Journal Pre-proof

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

Petra Marešová , John Koestel , Aleš Klement , Radka Kodešová , Michal Sněhota

Please cite this article as: Petra Marešová , John Koestel , Aleš Klement , Radka Kodešová , Michal Sněhota , A Dataset of μCT Images of Small Samples of Constructed Technosol from Bioretention Cells, *Data in Brief* (2024), doi: https://doi.org/10.1016/j.dib.2024.111066

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Data in Brief
Open access

Article template

1 ARTICLE INFORMATION

Article title

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

Authors

Petra Marešová[1,2], John Koestel[3,4], Aleš Klement[5], Radka Kodešová[5], Michal Sněhota[1,2]

Affiliations

[1]Czech Technical University in Prague, Faculty of Civil Engineering, 166 29 Prague, Czech Republic (petra.maresova@cvut.cz)

[2]Czech Technical University in Prague, University Centre for Energy Efficient Buildings, 273 43 Bustehrad, Czech Republic

[3]Agroscope, Standort Reckenholz, Soil Quality and Soil Use, 8046 Zurich, Switzerland

[4]Swedish University of Agricultural Sciences, Department of Soil and Environment, 750 07 Uppsala, Sweden

[5]Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, 165 00 Prague, Czech Republic

Corresponding author's email address and Twitter handle

petra.maresova@cvut.cz

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

system during early biofilter evolution, this extensive and high-quality dataset can be reused for further studies on constructed Technosol evolution, focusing on soil structure or hydraulic properties. It is particularly beneficial for research into macropore network development and changes in hydraulic properties in constructed soils. The dataset can support model validation and improve understanding of soil property variability in bioretention 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
Specific subject area	Datasets of CT images taken from constructed Technosol used in biofilter in two bioretention cells during 31 months
Type of data	3D images (.tiff files) Table (.xlsx format) Reconstructed 3D images of cylindrical samples, Straightened and centered
Data collection	Intact soil samples were collected from the biofilter 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 files at 20 and 12 µm resolution. Following completion of the imaging process, the physical characteristics 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 location	Institution: Czech Technical University in Prague - University Centre for Energy Efficient Buildings City/Town/Region: Bustehrad Country: Czech Republic Latitude 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: https://dataverse.harvard.edu/dataverse/CTimages [1]
Related research article	P. Heckova, J. Koestel, A. Klement, R. Kodesova, M. Snehota, Soil Structure Dynamics in Constructed Technosols for Bioretention Cells: X-Ray Microtomography Study, J Soils Sediments. (2024)

	https://doi.org/10.1007/s11368-024-03828-4 [2]

2   VALUE OF THE DATA

- The dataset captures detailed soil structure evolution in the biofilter of the bioretention cell over the initial 31 months after its construction 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 time-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 scientific inquiry.
- Researchers developing models of soil structure evolution can leverage this dataset to validate and refine their models. Models such as pore network models or the discrete element method can benefit from this data, as they allow to simulate soil structure dynamics and mechanical properties with high accuracy. The utilization of comprehensive time-series data derived from micro computed tomography (µCT) scans offers a robust foundation for hypothesis testing and the calibration of simulations.
- The majority of current models for the simulation of soil structure evolution were developed for use in agricultural soil. The dataset may be employed in the validation of these models for other soil types, such as constructed Technosols. It can also be used to characterize the hydraulic properties of these soils, such as water retention and permeability. In addition, the dataset allows for the study of soil organic matter, including its decomposition and stability within constructed Technosols.
- Dataset has the potential to contribute to understanding the temporal variability of constructed Technosol properties within bioretention systems, because the x-ray tomographs are accompanied by the environmental data. The findings can be employed in the design and optimization of sustainable drainage systems in urban environments.

