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The water repellency of earthworm (*Lumbricus terrestris*) casts depends on their particle size composition, organic carbon content and calcium carbonate content

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Abstract: At the soil level, earthworms are key indicators of water-related processes which help soils to accept, retain, release and transmit water by influencing the soil structure through their burrowing, casts, and drilosphere. The water repellency is an indicator of soil structure stability both for the natural soil and for the earthworm casts (bioturbated soil). The water repellency of earthworm casts is a complex property that should be approached both at ecological and functional level in earthworm categorization because this cast property influences the transport and flow processes in soil, such as those of water, nutrients, pollutants, and gas diffusion. The earthworms have been described as bioremediators of soil water repellency. Casts of the earthworm species *Lumbricus terrestris* collected from an urban green space have been analysed for particle size composition (texture), organic carbon (OC) content and $CaCO_3$ content in relation to their water repellency (the hydrophobicity). The findings of this study showed that the main drivers determining the water repellency of the casts of *L. terrestris*, as indicator of their structural stability, are chemical (the contents of OC and respectively $CaCO_3$) and physical (contents of clay, silt and fine sand). The water repellency (hydrophobicity) of the casts decreased with their content of clay and silt and increased with their content of organic matter and $CaCO_3$. The hydrophobicity of earthworm casts is in direct positive relation with their previous water accumulation, i.e. the current penetration time of water increases or decreases if the previous penetration time of the water increased or decreased, respectively. The water drop penetration times indicated that the analysed earthworm casts were slightly water-repellent. A small to medium degree of water repellency has been mostly reported as appropriate for the aggregate stability of the soil.

Keywords: clay; hydrophobicity; sand; silt; texture; water drop penetration time

The function of the soil system is strongly affected by the structure and activity of soil biota, which is dominated in the temperate ecosystems, as biomass and overall activity by earthworms (Lemtiri et al. 2014; Phillips et al. 2019). At the soil level, earthworms are key indicators of water-related pro-

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cesses which help soils to accept, retain, release and transmit water (Bhaduri et al. 2022) by influencing the structure and the content of organic matter of soil which lead to better infiltration and retention, flood avoidance through their burrowing, casting, and soil bioturbation (Li et al. 2021; Le Mer et al. 2021). The earthworms influence the aggregate stability of soil because, depending on their feeding ecology, they ingest soil particles collected across the soil profile and, after mixing and complex digestive transformations, these are excreted as new structures, different from the ingested soil – the casts, according to species-specific particularities (casting ecology) (Ge et al. 2001).

The earthworms have been described as bioremediators of soil water repellency (Müller & Deurer 2011) through several mechanisms such as the enhance of the decomposing rate of the water repellent substances by ingestion and digestive transformations, processes which are microbiologically mediated in their digestive tract. The water repellency of earthworm casts is a complex property that should be approached at two separate levels (ecological and functional) in earthworm categorization (Babiy et al. 2021) because this cast property influences the transport and flow processes in soil, such as those of water, nutrients, pollutants, gas diffusion (Haas et al. 2018; Li et al. 2021).

The water repellency is an indicator of soil structure stability both for the natural soil and for the bioturbated soil (earthworm casts) (Lipiec et al. 2015). However, there are two directions of opinions regarding the impact of soil water repellency in the environment: (*i*) a positive impact because the water repellency of soil is directly correlated with the content of the soil organic matter (Papadopoulos et al. 2009) and carbon sequestration (Bottinelli et al. 2010a; Chen et al. 2021) and because the water repellency is an indicator of the physical structural stability of soil (Chen et al. 2021) and mitigates the soil erosion (Shipitalo & Protz 1988; Lipiec et al. 2015) and crust formation (Shipitalo & Protz 1988); (*ii*) a negative impact (Müller & Deurer 2011) because a high degree of water repellency in soil is associated with high structural stability of soil which lead to soil surface leaching and runoff, compaction, carbon loss. A small to medium degree was reported as appropriate for the aggregate stability of the soil (Goebel et al. 2011).

The aim of this research was to identify several properties of earthworm (*Lumbricus terrestris*) casts known to be important in maintaining the structural stability of the soil: particle size composition (texture), water repellency (hydrophobicity), content of organic carbon (OC), content of $CaCO_3$, and respectively to identify the correlations between these factors to characterize the contribution of earthworms in maintaining the structural stability of the soil in the urban ecosystem.

