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A Dataset of μCT Images of Small Samples of Constructed Technosol from Bioretention Cells

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1 ARTICLE INFORMATION

Article title

A Dataset of µCT Images of Small Samples of Constructed Technosol from Bioretention Cells

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Keywords

X-ray microtomography, constructed Technosols, biofilter, bioretention cell, swale, rain garden, urban soil, soil structure

Abstract

The dataset represents micro computed tomography (µCT) images of undisturbed samples of constructed Technosol, obtained by sampling from the top layer of the biofilter in two bioretention cells. A bioretention cell is a stormwater management system designed to collect and temporarily retain stormwater runoff and treat it by filtering it through a soil media called a biofilter. Soil samples were collected at 7, 12, 18, 23, and 31 months after the establishment of bioretention cells. The constructed Technosol was composed of 50% sand, 30% compost, and 20% topsoil. The bioretention cell 1 (BC1) was designed to collect water from the nearby building roof, and bioretention cell 2 (BC2) was without regular inflow for possible irrigation events. This allowed for the capture of the dynamics of early soil structure development. The dataset comprises a total of 120 three-dimensional µCT images. The 16-bit µCT images obtained by industrial scanner have resolutions of 12 and 20 µm. The characteristics of total porosity, volumetric weight of the dry sample and field capacity were determined in the laboratory for each sample. The generated dataset captures the soil structure development within the biofilter during the initial years of operation of bioretention cells with two distinct water regimes. Originally produced to describe the development of the macropore

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system during early biof lter evolu ton, this extensive and high-quality dataset can be reused for further studies on constructed Technosol evolu ton, focusing on soil structure or hydraulic proper tes. It is par tcularly benef cial for research into macropore network development and changes in hydraulic proper tes in constructed soils. The dataset can support model valida ton and improve understanding of soil property variability in bioreten ton systems. It serves as a valuable resource for researchers who lack the means to collect and scan their own samples.

SPECIFICATIONS TABLE

Subject	Environmental Engineering, Soil Science
Specif c subject area	Datasets of CT images taken from constructed Technosol used in biof lter in two bioreten ton cells during 31 months
Type of data	3D images (.t f f les) Table (.xlsx format) Reconstructed 3D images of cylindrical samples, Straightened and centered
Data collec ton	Intact soil samples were collected from the biof lter layer over three years using small aluminum cylinders. The samples were saturated with water, drained, and equilibrated at -330 hPa before µCT imaging. Samples from 2018 and 2019 were scanned at SLU with a GE Phoenix X-ray scanner, and those from 2020 at CULS with a Nikon XT H 225ST. µCT imaging parameters were consistent, with images exported as 16-bit TIFF f les at 20 and 12 µm resolu ton. Following comple ton of the imaging process, the physical characteris tcs of the samples, namely total porosity, water capacity and dry bulk density, were determined. The 3-D images were straightened and centered based on the diameter of the inner cylinder.
Data source loca ton	Ins tu ton: Czech Technical University in Prague - University Centre for Energy E f cient Buildings City/Town/Region: Bustehrad Country: Czech Republic La tude and longitude for collected samples: 50°09'26.0"N 14°10'09.7"E GPS coordinates: 50.1572261N, 14.1693647E
Data accessibility	Repository name: Harvard Dataverse Direct URL to data: h tps://dataverse.harvard.edu/dataverse/CTimages [1]
Related research ar tcle	P. Heckova, J. Koestel, A. Klement, R. Kodesova, M. Snehota, Soil Structure Dynamics in Constructed Technosols for Bioreten ton Cells: X-Ray Microtomography Study, J Soils Sediments. (2024)

	h t ps://doi.org/10.1007/s11368-024-03828-4 [2]