3   BACKGROUND

The dataset comprises microcomputed tomography (µCT) images documenting the evolution of constructed Technosol soil over a 31-month period within the two bioretention cells (BC). Existing datasets do not provide such a comprehensive collection, and µCT scans predominantly focus on natural soils [3]. A BC is a landscaped depression with a constructed Technosol (biofilter) and vegetation, designed to manage stormwater runoff through accumulation, infiltration, treatment, and evapotranspiration [4]. The biofilter, plays a key role in the BC's functionality [5], although the long-term performance of BCs remain inadequately understood [6]. This dataset was compiled to support investigations on the soil structure dynamics in a biofilter and additional physical characterizations during the first years after installation under two different 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 article, the dataset was used to determine the metrics on macropore space geometry development in the context of changing hydraulic properties. The µCT image dataset can help to address the limitations

in models for soil structure evolution [6], leading to a better understanding of soil systems and improved prediction 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 schematic 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 characteristics. The datasets BC1 and BC2, respectively, contain 60 and 59 files, which are divided into three folders according to the sampling date. The files are in multiple slice TIFF format readable for example in ImageJ software. The number of files in each dataset is as follows: The datasets BC1_2018, BC1_2019, BC2_2018, and BC2_2019 contain 24 files (except for BC2_2018, which contains 23 files), while BC1_2020 and BC2_2020 contain 12 files. The two tables of soil characteristics and biofilter conditions includes data for all files from both BC1 and BC2.
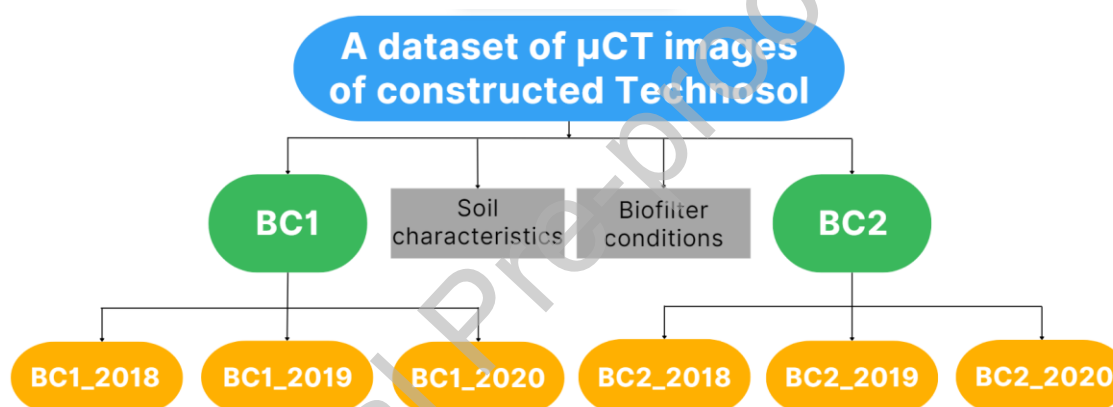

Fig. 1 Organization of μCT image folders

The size of each TIFF file ranges from 6 to 8.5 GB, with a total data volume for all images of 839 GB. The individual files are named according to the scheme shown in Fig. 2, which includes the name of bioretention cell, the sampling period, and the location (defined by plant species area) sampled.
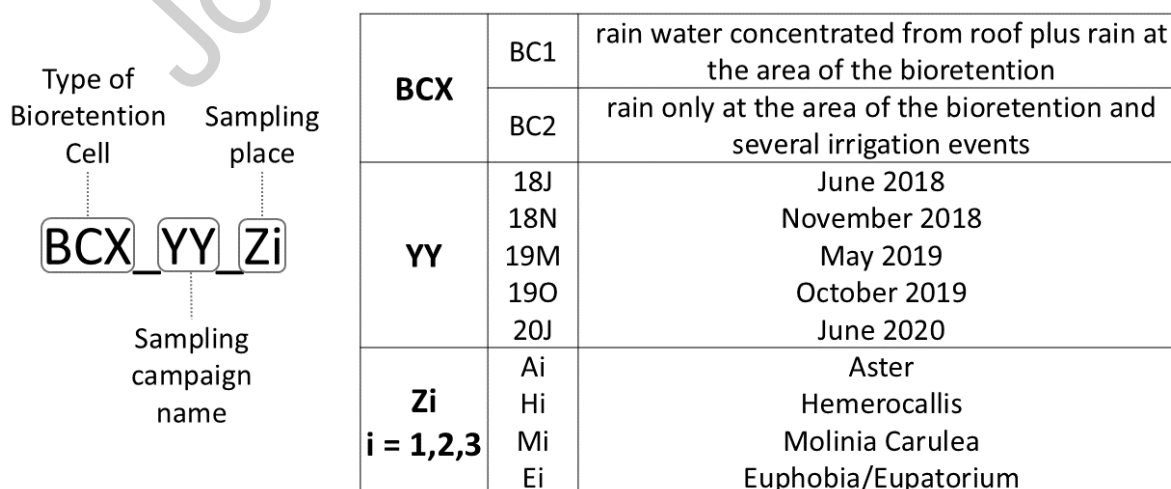