Although several studies have shown that earthworm casts are more stable than the surrounding soil and this fact is directly connected to their water repellency (Lipiec et al. 2015; Chen et al. 2020), there is a lack of data, especially in the temperate ecosystems, regarding the mechanisms inside earthworm cast which are responsible for its water repellency in order to answer the knowledge gap about the contribution of earthworm casts to the structural stability of the soil.

MATERIAL AND METHODS

The earthworm casts have been collected from the Plevnei Park of Timișoara City, Romania (45°45'18''N, 21°13'28''E) which is an urban ecosystem with temperate continental climate with Mediterranean influences. The soil of park is originally a chernozem (Borza et al. 2007), but, because of the many transformations specific to setting up and manage an urban park, the park soil is considered a technosol (Amossé et al. 2015). There have been collected the casts of the earthworm species *L. terrestris* from three sample points established within park based on the presence of earthworm casts on a surface with a diameter between 1 and 2 meters. From each sampling point, there were collected 12 earthworm casts. The casts of this species have been chosen for study because are large and easily recognizable and harvestable and because these earthworms, in order to move and feed, dig deep (even 2 m depth) into the soil profile (anecic species) and mix the soil layers with plant organic matter resulting soil bioturbation that ends in casts, thus influencing several physical, chemical and physicochemical parameters of the soil (Van Groenigen et al. 2019), such as the fertility and the structural stability through significant contributions to the soil aggregate formation (Józefowska et al. 2021).

After collection, the earthworm casts were air-dried and aged in the laboratory for 60 days before being analysed at room temperature (approximately 17 °C) because several studies showed that these processes

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make earthworm casts more stable (Ge et al. 2001; Le Mer et al. 2021). The study of stable earthworm casts was aimed considering the cast handling during the experiment: the surface of a fresh cast is more susceptible to be affected by repeated touching and handling, and during the repellence testing is important to have an unaltered surface of the cast; this is consistent to the natural processes, because the long-time drying of earthworm cast occurs naturally in the temperate ecosystems, especially during the long periods of drought.

The earthworm casts have hydro-physical and hydro-chemical properties (Hallam et al. 2020; Moraru et al. 2020) which contribute to the structural stability of the soil they inhabit, which motivated this research. Several indicators known to be important contributors in improving the hydro-physical and hydro-chemical properties of the soil which give its structural stability have been analysed in the collected earthworm casts: the particle size composition (texture): coarse sand (2.0–0.2 mm), fine sand (0.2–0.02 mm), silt (20–2 μm), colloidal clay (< 2 μm), physical clay (< 10 μm); the water repellency (the hydrophobicity); the OC content (%); the $CaCO_3$ content (%). This last indicator has been included in the study due to a characteristic of some species of earthworms from the Lumbricidae family, the presence of calciferous glands at the oesophagus level, which produce $CaCO_3$ granules excreted in their casts and which interact with water and have a pH-regulating role (Mandera et al. 2023).

The values of the indicators taken in the study were determined by analyses in the laboratories of O.S.P.A. Timiș (Office for Pedological and Agrochemical Studies), with the exception of the water repellency index which has been established within the Laboratory of Ecology and Sustainable Development of the University of Life Sciences "King Mihai I" of Timișoara. The particle size composition (texture) has been established by a gravimetric method according to the methodology STAS 7184/10-79-PS-04. The content of organic carbon has been determined using the Walkley method (Walkley 1947). The content of $CaCO_3$ has been determined according to the methodology STAS 7184/16-80-PS-09 by decomposition with hydrochloric acid. The water repellency has been determined by measuring the penetration time of water drops through the air-dried earthworm casts according to the methodology proposed by Doerr et al. (2000), modified, and interpreted according to the classification proposed by Dekker et al. (2009). The water repellency index is the equivalent of the penetration time necessary for a water drop to be absorbed by the soil (Letey 1969), respectively, in the case of this research, to penetrate the air-dried earthworm cast. The methodology of Doerr et al. (2000) has been modified by releasing three consecutive deionized water drops, instead of one, from a pipette, on the cast surface and the time necessary for a drop by 0.05 mL to completely penetrate the cast has been noted, each subsequent drop being released after the complete absorption of the previous one, noting the absorption time for each of them. The decision to apply three consecutive water drops on the air-dried earthworm casts was made considering the arguments of Lipiec et al. (2015) according to which, when are dried, the soil aggregate becomes more stable due to the strengthened organo-mineral bonds as a consequence of the different arrangement of the organic molecules and reorganization of the soil particle inside soil aggregate, and hypothesizing that this pattern is maintained in the earthworm casts too, and also considering several findings on wetting resistance of soil aggregates (Shipitalo & Protz 1988; Fér et al. 2016) which showed its decrease with the increase of the amount of water infiltrated in soil. The application way has been done perpendicularly on the flattest side of the cast, as described by Lipiec et al. (2015).

