Ohio's Professional Soil Scientists

2021 Spring Newsletter
Volume 48, Issue 1 Part 2

Journal Articles etc. of note

A Smithsonian Magazine contribution from Jerry Bigham for all to enjoy. My daughter Susan uses a similar technique to make the glazes for her ceramic pieces.

Meet the Soil Scientists Using Dirt to Make Stunning Paints

In September, as wildfire raged in Medicine Bow National Forest, Karen Vaughan watched smoke billow in a choked-off Wyoming sky. The sun was reduced to a matte neon-pink disc behind the haze, and Vaughan worried about her research site in the burning mountains. One of her graduate students still had one more day of fieldwork to complete, and the roads would soon be closed, if they weren't already. Vaughan's family—her husband and two kids—were outside too, watching as a light gray layer of wind-blown ash settled onto the landscape. The ash and vivid colors sparked something in Vaughan, who continually sought new inspiration for the paint she makes. She began dashing around, scraping the sediment from every flat surface and encouraging her kids to help collect the fine powder. She decided to incorporate that ash into watercolor pigments with hues reflecting the fire, indelibly preserving the moment. The small batch of paints, distributed to friends and local artists, would be used to create depictions of the destructive forces that allowed their creation in the first place. "You're breathing that air, even in your house, and you look outside and see that weird orange glow," says Vaughan. "You couldn't help but be a part of that."

A soil scientist and a professor at the University of Wyoming, Vaughan sees a lot more soils than the average person, and certainly knows them more intimately. Over many years spent examining them, she has come to appreciate their natural beauty and immense variability. Two years ago, she began channeling that appreciation into a product she could share with the world, turning the soils she loved into watercolor pigments. Now, she and her collaborator, Yamina Pressler, a soil scientist at California Polytechnic University, use soils to make pigments and paintings, bridging the gap between science and art. By sharing both their creative processes and scientific knowledge on social media and connecting with artists, scientists and the public, they aim to make soil education entertaining.

Vaughan's research is in pedology, which means she studies minute, subtle changes within a soil. Does the size of the grains change? Do the colors fade into each other or get cut off abruptly? What microorganisms are present at different levels in the soil? The very nature of her field, she says, is subjective. "It is an art form," she says. "It takes a nuanced eye to really be able to see the changes within a soil."

Her job requires her to hop in a deep hole, map out tiny changes few people notice and interpret the soil's history. Her specialty is studying water in soils: How much is there? When is it present? How does it change the soil's chemistry? What features does it leave behind? Her work helps us understand how soils form in unique environments, like wetlands in the otherwise arid Wyoming mountains, and how fragile soils like permafrost might respond to climate change.

To the uninitiated, the landscape of Wyoming might seem like a monotonous stretch of tan dirt. But that idea is exactly what Vaughan is trying to change through her art. By explaining to artists and curious laypeople how the myriad hues in soils come to be and sharing them visually through both her own creative works and those by other artists, she hopes to give people the ability to see soil as more than "just dirt."

Soils, paints and swatches from samples collected throughout Wyoming and Utah allow a glimpse at the belowground natural beauty of the western United States. (Karen Vaughan)

"Sometimes art opens the door to people wanting to learn about science, "says Laura Guerin, a geology professor at Pennsylvania State—Brandywine. Guerin too has brought art into science, both for her classrooms and her communities, by crocheting temperature records and quilting climate change stories. "Using different perspectives to introduce a topic, like soil, can help people understand and connect with it a little more."

Soil is often overlooked in basic geology classes, says Guerin, and understanding how it works and where it comes from is important. “Without soil, you don’t have the rest of Earth’s systems,” she says. “It’s such a fundamental material; it’s the basis of our food systems.” And society’s indifference to soil led to the Dust Bowl, one of the greatest environmental disasters in the history of the United States. “With my students, I talk about the Dust Bowl and how it was a loss of soil that triggered a chain reaction, impacting a broad cross-section of society,” says Guerin.

Vaughan began making pigments as a fun way to engage with her kids, now ages 7 and 9, and keep them away from screens. They come soil collecting with her, and occasionally help mix the pigments and paint. But the main reason she makes pigments now is to share her perspective on soils’ inherent beauty with the public. “I found all these amazing soil colors,” Vaughan says, “and I wanted to do something more with them. I wanted them to persist longer.”