2 VALUE OF THE DATA

- The dataset captures detailed soil structure evolu t on in the bio f lter of the bioreten t on cell over the ini t al 31 months a f er its construc t on in micro computed tomography images of replicated cylindrical undisturbed soil samples.
- Soil sampling over an extended period and subsequent micro computed tomography imaging is highly t me-consuming, making these data valuable.
- Some researchers lack the resources or means to collect and scan their own soil samples, making this dataset valuable for broader scien t f c inquiry.
- Researchers developing models of soil structure evolu t on can leverage this dataset to validate and re f ne their models. Models such as pore network models or the discrete element method can bene f t from this data, as they allow to simulate soil structure dynamics and mechanical proper t es with high accuracy. The u t liza t on of comprehensive t me-series data derived from micro computed tomography (µCT) scans o f ers a robust founda t on for hypothesis tes t ng and the calibra t on of simula t ons.
- The majority of current models for the simula t on of soil structure evolu t on were developed for use in agricultural soil. The dataset may be employed in the valida t on of these models for other soil types, such as constructed Technosols. It can also be used to characterize the hydraulic proper t es of these soils, such as water reten t on and permeability. In addi t on, the dataset allows for the study of soil organic ma t er, including its decomposi t on and stability within constructed Technosols.
- Dataset has the poten t al to contribute to understanding the temporal variability of constructed Technosol proper t es within bioreten t on systems, because the x-ray tomographs are accompanied by the environmental data. The f ndings can be employed in the design and op t miza t on of sustainable drainage systems in urban environments.

3 BACKGROUND

The dataset comprises microcomputed tomography (µCT) images documen t ng the evolu t on of constructed Technosol soil over a 31-month period within the two bioreten t on cells (BC). Exis t ng datasets do not provide such a comprehensive collec t on, and µCT scans predominantly focus on natural soils [3]. A BC is a landscaped depression with a constructed Technosol (bio f lter) and vegeta t on, designed to manage stormwater runo f through accumula t on, in f ltra t on, treatment, and evapotranspira t on [4]. The bio f lter, plays a key role in the BC's func t onality [5], although the long-term performance of BCs remain inadequately understood [6]. This dataset was compiled to support inves t ga t ons on the soil structure dynamics in a bio f lter and addi t onal physical characteriza t ons during the f rst years a f er installa t on under two di f erent water regimes [2]. Regular sampling and µCT imaging of soil from these BCs were conducted to provide empirical evidence on soil structure dynamics, forming the basis of this dataset. In the related research ar t cle, the dataset was used to determine the metrics on macropore space geometry development in the context of changing hydraulic proper t es. The µCT image dataset can help to address the limita t ons

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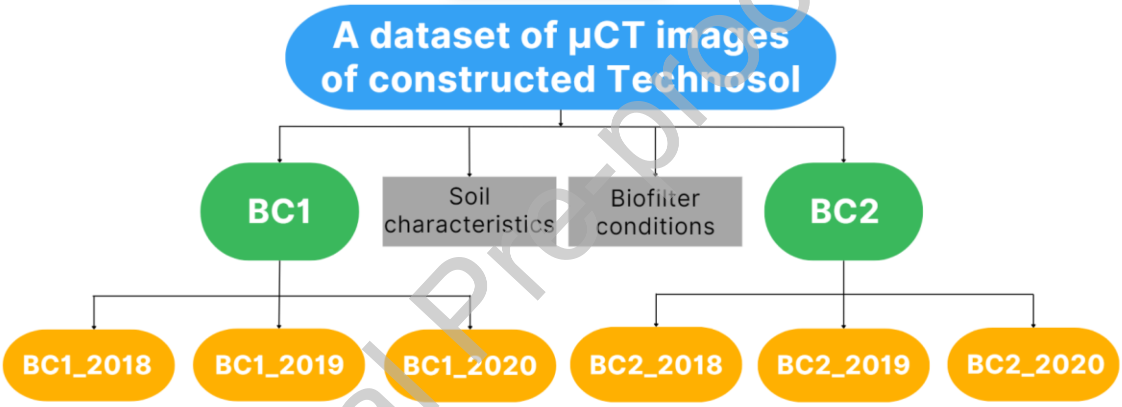
in models for soil structure evolu ton [6], leading to a be ter understanding of soil systems and improved predic ton model accuracy.