	BC1	rain water concentrated from roof plus rain at the area of the bioretention
BCX	BC2	rain only at the area of the bioretention and several irrigation events
	18J	June 2018
	18N	November 2018
YY	19M	May 2019
	19O	October 2019
	20J	June 2020
	Ai	Aster
Zi	Hi	Hemerocallis
i = 1,2,3	Mi	Molinia Carulea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

Fig. 2 Description of the name of the samples

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

Fig. 3 Timeline of the sampling campaigns names of dataset folders. The top row shows the number of months since the start of the experiment, the middle shows the sampling campaign name, the bottom row shows the name of the dataset folders.

A complete list of all filenames is shown in Tables 1 and 2. Additionally, the name of the folder in which the file is located is included in the table. The Excel spreadsheet *Soil_characteristics.xlsx* contains data on total porosity, dry bulk density, and field capacity. The values of these characteristics are provided for each file corresponding to the name given in Tables 1 and 2.

Table 1 Overview of samples taken in BC1

BC1	Hemerocallis	Aster	Molinia	Euphorbia	Eupatorium	Folder
18jun (M7)	BC1-18J-H1	BC1-18J-A1	BC1-18J-M1	BC1-18J-E1	-	
	BC1-18J-H2	BC1-18J-A2	BC1-18J-M2	BC1-18J-E2	-	
	BC1-18J-H3	BC1-18J-A3	BC1-18J-M3	BC1-18J-E3	-	BC1_2018
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	
	BC1-19M-H2	BC1-19M-A2	BC1-19M-M2	-	BC1-19M-E2	
	BC1-19M-H3	BC1-19M-A3	BC1-19M-M3	-	BC1-19M-E3	BC1_2019
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	
	BC1-20J-H2	BC1-20J-A2	BC1-20J-M2	-	BC1-20J-E2	BC1_2020
	BC1-20J-H3	BC1-20J-A3	BC1-20J-M3	-	BC1-20J-E3	

The Excel spreadsheet *Soil_characteristics.xlsx* is located in a separate folder, entitled "Physical characteristics of soil samples".

Table 2 Overview of samples taken in BC2

BC2	Hemerocallis	Aster	Molinia	Euphorbia	Eupatorium	Folder
18jun (M7)	BC2-18J-H4	BC2-18J-A4	BC2-18J-M4	BC2-18J-E4	-	
	BC2-18J-H5	BC2-18J-A5	BC2-18J-M5	BC2-18J-E5	-	
	BC2-18J-H6	BC2-18J-A6	BC2-18J-M6	BC2-18J-E6	-	BC2_2018
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	BC2-19M-A6	BC2-19M-M6	-	BC2-19M-E6	
	BC2-19N-H4	BC2-19N-A4	BC2-19N-M4	-	BC2-19N-E4	
	BC2-19N-H5	BC2-19N-A5	BC2-19N-M5	-	BC2-19N-E5	
	BC2-19N-H6	BC2-19N-A6	BC2-19N-M6	-	BC2-19N-E6	
20jun (M31)	BC2-20J-H4	BC2-20J-A4	BC2-20J-M4	-	BC2-20J-E4	
	BC2-20J-H5	BC2-20J-A5	BC2-20J-M5	-	BC2-20J-E5	BC2_2020
	BC2-20J-H6	BC2-20J-A6	BC2-20J-M6	-	BC2-20J-E6	

