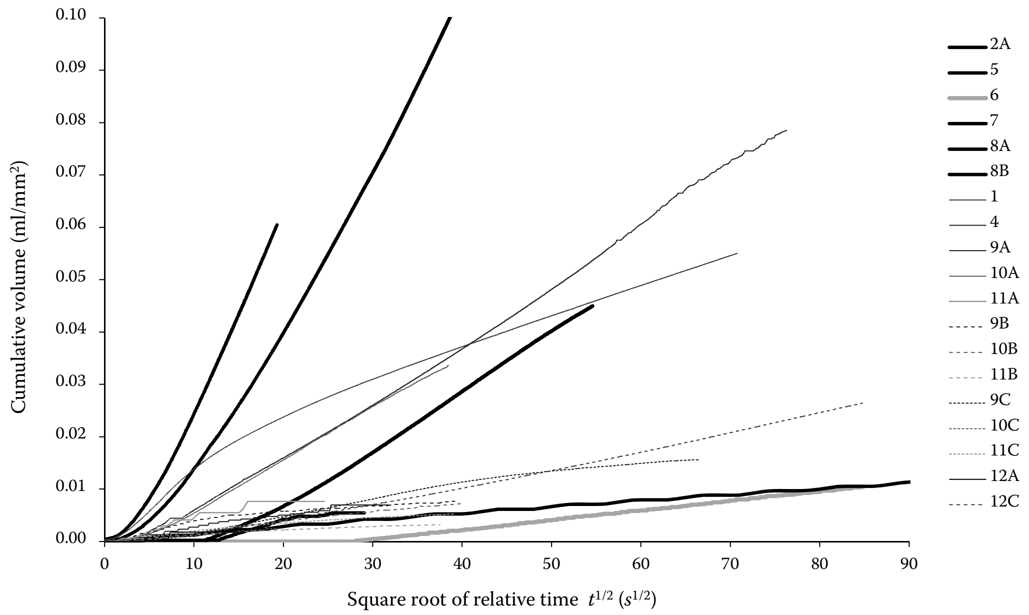

Figure 8. Intensity of water infiltration into macropore walls; supply of water from below; the thick lines represent natural macropores and the thin lines artificial macropores data

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This retardation occurred in natural samples with both free and paraffin-covered surfaces. An extreme case was a delay of 10 min in a sample that was completely embedded in paraffin up to the sample container walls (Figure 8, curve 6). In this instance, the resistance of the air enclosed in the sample might have played a role.

DISCUSSION

The minimum reach of the soil compaction outside the burrowed macropore wall is related to the macropore diameter and to different initial porosity Φ_0. The relationships are complex for several reasons. Namely, while producing burrows of different diameters, lumbricids (of different sizes) react to a varying scale of soil particle aggregation.

Burrowing processes have been studied in detail by many authors, e.g. Dorgan *et al.* (2006), Rogasik *et al.* (2014), Schrader *et al.* (2007). It may be assumed that at certain depths, the formation of vertical burrows is more advantageous for earthworms at some distance and direction against larger rock fragments. This process was documented by macropores formed along stone surfaces (Figure 9).

The compaction of macropore vicinity results in changes in the porosity and suction pressure. This condition can be described as a system of three environments, designated as (0) macropore cavity, (1) compacted close vicinity, and (2) surrounding soil. The mechanism of burrowing and the nature of the soil matrix may then result in varying sharpness of the (1)/(2) interface. We may assume that in particular conditions of the formation of (1) compacted layer and linkage to the pores of the (2) surrounding matrix, the (1) layer may function as a semi-permeable membrane for the macropore filled with air or, conversely, for the significantly drier porous soil environment, and may, for example, reduce the water output from the environment (2) to the macropore (0), or infiltration in the opposite direction. Infiltration and output processes are probably affected by soil particles that may be trapped in the macropore wall.

Figure 9. Example of an earthworm channel (diameter of macropore d_{MP} = 5 mm) formed along a stone surface

With a relatively short-term (minutes to days) infiltration process from above to the soil profile through earthworm channels we may assume that infiltration through macropore walls is low compared to the fast moving water in the macropore. Different intensities of the processes are observed during water rise, induced e.g. by manipulation of the water level in watercourses, when the infiltration velocity (v_i') is significantly lower than the inflow from above (except for the association of macropores with drains directly in a drainage trench) and when water volume accumulates for days or weeks and diffuses into the matrix environment. We may assume mucus dissolving, leaching, and consequent changes in the permeability and stability of the macropore walls. Similarly, during the inflow from above, running water combined with impulses generated by air bubbles escapes and may destroy and dissolve the mucus and the macropore walls.

CONCLUSION

During burrowing, earthworms compact material by pressing in the vicinity of burrows. Without soil compaction, the animal would have to cope with a volume of loosened soil particles that might exceed the volume of the burrow.

The precisely defined process of formation of anthropogenic macropores enables further description of the dependence of partial processes in more accurately defined soil conditions. The erosive effect of repeated water rise and water level stagnation during multiple wetting cycles and the development of temporal changes in the shape and hydrophysical parameters represent another open issue. In relation to the effectiveness of drainage irrigation, this study defines the variability of selected hydro-physical parameters according to the requirements for controlled or multifunctional drainage. The study contributes to finding solutions for the development of measures and techniques for the determination of macropore infiltration and soil water balance and water use in agricultural catchments.

doi: 10.17221/283/2014-SWR

Acknowledgements. The study was supported by the Ministry of Agriculure of the Czech Republic, Project No. QJ1220050 Enhancement of infiltration processes by regulation of water runoff from the small catchments. Thanks are also due to Z. Kulhavý and F. Doležal for valuable comments and advice and the Central RISWC Laboratory.

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Received for publication December 24, 2014
Accepted after corrections June 2, 2017
Published online August 9, 2017