She recognized that by making paints she could share science with people who lack her expert training. “Spending all that time as a pedologist looking at soil formation and thinking about how much the colors of the soil can tell us about the natural history of that area, I wanted to let people in, open their eyes a little bit,” she says.

Vaughan collects soils for pigments almost everywhere she goes, from dirt collected in a wetland study site high in the mountains to coal unearthed in her backyard. On a family road trip to Florida in a campervan, for instance, she grabbed a small bag of soil from every stop, with the intent of creating a palette that reflects that memory. One dull pandemic day, she and her kids took to their bikes on a scavenger hunt near her home for as many colors of the rainbow that they could find. It was a change of pace for Vaughan, who is normally more opportunistic than intentional in her soil collecting. She made a palette of red, brown, orange, white, yellow and purple to represent that effort. And, of course, she has the three-hue palette from the September wildfire, corners of which were still smoldering away when we spoke in November.

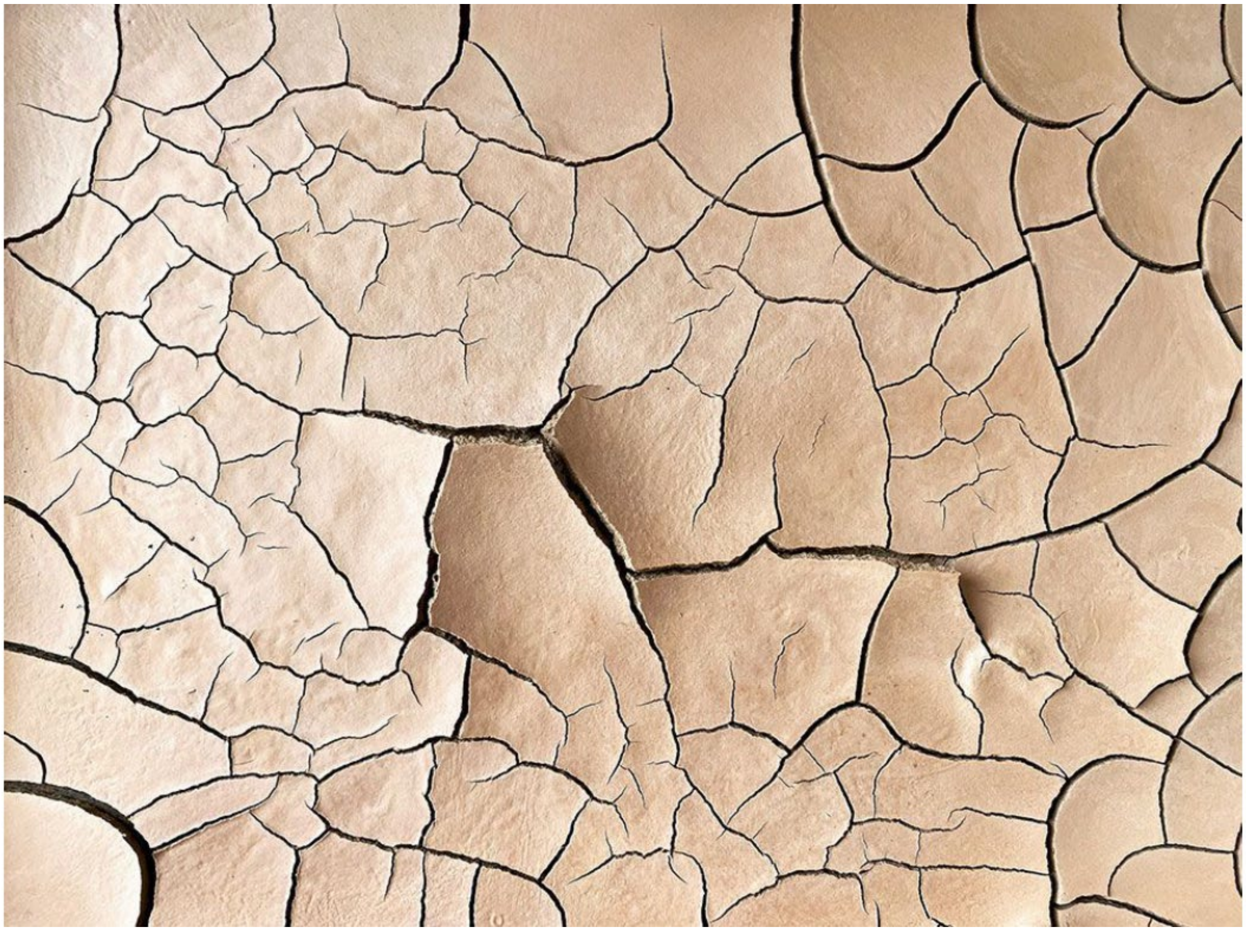
Because it was just a small batch, Vaughan distributed the ash-infused pigments to local artists and a few select clients to create works reflecting the wildfires. California artist Tina Pressler, Yamina’s mother, painted a patchwork American bison, the West’s once-ubiquitous megafauna, and Bethann Merkle, a Wyoming artist and science communicator, created a series of three abstract paintings of fire-wrought forest textures. The ash infused pigments felt fluid and heavy, says Tina. “The addition of ash made it seem really tactile, in a way, and I loved it.”