RESULTS AND DISCUSSION

The analysed characteristics of the earthworm casts are listed in Table 1. The mean values regarding the weight (g) and water repellency (hydrophobicity) of the earthworm casts expressed as penetration (infiltration) time (s) for the three consecutive releases of water drops. The penetration times indicated that the analysed earthworm casts were slightly water-repellent according to the second class (5–60 s) of interpretation of Dekker et al. (2009).

It was found that, as the amount of water applied increases, there is initially a tendency to increase the water penetration time (after the application of the first water drop), after which it decreases (after the application of the second drop) (Table 1). At the second drop application, the water penetration time increased very little, by 2.22% compared to the time required for the first water drop to penetrate the coprolites. For the infiltration of the third drops, it was found that the penetration time decreased, both in relation to the penetration time of the first

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Table 1. Statistics of the analysed parameters of the *Lumbricus terrestris* casts: cast weight, particle size composition (texture), OC and $CaCO_3$ contents, water-drop penetration time

Statistics	Weight of earthworm cast (g)	Particle size composition (texture) of earthworm casts: coarse sand (2.0–0.2 mm)	fine sand (0.2–0.02 mm)	silt (20–2 µm)	clay: colloidal fraction (< 2 µm)	clay: physical fraction (< 10 µm)	OC (%)	$CaCO_3$ (%)	Water drop penetration time (hydrophobicity) of earthworm casts (s): first drop	second drop	third drop
Mean	1.91	25.36	36.70	20.53	17.73	30.50	1.40	5.50	13.50	13.80	11.54
SD	0.73	4.28	2.45	1.04	2.70	2.25	0.43	0.97	2.77	4.15	3.23
Minimum	0.86	20.80	34.30	19.70	14.90	27.90	1.05	4.92	10.43	9.03	7.83
Maximum	3.93	29.30	39.20	21.70	20.30	31.90	1.89	6.63	15.82	16.61	13.78

SD – standard deviation

water drop (by 14.52%), and in relation to the time required for the penetration of the second applied water drop (by 16.38%). The statistical interpretation in Table 2 shows a statistically significant positive correlation between all water penetration times (resulting after the first, the second and the third drop release, respectively), which means that as their degree of wetting increases, the hydrophobicity of earthworm casts increases or decreases in direct relation with the previous water drop application, i.e. as the penetration time of the previous drop increases, the penetration time of the current drop will also increase and therefore increases the hydrophobicity of the coprolite (situation found in our study in the relationship between drop 1 penetration time – drop 2 penetration time), respectively as the penetration time of the previous drop decreases, the penetration time of the current drop also decreases and therefore the hydrophobicity of the coprolite decreases (situation encountered in our study in the relationship between drop 2 penetration time – drop 3 penetration time). This tendency could appear because the different textural particles of the earthworm casts lose their close contact gained by drying as they absorb water. This effect has been previously shown in the casts of the earthworm *L. terrestris* (Shipitalo & Protz 1988). Another explanation could be the decreasing role of OC in maintaining the surface water repellency of the aggregate with the increase of soil moisture (Fér et al. 2016).

The statistical processing of data has shown in many cases of this study non-statistical correlations between the analysed factors, but these were considered and debated together with the significant ones, because previously other studies on the same topic reported non-statistically significant results if the correlation coefficient had a value larger than 0.7 (Bottinelli et al. 2010a; Chen et al. 2021), motivating the lack of statistical significance as a consequence of other factors difficult to study and to be enclosed in interpretation in the same time with those targeted.

No statistically significant correlations have been found between the weight of earthworm casts and the first and respectively the second water drop penetration times (Table 2), but there was found a negative statistically significant correlation ($P < 0.05$) between the cast weight and the penetration time of the third water drop, which is probably a consequence of the fractal volume (ratio volume/surface) of the earthworm cast as the cast get moisten (Shipitalo & Protz 1988; Fér et al. 2016).