4 DATA DESCRIPTION

The data is stored in the Hardware Dataverse repository under the name "A dataset of µCT images of constructed Technosol". A schema tc of the data layout is shown in Fig. 1. The data are divided into two main folders, BC1 and BC2, and one folder containing an Excel spreadsheet of soil characteris tcs. The datasets BC1 and BC2, respec tvely, contain 60 and 59 fles, which are divided into three folders according to the sampling date. The fles are in mul tple slice TIFF format readable for example in ImageJ so fware. The number of fles in each dataset is as follows: The datasets BC1_2018, BC1_2019, BC2_2018, and BC2_2019 contain 24 fles (except for BC2_2018, which contains 23 fles), while BC1_2020 and BC2_2020 contain 12 fles. The two tables of soil characteris tcs and biofIter condi tons includes data for all fles from both BC1 and BC2.



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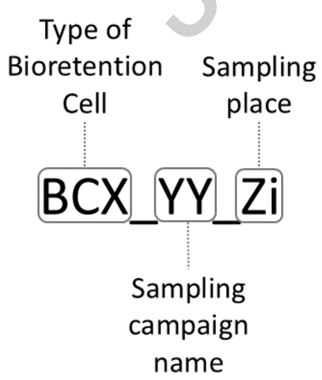
The size of each TIFF fle ranges from 6 to 8.5 GB, with a total data volume for all images of 839 GB. The individual fles are named according to the scheme shown in Fig. 2, which includes the name of bioreten ton cell, the sampling period, and the loca ton (de fned by plant species area) sampled.



BCX	BC1	rain water concentrated from roof plus rain at the area of the bioretention
	BC2	rain only at the area of the bioretention and several irrigation events
YY	18J	June 2018
	18N	November 2018
	19M	May 2019
	19O	October 2019
	20J	June 2020
Zi i = 1,2,3	Ai	Aster
	Hi	Hemerocallis
	Mi	Molinia Carulea
	Ei	Euphobia/Eupatorium

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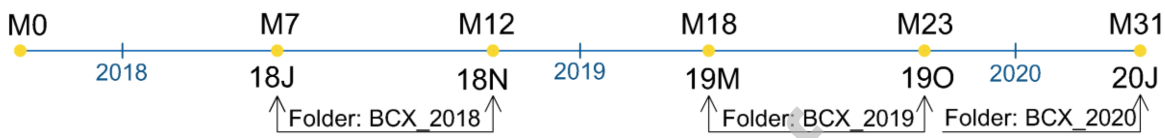
Fig. 3 illustrates the sampling tmeline and corresponding folders in the dataset. The tmeline at the top shows the number of months since the experiment was established, with the months labelled M0-M31. The tme M0 represents the tme of bioretenton establishment. Each sampling is indicated by a "sampling campaign name" e.g 18J. The names of folders in which the samples are located are ttled according to year of imaging e.g. BCX_2018. The name "BCX" in the folder name represents a specifc bioretenton cell, i.e., BC1 or BC2. The data can be downloaded either as an entre folder or specifc fles can be selected by checking the box. However, that individual fles can only be downloaded within a single folder. In both instances, the data is downloaded in ZIP format.