The folder entitled "Biofilter conditions" contains an Excel spreadsheet *Biofilter_conditions.xlsx*, which contains the records of pressure heads, soil temperatures, and volumetric water contents in the biofilter. The file contains data for both bioretention cells and is divided into two sheets, named BC1 and BC2. The pressure heads and soil temperatures were obtained from five tensiometers (T8_1-5), the locations of which are illustrated in Fig. 5. The pressure heads are expressed in centimeters, and temperatures in degrees Celsius. The height of the tensiometers' ceramic cups above the sand layer is recorded in an Excel spreadsheet. Furthermore, the file contains volumetric water contents in $cm^3 \, cm^{-3}$ from four TDR sensors located in the biofilter 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 section in Fig. 4a and a vertical section in Fig. 4b. All µCT images were aligned and centered using the inner wall of the roller. Excess cuts at the top and bottom edges of the specimens were removed as is shown in Fig. 4b. The uploaded dataset displays the individual files of 3-D image scans in TIFF format as horizontal sections shown in Fig. 4a. The inner diameter of the roller corresponds to a size of 29 mm.
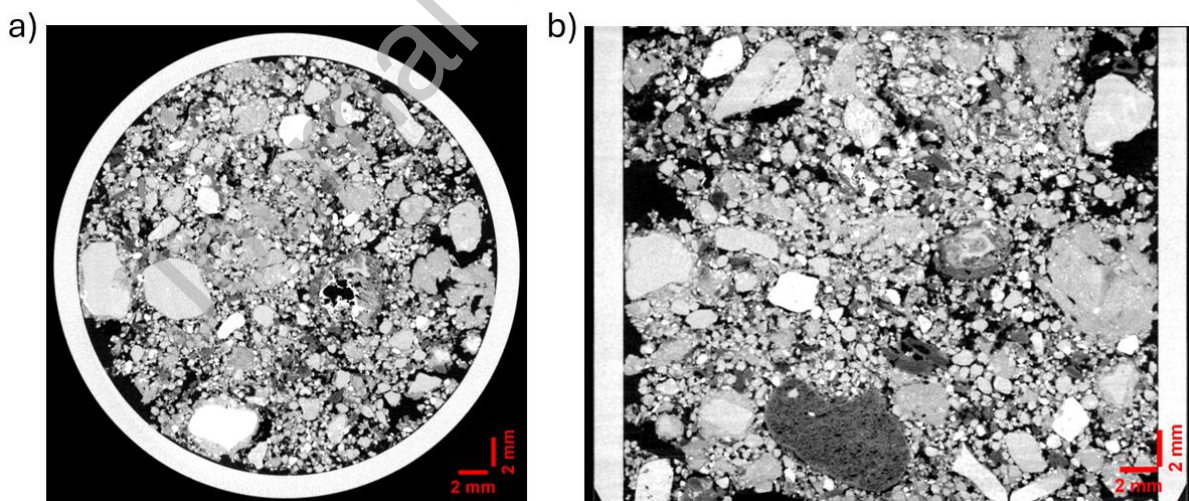

Fig. 4 a) µCT scan shows horizontal section of the sample b) µCT scan shows vertical section of the sample

5 EXPERIMENTAL DESIGN, MATERIALS AND METHODS

5.1 Experimental site

Two identical experimental BCs were established at the premises of University Centre for Energy Efficient 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 description of the