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Table 2. Correlations between the weight of earthworm casts and the three consecutive water drop penetration times

		Penetration time (s)		
		first drop	second drop	third drop
Weight of earthworm cast (g)	Pearson correlation	–0.320	–0.271	–0.366*
	Sig. (2-tailed)	0.057	0.109	0.028
First drop penetration time (s)	Pearson correlation	–	0.700**	0.717**
	Sig. (2-tailed)	–	0.000	0.000
Second drop penetration time (s)	Pearson correlation	0.700**	–	0.788**
	Sig. (2-tailed)	0.000	–	0.000
Third drop penetration time (s)	Pearson correlation	0.717**	0.788**	–
	Sig. (2-tailed)	0.000	0.000	–

*, ** $P < 0.05$, 0.01

Statistical correlations have been searched between the analysed characteristics of the earthworm casts (Table 3) in order to find the factors influencing the water repellency of the casts.

It was found that the water repellency of earthworm casts increases with the decrease of their silt (particle diameter 20–2 μm) content. This result is not statistically significant, but it is consistent with other findings and explained by the fact that higher silt content in the soil is associated with a higher capillarity and, therefore, with a shorter water infiltration time (Ma & Liu 2020). The negative not statistically significant correlation between the silt and water repellency of earthworm casts was found for all the three consecutive applications of water drops and could be in relation to the positive correlation found between the OC content and water repellency of the casts, meaning that the amount of hydrophobe organic matter is sufficient to coat the surface of silt particles, resulting in an water repellent response of the earthworm casts associated with its silt composition and carbon content. The hydrophobic response of the analysed earthworm casts increased with the increase of their OC content for each drop water application. Positive correlations between water repellency, structural stability and OC content were also found by other authors. Piyaruwan and Leelamanie (2020) showed that the main cause of the reduced water resistance and decreased structural stability of soil in a tropical ecosystem (*Eucalyptus grandis* plantation) was the decrease in organic matter content with increasing soil depth. This is explained by the presence of organic matter that covers the mineral soil particles and/or represents interstitial matter in the soil matrix that prevents water infiltration in depth. The OC is considered one of the most important cementing and stabilizing agents of soil aggregates (Amézketa 1998), which explains the result found in this study.

The water repellency of earthworm casts is an indicator of the organic matter protection at the soil level, through several mechanisms: its raised value could indicate organic matter protection due to the polysaccharide cementing agents (Ge et al. 2001) and other binding agents like the mucilaginous excretions of the cast microorganisms (Haynes & Fraser 1998) which keep together the aggregate particles making them more stable; it could be an indicator of cast slaking (Bottinelli et al. 2010b) which determines the obstruction of cast pores (and less air exposure to the microorganisms which produce binding sub-

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Table 3. Statistical correlations between the analysed characteristics of the earthworm casts

		Coarse sand (2.0–0.2 mm)	Fine sand (0.2–0.02 mm)	Silt (20–2 μm)	Clay colloidal fraction (< 2 μm)	Clay physical fraction (< 10 μm)	OC (%)	$CaCO_3$ (%)	Penetration time (s) first drop	Penetration time (s) second drop	Penetration time (s) third drop
Coarse sand (2.0–0.2 mm)	Pearson correlation	1	–0.634	0.362	–0.977	–0.821	0.626	0.786	0.154	–0.027	–0.011
	Sig. (2-tailed)	0	0.562	0.764	0.136	0.387	0.569	0.425	0.902	0.983	0.993
Fine sand (0.2–0.02 mm)	Pearson correlation	–0.634	1	–0.950	0.456	0.080	0.206	–0.020	0.666	0.790	0.780
	Sig. (2-tailed)	0.562	0	0.201	0.698	0.949	0.868	0.987	0.536	0.420	0.431
Silt (20–2 μm)	Pearson correlation	0.362	–0.950	1	–0.157	0.234	–0.500	–0.292	–0.865	–0.941	–0.936
	Sig. (2-tailed)	0.764	0.201	0	0.900	0.849	0.667	0.811	0.335	0.219	0.229
Clay (colloidal fraction) (< 2 μm)	Pearson correlation	–0.977	0.456	–0.157	1	0.923	–0.777	–0.899	–0.360	–0.185	–0.202
	Sig. (2-tailed)	0.136	0.698	0.900	0	0.251	0.433	0.289	0.765	0.881	0.871
Clay (physical fraction) (< 10 μm)	Pearson correlation	–0.821	0.080	0.234	0.923	1	–0.959	–0.998*	–0.691	–0.548	–0.562
	Sig. (2-tailed)	0.387	0.949	0.849	0.251	0	0.183	0.038	0.515	0.630	0.620
OC (%)	Pearson correlation	0.626	0.206	–0.500	–0.777	–0.959	1	0.974	0.867	0.763	0.773
	Sig. (2-tailed)	0.569	0.868	0.667	0.433	0.183	0	0.145	0.332	0.448	0.437
$CaCO_3$ (%)	Pearson correlation	0.786	–0.020	–0.292	–0.899	–0.998*	0.974	1	0.732	0.597	0.610
	Sig. (2-tailed)	0.425	0.987	0.811	0.289	0.038	0.145	0	0.477	0.592	0.582