CⅈƎφ o ₵ⅈYŜ fⅈyŜ Ƨŧ ǘKŜ ăl·YǇfⅈyƎ Ŏl·YǇl·ⅈƎyã yl·YŜă Ƨŧ Řl·ǘl·ăŜǘ ŦƧfŘŜǈăφ ₵KŜ ǘƧǇ ǈƧǿ ăKƧǿă ǘKŜ yǳYōŜǈ Ƨŧ YƧyǘKă ăⅈyŎŜ ǘKŜ ăǘl·ǈǘ Ƨŧ ǘKŜ ŜȄǇŜǈⅈYŜyǘ ǘKŜ YⅈŘŘfŜ ăKƧǿă ǘKŜ ăl·YǇfⅈyƎ Ŏl·YǇl·ⅈƎy yl·YŜ ǘKŜ ōƧǘǘƧY ǈƧǿ ăKƧǿă ǘKŜ yl·YŜ Ƨŧ ǘKŜ Řl·ǘl·ăŜǘ ŦƧfŘŜǈăφ

A complete list of all flenames is shown in Tables 1 and 2. Additonally, the name of the folder in which the fle is located is included in the table. The Excel spreadsheet *{ƧⅈfψŎKl·ǈl·ŎǘŜǈⅈăəŎăφȄfăȄ* contains data on total porosity, dry bulk density, and feld capacity. The values of these characteristcs are provided for each fle corresponding to the name given in Tables 1 and 2.

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BC1	Hemerocallis	Aster	Molinia	Euphorbia	Eupatorium	Folder
18jun (M7)	BC1-18J-H1	BC1-18J-A1	BC1-18J-M1	BC1-18J-E1	-	BC1_2018
	BC1-18J-H2	BC1-18J-A2	BC1-18J-M2	BC1-18J-E2	-	
	BC1-18J-H3	BC1-18J-A3	BC1-18J-M3	BC1-18J-E3	-	
18nov (M12)	BC1-18N-H1	BC1-18N-A1	BC1-18N-M1	BC1-18N-E1	-	
	BC1-18N-H2	BC1-18N-A2	BC1-18N-M2	BC1-18N-E2	-	
	BC1-18N-H3	BC1-18N-A3	BC1-18N-M3	BC1-18N-E3	-	
19may (M18)	BC1-19M-H1	BC1-19M-A1	BC1-19M-M1	-	BC1-19M-E1	BC1_2019
	BC1-19M-H2	BC1-19M-A2	BC1-19M-M2	-	BC1-19M-E2	
	BC1-19M-H3	BC1-19M-A3	BC1-19M-M3	-	BC1-19M-E3	
19oct (M23)	BC1-19O-H1	BC1-19O-A1	BC1-19O-M1	-	BC1-19O-E1	
	BC1-19O-H2	BC1-19O-A2	BC1-19O-M2	-	BC1-19O-E2	
	BC1-19O-H3	BC1-19O-A3	BC1-19O-M3	-	BC1-19O-E3	
20jun (M31)	BC1-20J-H1	BC1-20J-A1	BC1-20J-M1	-	BC1-20J-E1	BC1_2020
	BC1-20J-H2	BC1-20J-A2	BC1-20J-M2	-	BC1-20J-E2	
	BC1-20J-H3	BC1-20J-A3	BC1-20J-M3	-	BC1-20J-E3	

The Excel spreadsheet *{ƧⅈfψŎKl·ǈl·ŎǘŜǈⅈăəŎăφȄfăȄ* is located in a separate folder, enttled "Physical characteristcs of soil samples".

