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Supplement of

Electrical conductivity measurements as proxies for diffusion-limited microbial activity in soils under controlled laboratory conditions

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S1: Experimental design

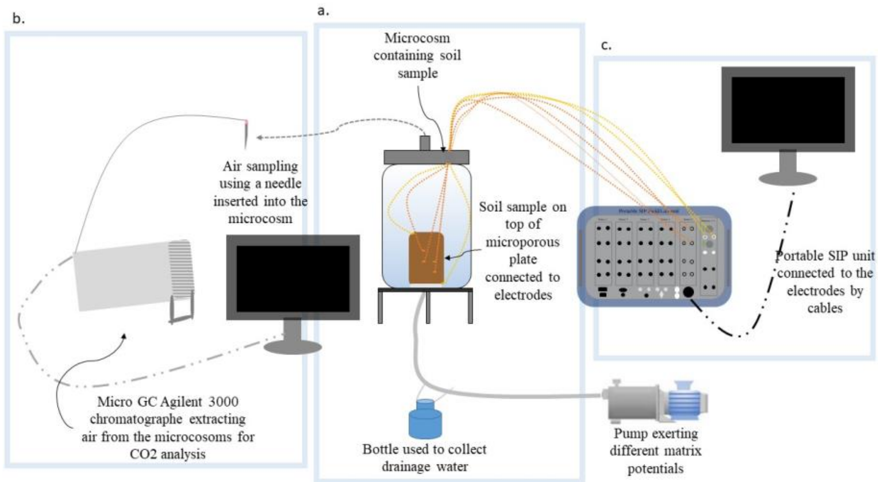

Fig. S1: Experimental set-up used to measure electrical conductivity and soil respiration rate at different matric potentials. (a) Samples are placed on microporous plates inside an air-tightly closed microcosm. The microcosms are connected to a pump that exerts different matric potentials through drainage collecting bottles placed inside an 8°C fridge. (b) Micro GC Agilent 3000 connected to a needle used to directly take 20 ml from the microcosms for CO_2 analysis. (c) Electrical conductivity is measured by a PSIP unit, current injection and potential measurements is performed through electrodes connected to the PSIP unit by cables sealed by silicone at the top of the microcosm.

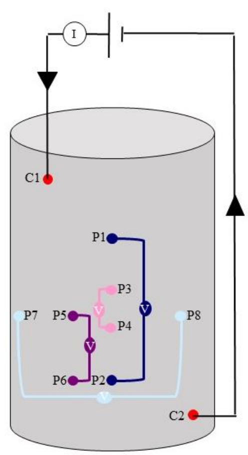

Fig. S2: Sketch of the electrode configuration used for the electrical conductivity measurements: C1 and C2 are the current electrodes (injection), while P1 to P8 are potential electrodes (potential measurements). Measurement pair 1 to 4 correspond to P1-P2, P3-P4, P5-P6, and P7-P8, respectively (see Table S1).