site is given by Snehota et al. (2021) [7] and Jelinkova et al. (2016) [8]. Positioned 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 evaluating rainfall-runoff characteristics, assessing biofilter 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 fraction 16/32, functioning as a mulch layer to suppress weed growth and reduce evaporation. Beneath this mulch layer lies a 30 cm thick biofilter, comprised of 50% sand, 30% compost, and 20% topsoil, with a specific texture breakdown: 12% clay (<0.002 mm), 14% silt (0.002–0.05 mm), and 74% sand (0.05–2 mm). The biofilter's drainage layer, averaging 19 cm in thickness and made of gravel fraction 16/32, collects water, which is then directed to a drainage pipe. A 10 cm thick layer of sand (0/4 fraction) separates the biofilter and drainage layer to capture fine particles, while a geotextile with a grammage of 200 g m^{-2} is inserted beneath the sand layer. The layers are shown in Fig. 5. The biofilter's filling is isolated from surrounding soil by a PVC membrane. Each BC was initially planted with four perennial species, including *Aster novae-angliae* 'Purple Dome', *Hemerocallis* 'Lemon Bells', *Eupatorium* 'Phantom', and *Molinia caerulea*. However, in spring 2019, *Eupatorium* 'Phantom' replaced *Euphorbia amygdaloides* due to unsuitable conditions. The study related to this data paper commenced on 14/12/2017, by finalized BC construction and concluded on 18/06/2020 after the final soil sample collection.
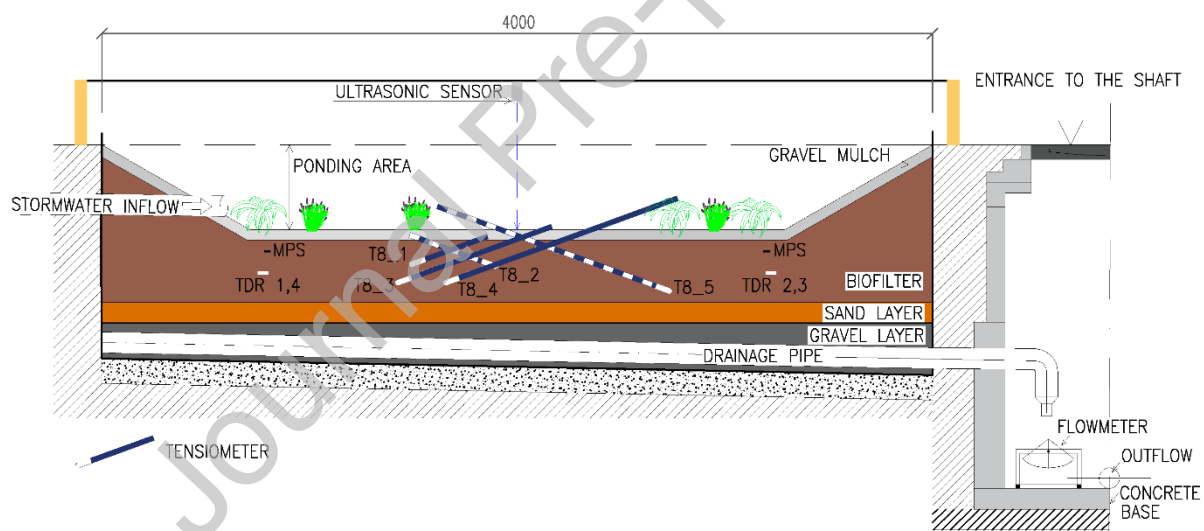

Fig. 5 Longitudinal section of a bioretention cell [9]. Adapted from Journal of Hydrology and Hydromechanics, with permission

5.2   Water regime of biofilters

Throughout the 31-month duration 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 precipitation at the bioretention 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 irrigation experiments.

5.3 Soil sampling and µCT imaging

Intact soil samples, retrieved from the biofilter layer at five distinct time points spanning three consecutive years, commencing in 2018, were obtained from the surface layer of biofilter 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 time sample collection involved the acquisition of three replicated samples from the vicinity of each four plant species for subsequent µCT analysis. With respect to sustainability of the experimental efforts the main consumable material were custom made aluminum rings, that were re-used throughout the study. After study, the rings are kept by our lab for similar studies in future or for recycling.

Subsequent analytical procedures entailed saturating the samples with water, followed by weighing and placement in a pressure extractor (Soil Moisture Equipment Corp., Goleta, CA) to attain a field capacity value (at -330 hPa) before µCT imaging. Following the scanning, samples underwent drying and subsequent weighing, facilitating the calculation of porosity, bulk density of the dry sample, and water content at a pressure of -330 mbar for all scanned samples. Porosity calculations employed a particle density of the biofilter, 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 different brands were used, both instruments were state-of-the-art industrial/research grade, ensuring comparable µCT imaging conditions. Samples from 2018 and 2019 underwent scanning at the Swedish University of Agricultural Sciences, Uppsala, utilizing 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 resolution remained consistent for both imaging instruments, with subsequent 3-D image processing conducted using dedicated software and exported for further analysis. All images underwent straightening and centering using the SoilJ [10] plugin within the ImageJ software [11]. The resolution of all µCT images was 20 µm. The original images from June 2020 were scanned at 12 µm resolution but were subsequently resampled to a uniform 20 µm resolution so that all images have the same voxel size.

Table 3 Detailed description of sampling and µCT imaging

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 better 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 final editing of the images uploaded to the online repository.

Table 4 Step-by-step protocol of the experimental process

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 recommendations

The methodology of sampling into relatively small aluminum container proves to be correct in the current case of relatively uniform, stone-free Technosol. As visible from µCT images only thin band close to the sample walls was affected by sample collection. For more heterogeneous soils we would recommend larger sample rings to achieve sufficient reproducibility, however increasing of the sample size would lower the resolution of the images. It is always recommended that sampling be conducted under the comparable conditions.