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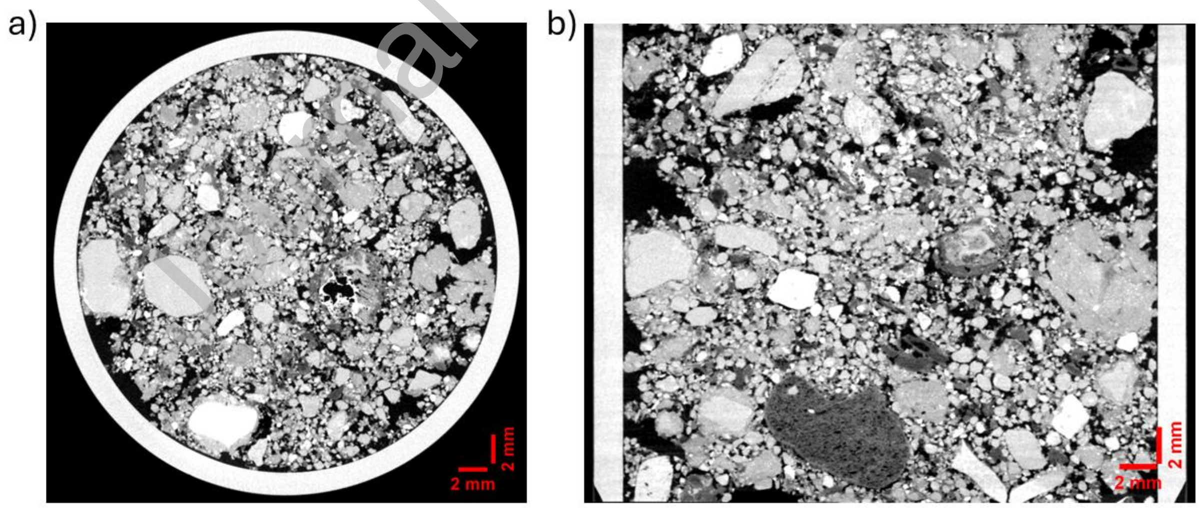
BC2	Hemerocallis	Aster	Molinia	Euphorbia	Eupatorium	Folder
18jun (M7)	BC2-18J-H4	BC2-18J-A4	BC2-18J-M4	BC2-18J-E4	-	BC2_2018
	BC2-18J-H5	BC2-18J-A5	BC2-18J-M5	BC2-18J-E5	-	
	BC2-18J-H6	BC2-18J-A6	BC2-18J-M6	BC2-18J-E6	-	
18nov (M12)	BC2-18N-H4	BC2-18N-A4	BC2-18N-M4	BC2-18N-E4	-	
	BC2-18N-H5	BC2-18N-A5	BC2-18N-M5	BC2-18N-E5	-	
	BC2-18N-H6	BC2-18N-A6	BC2-18N-M6	BC2-18N-E6	-	
19may (M18)	BC2-19M-H4	BC2-19M-A4	BC2-19M-M4	-	BC2-19M-E4	BC2_2019
	BC2-19M-H5	BC2-19M-A5	BC2-19M-M5	-	BC2-19M-E5	

19oct (M23)	BC2-19M-H6 BC2-19N-H4 BC2-19N-H5 BC2-19N-H6	BC2-19M-A6 BC2-19N-A4 BC2-19N-A5 BC2-19N-A6	BC2-19M-M6 BC2-19N-M4 BC2-19N-M5 BC2-19N-M6	- - - -	BC2-19M-E6 BC2-19N-E4 BC2-19N-E5 BC2-19N-E6	
20jun (M31)	BC2-20J-H4 BC2-20J-H5 BC2-20J-H6	BC2-20J-A4 BC2-20J-A5 BC2-20J-A6	BC2-20J-M4 BC2-20J-M5 BC2-20J-M6	- - -	BC2-20J-E4 BC2-20J-E5 BC2-20J-E6	BC2_2020

The folder en ttled "Biof lter condi tons" contains an Excel spreadsheet .ŀ2ŬfűŜẂψŎ2ẏŘŀə2ẏã͞ĚfăĚ, which contains the records of pressure heads, soil temperatures, and volumetric water contents in the biof lter. The f le contains data for both bioreten ton cells and is divided into two sheets, named BC1 and BC2. The pressure heads and soil temperatures were obtained from f ve tensiometers (T8_1-5), the loca tons of which are illustrated in Fig. 5. The pressure heads are expressed in cen tmeters, and temperatures in degrees Celsius. The height of the tensiometers' ceramic cups above the sand layer is recorded in an Excel spreadsheet. Furthermore, the f le contains volumetric water contents in cm^3 cm^{-3} from four TDR sensors located in the biof lter 15 cm above the sand layer. The data starts on April 19, 2018, and ended on June 18, 2020 and is recorded at 6-minute intervals. Missing values are indicated by empty cells.