*$P < 0.05$

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stances resulting thus a physical destructuration of the cast) or the exposure of the cast to decaying microorganisms (and thus a microbiologically-mediated physical de-protection of carbon), all with important consequences in the de-protection of the organic matter at soil level.

The positive correlation between OC and water-repellency of earthworm casts found in this study could be explained through the bonding property of the carbon, which ties the mineral particles of the cast, making them more cohesive and thus more water-repellent (Lipiec et al. 2015) and more structurally stable. The organo-mineral coating of the soil aggregates can determine changes in the surface hydraulics of the cast (Fér et al. 2016). Other previous studies demonstrated that the organic matter is an intrinsic factor of earthworm cast responsible for its stabilization (Haynes & Fraser 1998) and, when the organic matter is lining the earthworm burrows, it enhance the preferential flow of water (Haas et al. 2018).

Stabilization of soil organic carbon is connected to physical parameters, mechanisms resulting in physical protection of carbon not only with chemical transformations mediated by the microorganisms which colonised the cast (Haynes & Fraser 1998). The positive correlation found between the content of fine sand (0.2–0.02 mm; 200–20 μm) and water repellency of cast could be a consequence of the mechanical reciprocal blocking of the mineral particles of sand (Haynes & Fraser 1998) and of the modified number of contact points between particles (Arthur et al. 2013) which modify the cohesion forces between particles after the grinding and mixing of the ingested material (soil and organic matter) by the earthworm digestive system (Haynes & Fraser 1998) resulting a new physical arrangement of the fine sand particles within the cast.

A negative correlation has been found in this study between the content of the two size types of clay and the OC content (Table 3) of the earthworm casts. Although this negative correlation is not statistically significant it describes a pattern also encountered by other studies in the non-biogenic soil aggregates (Müller & Deurer 2011), the addition of clay being a method to fight against soil water repellency. Fér et al. (2016) found that the different fractions of clay in the composition of the soil aggregate also influence the surface wettability of the soil aggregate although the soil organic matter has a dominant effect.

A non-significant positive correlation has been found between the content of $CaCO_3$ and water repellency of earthworm casts (Table 3), indicating that the water resistance of the analysed casts increased with the increase of their $CaCO_3$ content. This correlation has been expressed through a higher value of the correlation coefficient (0.732) for the first water drop release on the cast surface than the other two subsequent water drop releases. The reaction of water with $CaCO_3$ in earthworm casts depends on several factors, one of these being the reaction surface. A source of $CaCO_3$ in the casts of earthworms *L. terrestris* is the $CaCO_3$ granules produced by the oesophageal calciferous glands located in segments 10–12 of the body, stabilised mainly as calcite. Within the drying process, the casts of *L. terrestris* lose water and also lose water their calcite granules, and thus the roughness and the porosity of the granule surface increase, factors favouring the dissolution at the granular surface (Mandera et al. 2023) and therefore the release of the Ca^{2+} in reaction with water (Versteegh et al. 2017; Mandera et al. 2023). The reaction is possibly to be mostly consumed at the first water drop absorption by the earthworm cast. The formation and stabilization of soil aggregates are related to a series of physical factors and inorganic and organic stabilizing agents, and among the inorganic ones, the Ca^{2+} cations and carbonates are considered very important because they modify the mechanical properties of some textural components of soil aggregates, such as those of the physical clay. A study on the effect of $CaCO_3$ on a type of clay (red, particle size between 1.63 and 282.06 μm) sampled from a soil profile in a natural ecosystem in China (Chen et al. 2020) showed that certain mechanical properties of the studied clay, supplemented with $CaCO_3$, such as shear strength, particle cohesion, and internal friction angle, changed due to the addition of $CaCO_3$, as follows: shear strength increased, and particle cohesion and internal friction angle decreased. These results may explain why, in this study, the hydrophobicity of coprolites correlated negatively with soil physical clay content and positively with $CaCO_3$ content. Also, in the analysed casts it has been found a statistically significant negative correlation ($P < 0.05$) between the content of clay and the content of $CaCO_3$ (Table 3) regardless of the particle-sized fractions of clay (< 2 μm and, respectively, < 10 μm). The relations between calcium and clay are very important because calcium is a determining element of the cation exchange capacity, which is a commonly used technique to physically and chemically characterize the clays (Elhechi et al.