S2: Additional results of the paper

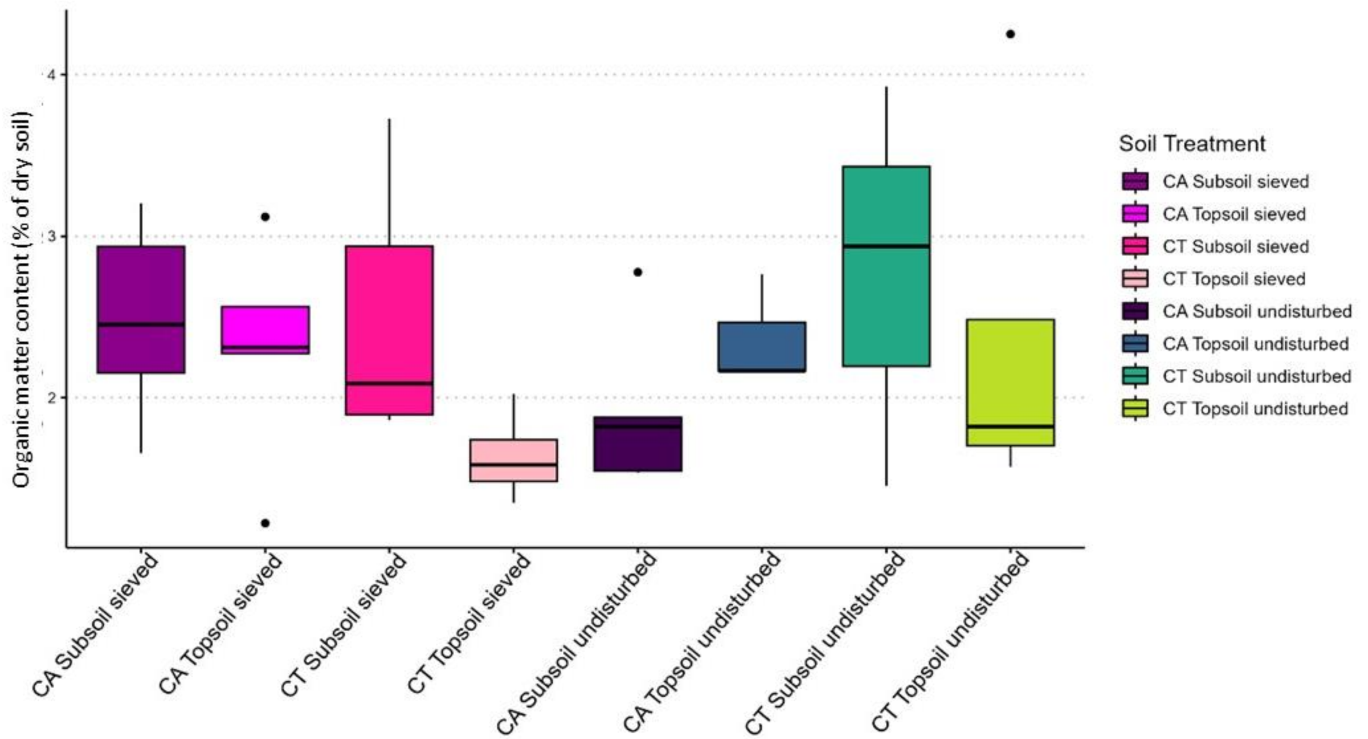

Fig. S3: Boxplot showing the organic matter content (%) of each study site based on soil treatment. Each soil treatment consists of the triplicate samples with one of the triplicates being tested thrice to allow analytical verification of the laboratory results. CA stands for conservation agriculture while CT stands for conventional tillage. The undisturbed samples are undisturbed soil cores while the sieved samples were sieved down to a 2 mm particle size and packed to a bulk density of 1.73 g/cm^{3}.