4.1 Data example

Fig. 4 illustrates an example of a µCT image, featuring a plan view sec ton in Fig. 4a and a ver tcal sec ton in Fig. 4b. All µCT images were aligned and centered using the inner wall of the roller. Excess cuts at the top and bo tom edges of the specimens were removed as is shown in Fig. 4b. The uploaded dataset displays the individual f les of 3-D image scans in TIFF format as horizontal sec tons shown in Fig. 4a. The inner diameter of the roller corresponds to a size of 29 mm.



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5 EXPERIMENTAL DESIGN, MATERIALS AND METHODS

5.1 Experimental site

Two iden tcal experimental BCs were established at the premises of University Centre for Energy E f cient Buildings (UCEEB) of the Czech Technical University in Prague (CTU in Bustehrad, Czech Republic (50°9.41797'N, 14°10.19195'E, 355 m a.s.l.) in December 2017. Detailed descrip ton of the

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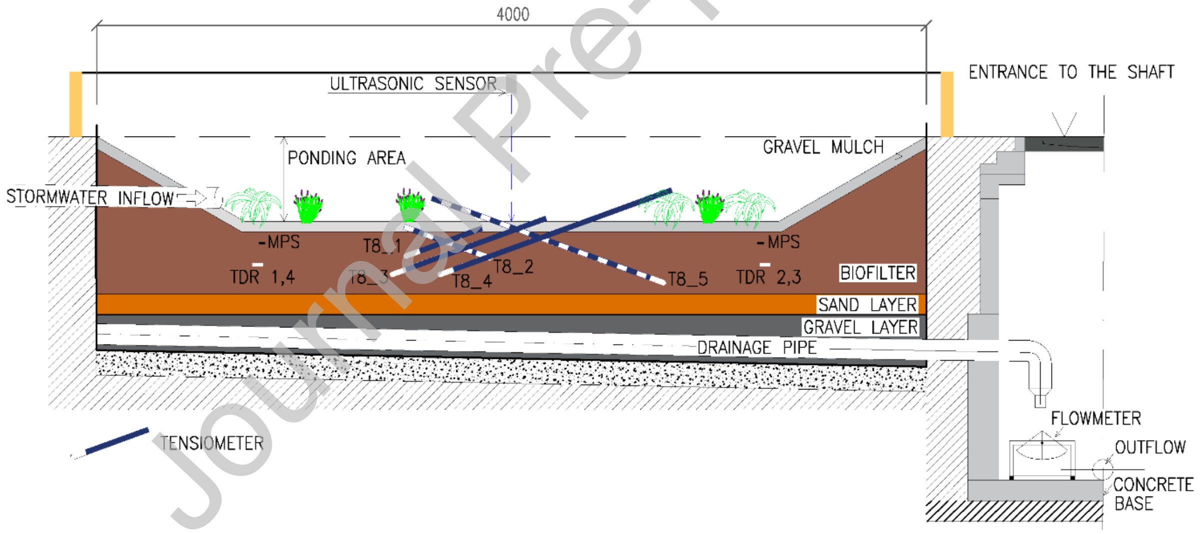
site is given by Snehota et al. (2021) [7] and Jelinkova et al. (2016) [8]. Positoned in a temperate region with an average annual rainfall of 500-550 mm and an average air temperature of 9 °C, these BCs were equipped for long-term monitoring, including evaluatng rainfall-runof characteristcs, assessing biofIter property development, and observing plant growth dynamics. The setup is extensively described in previous study [9]. Each BC spans 2.4 meters in width and 4.0 meters in length, featuring a top layer composed of a 5 cm thick layer of gravel fracton 16/32, functoning as a mulch layer to suppress weed growth and reduce evaporaton. Beneath this mulch layer lies a 30 cm thick biofIter, comprised of 50% sand, 30% compost, and 20% topsoil, with a specifc texture breakdown: 12% clay (<0.002 mm), 14% silt (0.002–0.05 mm), and 74% sand (0.05–2 mm). The biofIter's drainage layer, averaging 19 cm in thickness and made of gravel fracton 16/32, collects water, which is then directed to a drainage pipe. A 10 cm thick layer of sand (0/4 fracton) separates the biofIter and drainage layer to capture fne partcles, while a geotextle with a grammage of 200 g m^{-2} is inserted beneath the sand layer. The layers are shown in Fig. 5. The biofIter's fIling is isolated from surrounding soil by a PVC membrane. Each BC was initally planted with four perennial species, including *!ǎűŜǐ yƻØl·Ŝ-l·yƎťǐl·Ŝ* 'Purple Dome', *l ŜYŜǐƻŎl·ťťǐǎ* 'Lemon Bells', *9dzLJl·űƻǐǐdzY* 'Phantom', and *a ƻťǐyǐl· Ŏl·ŜǐdzťŜl·*. However, in spring 2019, *9dzLJl·űƻǐǐdzY* 'Phantom' replaced *9dzLJKƻǐōǐl· l·YèƎŘl·ťƻǐŘŜǎ* due to unsuitable conditons. The study related to this data paper commenced on 14/12/2017, by fnalized BC constructon and concluded on 18/06/2020 afer the fnal soil sample collecton.