Artist Tina Pressler used pigments made of ancient Wyoming soils and recent ash to paint this bison, which she says "represents a visual amalgamation of flora and fauna over time." (Tina Pressler)

"I've long had a fondness for rocks—my windowsills are piled up with them at home and at work—but [Vaughan's] work and pigments have helped me expand that curiosity and appreciation to the soil," says Merkle.

Before Vaughan began sharing her pigments with artists, she had to spend some time getting the day-long pigment-making process down. It took her a few tries: "My first pigments," she says with a laugh, "were chunky and terrible. But I gave them away with a disclaimer."

In the first step of her process, Vaughan removes the sandy portions of the soil, leaving only fine silts and clays mixed in water, which she then pours into a cookie sheet and bakes in the oven for a few hours. After all the water has evaporated, the soil appears cracked and desiccated, like a mudflat after a long summer drought. "Look, mom, it's all wrinkly like you," her daughter once helpfully said. Vaughan grinds the baked silt into a fine, homogenous powder. Then comes Vaughan's most meditative step: mulling, or combining the soil with the watercolor medium— a mixture of water, gum arabic, honey and vegetable glycerin. Only then does she get a sense for what the final hue will be. "You might start with an amazing green soil that, all of a sudden, becomes this dull, greenish white. And that's okay," Vaughan says. "It's always a color I've never made before, so I'm thrilled."



After Vaughan bakes the pigment, cracks appear that reflect patterns seen throughout nature—such as in this ancient orange soil pigment collected in the Red Desert of Wyoming. (Karen Vaughan)

The colors of the paint come straight from the soil's geologic past: Bright reds and oranges mean the soils were exposed to the oxidizing effects of intense climates, long stretches of time or both. Dark browns and blacks represent rich organic matter, reflecting the cycle of life and death at the Earth's surface. Brighter hues result from minerals with specific elements; the presence of copper lends minerals blue-green colors, sulfur creates vibrant yellows and manganese presents as faded purple. Stark whites could mean acid once trickled down through the soil from a pine copse, or that ash once settled over the landscape, like that which Vaughan collected in September.

"Everything has a story," Guertin says. "What's been here in the past? Where do these colors come from? Where do these materials come from that give us these colors? I love that [Vaughan is] taking the soil science and showing how you can break it down to materials, to these pigments that have cultural meaning and to painting, which people already have a familiarity with."

Vaughan describes her soil collecting, her artistic process and the science of each soil on Instagram, where she answers questions about chemistry, location and geology. Sometimes

artists send in questions about the science of pigment-making itself, but many are just interested in learning more about the natural world. Depending on how much detail people want, she'll even send along some scientific papers in a private message. Because so many of her clients are interested in learning about the soils,
Vaughan is planning to start including a "soil story" with each palette shipped out.
Vaughan's connections with artists sometimes grow from the virtual world to working together in person.