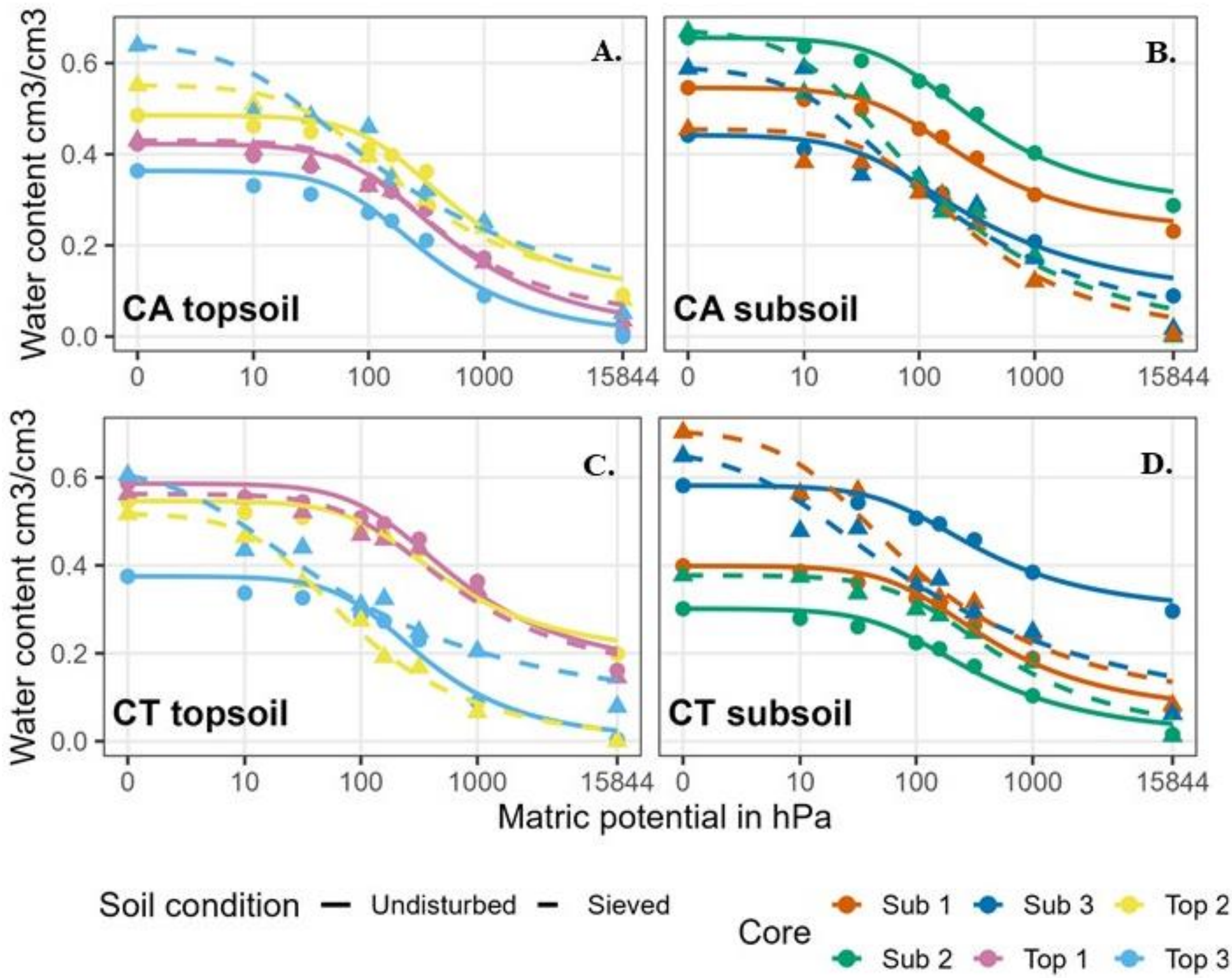

Fig. S4: Water retention curves for all soil treatments.
Volumetric water content (cm³ cm⁻³) as a function of matric potential for conservation agriculture (CA) and conventional tillage (CT) soils. Panels show (A) CA topsoil, (B) CA subsoil, (C) CT topsoil, and (D) CT subsoil. Points represent measured values for individual soil cores and lines show fitted van Genuchten retention curves. Solid lines indicate undisturbed samples and dashed lines indicate sieved samples. Colours correspond to individual cores as indicated in the legend.