If possible, use of the same instrumentation is recommended for imaging of all the data. However, this can be difficult 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 files, averaging approximately 8 GB per three dimensional image imposes constraints on both processing capabilities and storage capacity. Handling such large files requires a robust computational infrastructure, including powerful processors and ample memory resources. However modern PC with adequate RAM is sufficient for basic operation with the images. The two different resolutions of the original µCT images can be considered a minor limitation but does not affect the processing or data quality. Another possible limitation 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

Data in Brief
Open access

Article template

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

7 CRediT AUTHOR STATEMENT

Petra Heckova: Samples collection, Data curation, Original draft preparation. **Michal Snehota:** Conceptualization, Methodology, Reviewing, Editing. **John Koestel:** µCT imaging, Reviewing, Editing. **Ales Klement:** µCT imaging **Radka Kodesova:** Reviewing, Editing.

8 ACKNOWLEDGEMENTS

9 DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

10 REFERENCES

[1] P. Heckova, A dataset of µCT images of constructed Technosol, (2024). https://dataverse.harvard.edu/dataverse/CTimages (accessed June 18, 2024).

[2] P. Heckova, J. Koestel, A. Klement, R. Kodesova, M. Snehota, Soil structure dynamics in constructed Technosols for bioretention cells: X-ray microtomography study, J. Soils Sediments (2024). https://doi.org/10.1007/s11368-024-03828-4.

[3] U. Weller, L. Albrecht, S. Schlüter, H.-J. Vogel, An open *Soil Structure Library* based on X-ray CT data, SOIL 8 (2022) 507–515. https://doi.org/10.5194/soil-8-507-2022.

[4] M.E. Dietz, J.C. Clausen, A field evaluation of rain garden flow and pollutant treatment, Water. Air. Soil Pollut. 167 (2005) 123–138. https://doi.org/10.1007/s11270-005-8266-8.

[5] G. Séré, C. Schwartz, S. Ouvrard, J.-C. Renat, F. Watteau, G. Villemin, J.-L. Morel, Early pedogenic evolution of constructed Technosols, J. Soils Sediments 10 (2010) 1246–1254. https://doi.org/10.1007/s11368-010-0206-6.

[6] S. Coustumer, T. Fletcher, A. Deletic, S. Barraud, J. Lewis, Hydraulic performance of biofilter systems for stormwater management: Influences of design and operation, J. Hydrol. 376 (2009) 16–23. https://doi.org/10.1016/j.jhydrol.2009.07.012.

[7] P. Chandrasekhar, J. Kreiselmeier, A. Schwen, T. Weninger, S. Julich, K.-H. Feger, K. Schwärzel, Modeling the evolution of soil structural pore space in agricultural soils following tillage, Geoderma 353 (2019) 401–414. https://doi.org/10.1016/j.geoderma.2019.07.017.

[8] M. Snehota, J. Hanzlíková, M. Sobotkova, P. Moravcik, Water and thermal regime of extensive green roof test beds planted with sedum cuttings and sedum carpets, J. Soils Sediments (2021). https://doi.org/10.1007/s11368-020-02778-x.

[9] V. Jelinkova, M. Dohnal, T. Picek, A green roof segment for monitoring the hydrological and thermal behaviour of anthropogenic soil systems, Soil Water Res. 10 (2015) 262–270. https://doi.org/10.17221/17/2015-SWR.

[10] P. Heckova, V. Bareš, D. Stránský, M. Sněhota, Performance of experimental bioretention cells during the first year of operation, J. Hydrol. Hydromech. 70 (2022) 42–61. https://doi.org/10.2478/johh-2021-0038.

[11] J. Koestel, SoilJ: An ImageJ Plugin for the Semiautomatic Processing of Three-Dimensional X-ray Images of Soils, Vadose Zone J. 17 (2018). https://doi.org/10.2136/vzj2017.03.0062.

[12] J. Schindelin, I. Arganda-Carreras, E. Frise, V. Kaynig, M. Longair, T. Pietzsch, S. Preibisch, C. Rueden, S. Saalfeld, B. Schmid, J.-Y. Tinevez, D.J. White, V. Hartenstein, K. Eliceiri, P. Tomancak, A. Cardona, Fiji: an open-source platform for biological-image analysis, Nat. Methods 9 (2012) 676–682. https://doi.org/10.1038/nmeth.2019.