Diana Baumbach, a Wyoming artist who Vaughan collaborated with a few years ago, loved going into the field with the scientist to forage for natural materials, including soil. "I really hadn't thought about soil or considered it as a material before," Baumbach said.
"Looking at soil profiles with [Vaughan] was totally new for me. We both pulled each other into our worlds, which I thought were quite different. In the end, it was surprising how many intersections there actually were between my work and her work."
While Vaughan does paint with her pigments, she doesn't typically share her work; she leaves that to the younger Pressler, for whom painting has become a public affair. Growing up with an artist mother, Pressler says, meant that art was always in the background. "But it wasn't until I started painting soils that I began to embody being an artist as part of my identity."

Created during a soil art live stream on Instagram, this piece by Yamina Pressler is painted on post-card paper as a reminder that the beauty of soils is meant to be shared far and wide. (Yamina Pressler)

Pressler also connects with an interested audience through social media. She hosts live paint-along sessions in her 'virtual soil art studio' on Instagram, inviting participants of all backgrounds to create soil-focused art inspired by where they live. These two-hour public sessions are open to children and adults, scientists and laypeople.

Tatiana Prestininzi, who has a bachelor's in agricultural science but never cared much for soil science, now brings her young niece and nephew to Pressler's paint-along sessions. "It's not only from the artistic side, but we're also getting the educational side of things," she says. "It's not just the 15-to-30-somethings on Instagram, she's got 7 and 5-year-olds learning about soil profiles… so now I can go hike around San Diego with my eight year-old niece and have a conversation about the soils she sees. She'll ask to paint it and send it to the 'soil doctor.'"

Through Vaughan's art outreach and Pressler's educational outreach, the scientists aim to inspire in the public the feelings children have while digging in the dirt and wondering at the world around them. Vaughan's process of finding soils for pigments has a sense of play that is really infectious, says Baumbach. And while Pressler does draw soils realistically, she's more drawn to whimsical doodles that reflect her feelings towards soil, which she shares on her Instagram sessions, along with the science stories behind them.

Yamina Pressler's painting "Mojave Dreaming 28" was inspired by the unexpected winter tones of the Mojavedesert. (Yamina Pressler)

Tapping into her artistic side has helped Vaughan re-imagine what college soil science classes can be. She has her students sketch frequently, and she occasionally has them paint with soils. Her collaboration with Baumbach led the pair to cross-pollinate art and science further, with Baumbach bringing her art students to Vaughan's science labs to talk about color and Vaughan giving guest lectures in Baumbach's art materials courses. "Really, basic things like observation and analysis are at the core of what we both do, and we're communicating through materials and visual forms," Baumbach says. "The students are just starting to think broadly about materials, so hearing Karen talk about soils as a raw material is really interesting for them."

In addition to giving talks about soil science and life as a researcher at K-12 schools and museums, Pressler works directly with teachers, taking them into the field and lab so they can get firsthand experience with soils. "They can then go back to their students and talk about soils and ecology, and the process of science, from their perspective," says Pressler. "It's more meaningful to the students that way."
Michelle Bartholomew, a middle- and high-school science teacher, jumped at the chance to head into the field with Pressler in Colorado and Alaska.

They developed soil science classes together, did some drawing and studied soils. "That was the highlight of my time with her, working on those tundra soils," Bartholomew says. "It's *doing* science, you know? Even though we're science teachers, we don't get to do that. It rejuvenated me…and gave me new ways of teaching old concepts."

Artist Bethann Merkle, who has worked with scientist Karen Vaughan for two years, used soil pigments created from a burned area to paint scenes of the charred landscape. (Bethann Merkle)

Pressler and Vaughan also believe in the importance of being role models who break out of the compartmentalization so common in science today.

“It’s about showing young people that there are lots of different ways to be a scientist,” Pressler says, “that you can be colorful and explore different parts of your curiosity and still be a scientist.”

“We used to be Renaissance people,” Vaughan says. “Now it’s, ‘You need to stay in your box so you can do well at that.’ I feel like we've almost made it okay to be artistic while also being a scientist.”