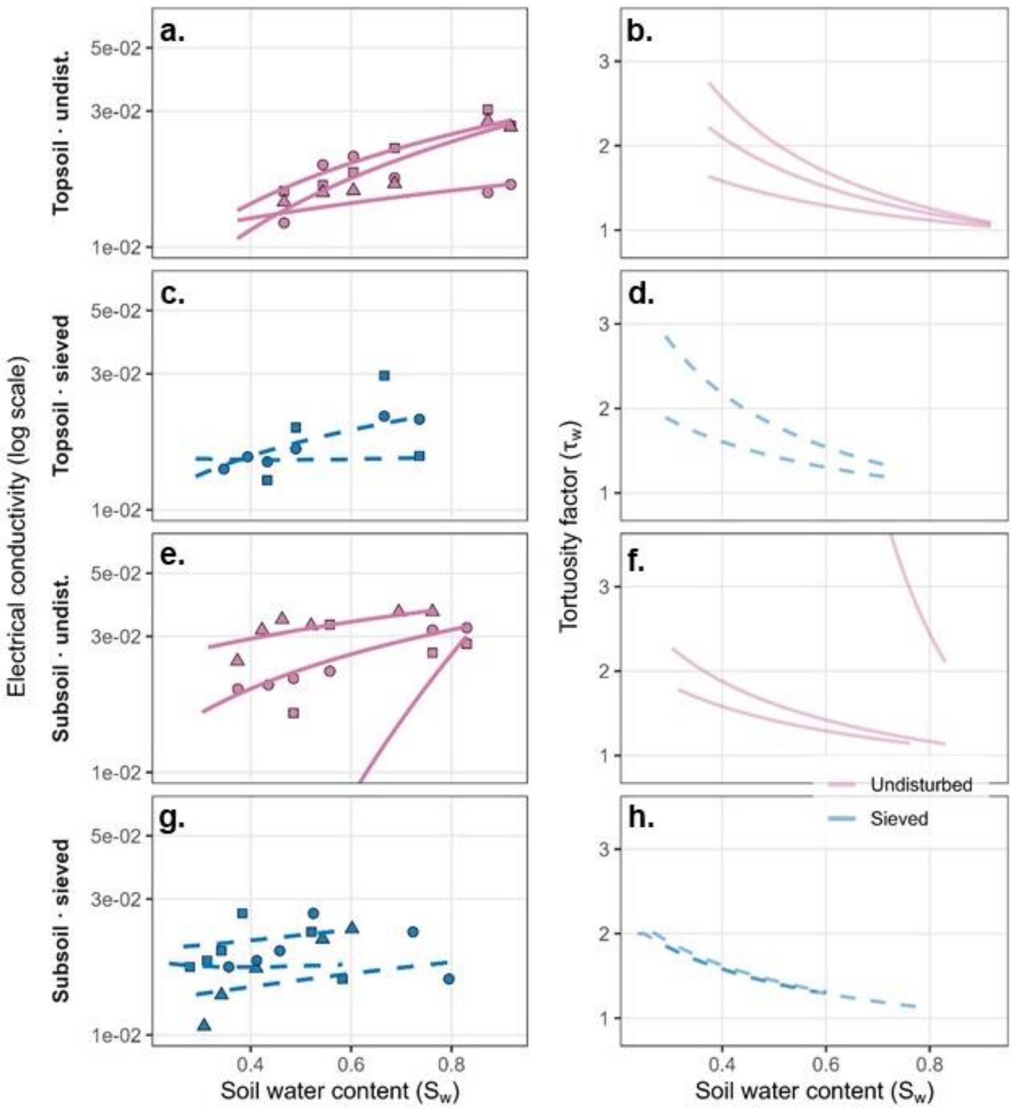

Fig. S5: Electrical conductivity and derived tortuosity as a function of water saturation for conservation agriculture (CA) soils. **(a, c, e, g) Bulk electrical conductivity (EC) plotted against water saturation (S_x) for topsoil and subsoil samples under undisturbed and sieved conditions. EC is shown on a logarithmic scale. Points represent measured values for individual soil cores, and lines represent fits of the pedophysical model (Eq. 4) for each core.**

(b, d, f, h) Corresponding tortuosity factor (τ_x) derived from EC measurements using Eq. 5. Solid lines indicate undisturbed soils and dashed lines indicate sieved soils.

Panels correspond to (a-b) topsoil undisturbed, (c-d) topsoil sieved, (e-f) subsoil undisturbed, and (g-h) subsoil sieved.One replicate in the undisturbed subsoil treatment was excluded from the plotted relationship due to unstable electrode contact that produced non-physical EC values approaching zero. The raw measurements are retained in the accompanying dataset for transparency.