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5.2 Water regime of biofIters

Throughout the 31-month duraton of the monitoring, the rain gauge recorded a total rainfall amount of 841 mm. During this study period, BC1 received a total normalized water input of 4347 mm, that sums the direct precipitaton at the bioretenton surface and rainfall concentrated from the roof. BC2, received a total normalized water input of 1779 mm, which accounts for rainfall directly received by the BC as well as water introduced during ponding irrigaton experiments.

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5.3 Soil sampling and µCT imaging

Intact soil samples, retrieved from the bioflter layer at fve distnct tme points spanning three consecutve years, commencing in 2018, were obtained from the surface layer of bioflter within a depth of 0-10 cm. Employing small aluminum cylinders with an inner diameter and height of 29 mm, the sampling process adhered to a schedule detailed in Table 3. Each tme sample collecton involved the acquisiton of three replicated samples from the vicinity of each four plant species for subsequent µCT analysis. With respect to sustainability of the experimental eforts the main consumable material were custom made aluminum rings, that were re-used throughout the study. Afer study, the rings are kept by our lab for similar studies in future or for recycling.

Subsequent analytcal procedures entailed saturatng the samples with water, followed by weighing and placement in a pressure extractor (Soil Moisture Equipment Corp., Goleta, CA) to atain a feld capacity value (at -330 hPa) before µCT imaging. Following the scanning, samples underwent drying and subsequent weighing, facilitatng the calculaton of porosity, bulk density of the dry sample, and water content at a pressure of -330 mbar for all scanned samples. Porosity calculatons employed a partcle density of the bioflter, set at 2563 kg m^{-3}.

The µCT imaging of samples took place across two research infrastructures upon the availability. Despite two µCT imager of diferent brands were used, both instruments were state-of-the-art industrial/research grade, ensuring comparable µCT imaging conditons. Samples from 2018 and 2019 underwent scanning at the Swedish University of Agricultural Sciences, Uppsala, utlizing a GE Phoenix industrial X-ray scanner. Conversely, samples from autumn 2020 were scanned at the Czech University of Life Sciences, Prague, employing a Nikon XT H 225ST. µCT imaging parameters except the resoluton remained consistent for both imaging instruments, with subsequent 3-D image processing conducted using dedicated sofware and exported for further analysis. All images underwent straightening and centering using the SoilJ [10] plugin within the ImageJ sofware [11]. The resoluton of all µCT images was 20 µm. The original images from June 2020 were scanned at 12 µm resoluton but were subsequently resampled to a uniform 20 µm resoluton so that all images have the same voxel size.