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2023) in relation to their rheological properties. Some studies (Elhechi et al. 2023) showed that the calcite forms large agglomerations with the clay particles and that the interlayer hydration determines a higher dispersion rate of the clay particles and therefore the rheological properties of the clay will be modified, which might be an explanation for the positive correlations found in this study between the $CaCO_3$ content of earthworm casts and water repellency. Other studies showed that clay minerals can accelerate the aggregation of some bacteria (Wang et al. 2023) associated with the increase of organic matter in the aggregate and that Ca^{2+} is involved in the carbonate precipitations mechanisms microbially mediated in the presence of clay minerals. This could explain why, in this study, there was found a positive correlation (although not statistically significant) between the contents of OC and $CaCO_3$ (Table 3) in earthworm casts. Also, the relation between the organic matter and $CaCO_3$ was also shown by recent studies which demonstrated that the earthworms *L. terrestris* produce amorphous $CaCO_3$ granules which mostly crystallize into the more stable calcite (Mandera et al. 2023) which undergo structural and crystallographic transformations and, in a phase of its formation process, the presence of organic matter is essential because the poorly ordered proto-vaterite is transforming into more stable calcite through nanoparticle attachment within the organic framework, being stabilized and regulated by the organic macromolecules, as Mandera et al. (2023) showed in a microcosmos experiment on the biocrystallization of the biogenic calcite granules produced by the species *L. terrestris*. The role of the organic molecules is to delay the transformations of $CaCO_3$ in the oesophageal pouches of the earthworms *L. terrestris* (Mandera et al. 2023) and therefore this species, as well as other earthworm species producing calcite granules, could be considered depositors of $CaCO_3$ that will be gradually eliminated in the environment (earthworm drillosphere).

Although several correlations found in this study between the analysed factors of the earthworm casts were not statistically significant, results without statistical significance about the relation between certain parameters of structural stability of earthworm casts have been previously reported (Bottinelli et al. 2010a; Chen et al. 2021), and considered to be relevant if the correlation coefficient was greater than 0.7 (Bottinelli et al. 2010a; Chen et al. 2021), because of other possible indirect internal factors of influence inside earthworm casts: micro-cracks (Chen et al. 2021), microorganisms, the pore volume (Lipiec et al. 2015), the pore shape (Jouquet et al. 2008), the pore morphology (Papadopoulos et al. 2009), decomposition rate of organic matter, carbon adsorption on mineral surfaces (Lipiec et al. 2015), the ratio of alkyl/carboxyl groups in the organic matter (Leue et al. 2015). Also, the reduced number of measurements could influenced the statistical significance. However, the findings of this study are consistent with the findings of other authors which emphasize the contribution of the organic carbon and of the textural fractions to the water repellency of earthworm casts. This study also shows the contribution of $CaCO_3$ to the water repellency of *L. terrestris*'s casts.

CONCLUSION

The findings of this study showed that the main drivers determining the water repellency of the casts of the earthworm *L. terrestris*, as indicators of their structural stability, are chemical (the contents of OC and respectively $CaCO_3$) and physical (contents of clay, silt and fine sand as fractions of the particle size composition).

The casts' water repellency (hydrophobicity) decreased with their clay and silt content and increased with their OC and $CaCO_3$ content.

The hydrophobicity of earthworm casts is in direct positive relation with their previous water accumulation, i.e. the current penetration time of water increases or decreases if the previous penetration time of the water increased or decreased, respectively.

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