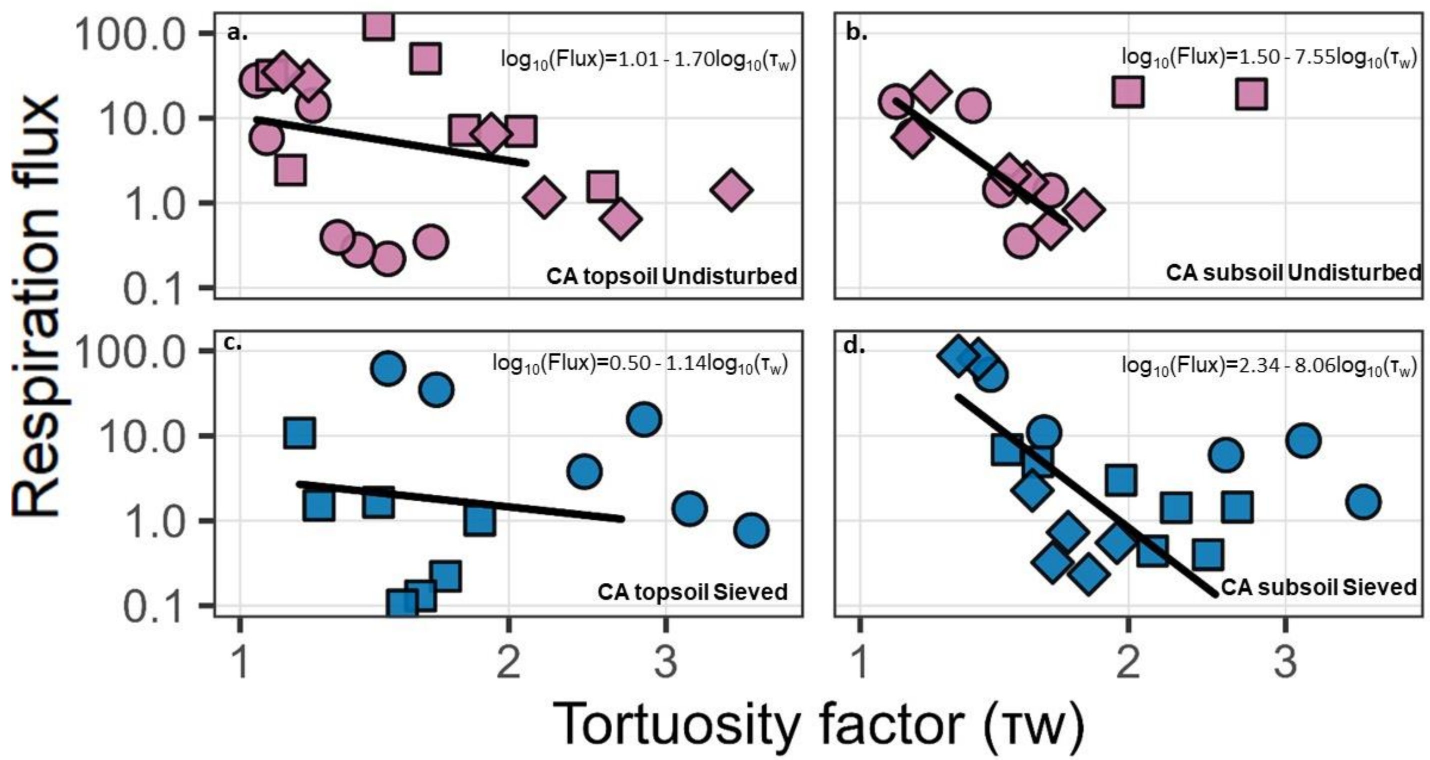

Fig. S6: Relationship between soil respiration flux and EC-derived tortuosity (τ_w) for the conservation agriculture (CA) samples. Panels (a-b) show undisturbed samples and panels (c-d) show sieved samples. The left column corresponds to topsoil and the right column to subsoil. Points represent individual measurements from soil cores, with symbol shape indicating replicate. Respiration flux is plotted on a logarithmic scale. Solid black lines represent linear regressions fitted between $\log_{10}$-transformed respiration flux and $\log_{10}$-transformed tortuosity (τ_w) within the diffusion-limited range used for the statistical analysis. Only measurements within this range were included in the regressions. Regression equations are shown in each panel.

S3: Supplementary tables used in the article

Table S1: Table showing the electrode pairs, their names indicated in Figure 3, the distance between the electrodes and the geometric factor calculated for each pair.

Electrode Pairs	Electrode names	Distance/angle between electrodes	Geometric factor (in m)
Pair 1	P1-P2	4 cm, vertical	0.060
Pair 2	P3-P4	1 cm, vertical	0.199
Pair 3	P5-P6	2 cm, vertical	0.199
Pair 4	P7-P8	45°, horizontal	0.284

Table S2: Average net respiration flux (in µmol/hour/grams of organic matter) at the highest measured saturation of -70hPa. CT stands for conventional tillage and CA stands for conservation agriculture. The sieved samples were sieved down to a 2 mm particle size and packed to a bulk density of 1.73 g/cm^3.