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Sampling campaign no.	Sampling campaign name	Sampling date	Number of months after BC foundation	Number of samples taken from each BC	µCT imaging facility	Date of µCT imaging
1	18jun	5.6. 2018	M7	12	SLU	11.11. - 14.11. 2018
2	18nov	1.11. 2018	M12	12		
3	19may	24.5. 2019	M18	12		11.11 – 14.11. 2019
4	19oct	15.10. 2019	M23	12		
5	20jun	18.6. 2020	M31	12	CZU	1.7. 2020

To provide beter clarity of the above procedure, a step-by-step summary of the protocol has been created in Table 4, summarizing the steps from sampling to the fnal editng of the images uploaded to the online repository.

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Step no.	Process	Description
1	Sample collection	Samples were collected in aluminum cylinders with a diameter and length of 2.9 mm
2	Storage of samples	Following collection, the samples were stored in a refrigerator until to µCT imaging
3	Sample preparation before µCT imaging	The samples were saturated in water for a minimum of 24 hours and then placed in a pressure extractor to attain a field capacity value - 330 mbar
4	Imaging	Type: GE Phoenix industrial X-ray scanner (2018,2019), Nikon XT H 225ST (2020) Tube voltage: 100 kV Current: 200 µm Average: 3 Images: 2000 Expose radiograph: 200 ms
5	Reconstruction	GE software Datos X (version 2.1) (2018,2019), VGSTUDIO MAX 2022.4 (2020)
6	Data export	Format: 16-bit with resolution 20 µm (2018, 2019) and 12µm (2020)
7	Image processing	The raw images were straightened and centered using the inside of the cylinder. From the raw images the horizontal slices extending above and below the upper and lower ends of the soil columns were removed from the 3D images. Use software: ImageJ, plugin SoilJ

5.4 Tips and recommenda t ons

The methodology of sampling into rela t vely small aluminum container proves to be correct in the current case of rela t vely uniform, stone-free Technosol. As visible from µCT images only thin band close to the sample walls was a f ected by sample collec t on. For more heterogeneous soils we would recommend larger sample rings to achieve su f cient reproducibility, however increasing of the sample size would lower the resolu t on of the images. It is always recommended that sampling be conducted under the comparable condi t ons.

If possible, use of the same instrumenta t on is recommended for imaging of all the data. However, this can be di f cult in long term studies. In order to conduct a subsequent µCT analysis, it is recommended that a computer with a RAM of at least 96 GB be used.

6 LIMITATIONS

The considerable size of the µCT image f les, averaging approximately 8 GB per three dimensional image imposes constraints on both processing capabili t es and storage capacity. Handling such large f les requires a robust computa t onal infrastructure, including powerful processors and ample memory resources. However modern PC with adequate RAM is su f cient for basic opera t on with the images. The two di f ferent resolu t ons of the original µCT images can be considered a minor limita t on but does not a f ect the processing or data quality. Another possible limita t on is disturbance of the soil during sampling process. However, the samples were taken with the utmost care and very limited disturbance is seen in the images.

ETHICS STATEMENT

Authors have read and follow the ethical requirements for publicaton in Data in Brief and confrming that the current work does not involve human subjects, animal experiments, or any data collected from social media platorms.

7 CRediT AUTHOR STATEMENT

Petra Heckova: Samples collecton, Data curaton, Original draf preparaton. Michal Snehota: Conceptualizaton, Methodology, Reviewing, Editng. John Koestel: µCT imaging, Reviewing, Editng. Ales Klement: µCT imaging Radka Kodesova: Reviewing, Editng.

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9 DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competng fnancial interests or personal relatonships that could have appeared to infuence the work reported in this paper.

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