Soil Treatment	Mean Flux	Standard error of mean
CA Subsoil undisturbed	13.98	4.25
CT Subsoil undisturbed	7.38	4.75
CA Topsoil undisturbed	31.55	2.12
CT Topsoil undisturbed	19.46	1.79
CA Subsoil sieved	47.17	40.29
CT Subsoil sieved	88.14	52.700
CA Topsoil sieved	36.34	25.54
CT Topsoil sieved	32.42	0.14

Table S3: Average relative respiration flux and standard error of the mean relative respiration of each soil treatment type. The data was normalized to the values at -70hPa and is graphically represented in Fig.1 of the main body of the article. CT stands for conventional tillage and CA stands for conservation agriculture.

Treatment	Soil structure	Applied suction	Average respiration	Standard error of the mean
CA Subsoil	Sieved	-70	1	0
CA Subsoil	Sieved	-100	6.184	5.466
CA Subsoil	Sieved	-250	0.400	0.035
CA Subsoil	Sieved	-350	0.055	0.009

CA Subsoil	sieved	-450	0.157	0.050
CA Subsoil	sieved	-630	0.046	0.012
CA Subsoil	sieved	-996	0.145	0.065
CA Subsoil	undisturbed	-70	1	0
CA Subsoil	undisturbed	-100	0.975	0.291
CA Subsoil	undisturbed	-250	0.609	0.283
CA Subsoil	undisturbed	-350	0.100	0.020
CA Subsoil	undisturbed	-450	0.065	0.026
CA Subsoil	undisturbed	-630	0.049	0.020
CA Subsoil	undisturbed	-996	0.031	0.018
CA Topsoil	sieved	-70	1	0
CA Topsoil	sieved	-100	2.647	2.426
CA Topsoil	sieved	-250	0.550	0.001
CA Topsoil	sieved	-350	1.140	1.126
CA Topsoil	sieved	-450	0.110	0.091
CA Topsoil	sieved	-630	0.072	0.039
CA Topsoil	sieved	-996	0.147	0.001
CA Topsoil	undisturbed	-70	1	0
CA Topsoil	undisturbed	-100	0.759	0.498
CA Topsoil	undisturbed	-250	4.452	3.556
CA Topsoil	undisturbed	-350	1.212	0.100

CA Topsoil	undisturbed	-450	0.184	0.139
CA Topsoil	undisturbed	-630	0.167	0.1340
CA Topsoil	undisturbed	-996	0.071	0.024
CT Subsoil	Sieved	-70	1	0
CT Subsoil	Sieved	-100	5.977	1.498
CT Subsoil	Sieved	-250	2.368	1.964
CT Subsoil	Sieved	-350	2.267	1.569
CT Subsoil	Sieved	-450	0.137	0.048
CT Subsoil	Sieved	-630	0.137	0.106
CT Subsoil	Sieved	-996	0.161	0.078
CT Subsoil	undisturbed	-70	1	0
CT Subsoil	undisturbed	-100	0.256	0.072
CT Subsoil	undisturbed	-250	0.362	0.092
CT Subsoil	undisturbed	-350	0.073	0.020
CT Subsoil	undisturbed	-450	0.060	0.014
CT Subsoil	undisturbed	-630	0.024	0.010
CT Subsoil	undisturbed	-996	0.040	0.015
CT Topsoil	Sieved	-70	1	0
CT Topsoil	Sieved	-100	1.039	0.724
CT Topsoil	Sieved	-250	0.502	0.134
CT Topsoil	Sieved	-350	0.077	0.060

CT Topsoil	sieved	-450	0.056	0.002
CT Topsoil	sieved	-630	0.046	0.013
CT Topsoil	sieved	-996	0.081	0.006
CT Topsoil	undisturbed	-70	1	0
CT Topsoil	undisturbed	-100	0.368	0.176
CT Topsoil	undisturbed	-250	1.235	1.133
CT Topsoil	undisturbed	-350	0.204	0.164
CT Topsoil	undisturbed	-450	0.100	0.024
CT Topsoil	undisturbed	-630	0.040	0.014
CT Topsoil	undisturbed	-996	0.017	0.008

Table S4: Ionic conductivity of drained pore water measured at the end of the experiment for each soil treatment. These values were used as estimates of pore water conductivity (σ_w) in the pedophysical model described in Eq. (4).

Soil Treatment	Soil structure	Mean	Standard error of mean
CA Topsoil	undisturbed	637.33	12.41
CA Subsoil	undisturbed	463.67	22.51
CT Topsoil	undisturbed	433.00	15.57
CT Subsoil	undisturbed	413.67	38.89
CA Topsoil	sieved	481.00	58.24
CA Subsoil	sieved	597.67	48.90
CT Topsoil	sieved	1052.33	8.69

CT Subsoil	sieved	742.33	28.67

Table S5: Parameters obtained from fitting the pedophysical model relating bulk electrical conductivity to water saturation (Eq. 4) for each soil core using Channel 3 measurements. The formation factor (*F*) and the saturation exponent (*n*) describe how electrical conductivity varies with water saturation. These parameters were used to calculate the tortuosity factor (τ_n) following Eq. (5). RMSE represents the root mean square error of the model fit. One CT undisturbed topsoil replicate showed an unusually steep decline in electrical conductivity with decreasing saturation, resulting in a large fitted exponent; this replicate is retained for transparency.

Management	Depth	Structure	Core	σ_o	n	RMSE
CA	subsoil	sieved	Subsoil 1	2.47	0.27	6.15E-09
CA	subsoil	sieved	Subsoil 2	0.878	0.286	9.87E-10
CA	subsoil	undisturbed	Subsoil 1	4.333	1.292	0.061
CA	subsoil	undisturbed	Subsoil 2	0.374	5.528	2.30E-08
CA	subsoil	undisturbed	Subsoil 3	1.133	0.368	1.60E-08
CA	topsoil	sieved	Topsoil 1	2	1.21	0.0194
CA	topsoil	sieved	Topsoil 2	0.132	3.314	0.00772
CA	topsoil	undisturbed	Topsoil 2	5.857	1.714	0.0813
CA	topsoil	undisturbed	Topsoil 3	3.192	1.811	0.0409
CT	subsoil	sieved	Subsoil 1	1.751	0.706	2.35E-09
CT	subsoil	sieved	Subsoil 2	0.743	0.706	4.97E-09
CT	subsoil	sieved	Subsoil 3	3.148	1.039	0.0164
CT	subsoil	undisturbed	Subsoil 1	1.75	0.222	0.0194
CT	subsoil	undisturbed	Subsoil 2	0.967	2.761	3.34E-08
CT	subsoil	undisturbed	Subsoil 3	2.165	0.348	1.25E-07
CT	topsoil	sieved	Topsoil 1	35.178	3.173	0.0133
CT	topsoil	sieved	Topsoil 2	10.99	2.762	2.86E-09
CT	topsoil	sieved	Topsoil 3	5.984	0.718	1.81E-08
CT	topsoil	undisturbed	Topsoil 1	0.338	16.866	4.38E-06
CT	topsoil	undisturbed	Topsoil 2	2.984	1.401	0.0255
CT	topsoil	undisturbed	Topsoil 3	0.357	2.685	0.0307

Table S6:Regression parameters describing the relationship between soil respiration flux and EC-derived tortuosity (τw). Linear regressions were fitted between $\log_{10}$-transformed respiration flux and $\log_{10}$-transformed tortuosity using individual measurements from soil cores within the diffusion-limited range of water saturation. The table reports the intercept (*a*), slope (*b*), coefficient of determination (R^2) and number of observations (*n*) for each depth–structure combination.

Management	Depth	Structure	Intercept	Slope	R^2	n
CT	topsoil	undisturbed	1.34	−9.35	0.343	13
CT	subsoil	undisturbed	0.885	−7.36	0.329	13
CT	topsoil	sieved	1.97	−6.33	0.283	16
CT	subsoil	sieved	2.7	−8.14	0.318	17
CA	topsoil	undisturbed	1.01	−1.70	0.034	16
CA	subsoil	undisturbed	1.5	−7.55	0.672	11
CA	topsoil	sieved	0.505	−1.136	0.011	10
CA	subsoil	sieved	2.34	−8.06	0.577	15