And another article about soils from Nathan Wright

A review of the world’s soil museums and exhibitions

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Advances in Agronomy # 2020 Elsevier Inc.

https://doi.org/10.1016/bs.agron.2020.10.003

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Contents

Abstract

The soil science community needs to communicate about soils and the use of soil information to various audiences, especially to the general public and public authorities. In this global review article, we synthesis information pertaining to museums solely dedicated to soils or which contain a permanent exhibition on soils. We identified 38 soil museums specifically dedicated to soils, 34 permanent soil exhibitions, and 32 collections about soils that are accessible by appointment. We evaluate the growth of the number of museums since the early 1900s, their geographical distribution, their contents, and their attendance. The number of museums has been continuously growing since the early 1900s. A noticeable increase was observed from 2015 to 2019. Europe (in a geographical sense), Eastern and South-East Asia have the highest concentration of soil museums and permanent exhibitions related to soils. Most of the museums' attendance ranged from 1000 to 10,000 visitors per year. Russia has the largest number of soil monoliths exhibited across the world's museums, whereas the ISRIC-World Soil Museum has the richest and the most diverse collection of soil monoliths. Museums, collections, and exhibitions of soil play an important role in educating the population about this finite natural resource that maintains life on the planet, and for this reason, they must be increasingly supported, extended, and protected.

1. Introduction

The interest in and concern about soils is increasing among the general population, and this increase is largely related to concerns about environmental quality, food quality, and human health (Brevik and Burgess, 2014). Quite importantly, this interest is consumer driven and requires an adequate response from science to satisfy this curiosity. One of the means to present a soil and its part in the history of the Earth and function in modern society is a museum, which can combine in one place information and other items scattered over the surface of the planet.

A museum may be defined as an institution in which collections of objects of historical, technical, scientific, and artistic interest are collected and classified for preservation and presentation to the public. A museum is a cultural entity representing a community in order to make it known (Tahriri and Ghaedi, 2016). Museums are classified based on the type of collection that they specialize in and can range from museums that house a specific type of collection (e.g., a museum of pottery) to general museums
(e.g., national museums) that house different types of collections. Some of the most important functions of a museum are to promote a section of science or culture to educate the public and to communicate information.

As with other disciplines in science, the soil science community needs to communicate on soils and on soil information to various audiences (especially to the general public and public authorities). Among the dimensions of the concept of "soil security" (Bennett et al., 2019; Koch et al., 2014; McBratney et al., 2013; Richer-de-Forges et al., 2019a), the development of "connectivity," which encompasses the relationship that societal actors have with soil, is recognized as a priority to bridge the gap and to ensure the interface between soil science and society is maintained (Richer-de-Forges et al., 2019b). Connectivity also encompasses soil knowledge, education, training, and awareness. Indeed, the proportion of the population of urban origin is constantly increasing. Currently, 53% of the world's population is urban, and it is expected to reach 65% in 2050. As a result, this population is generally becoming less connected with their natural environment, and particularly with the soil. Societal perceptions and understanding of soil and its many functions are therefore diminishing. Yet, soils are at the center of many global concerns such as food security, water security, climate change adaptations and mitigation, biodiversity protection, soil and water quality and degradation, and human health (e.g., Amundson et al., 2015; McBratney et al., 2013). The transfer of soil knowledge to the general public has therefore become a major challenge for communication about the necessity to securing soils (Amundson et al., 2015; Montanarella et al., 2016) and the ecosystem services they render (e.g., Dominati et al., 2010; Turner et al., 2016). Therefore, it is natural and sensible for the soil science community to provide museums on soils and their functioning, applications, and pivotal role in civilization throughout history (e.g., Churchman and Landa, 2014; Hillel, 1991; Minami, 2009).
We wanted to know how the soil museums, exhibitions, and collections around the world are organized and what they offer to the public. Thus, we provide an analysis of the world's museums dedicated only to soils or museums containing a permanent exhibition on soils.

2. Methods

Initial research on the internet identified approximately 30 museums specific to soil or that had a permanent exhibition on soil and led to compilation of a first contact list. This first contact list was used to obtain information on these museums. It also enhanced the number of contacts we had acquired because museums are more or less familiar with each other; thus, we were able to provide extra names to make further inquiries. A file listing the museums was shared to collect as much information as possible about the content of museums and their attendance rate.
We identified 38 soil museums worldwide specifically dedicated to soils, 34 permanent exhibitions, 32 collections accessible by appointment (Fig. 1), and 3 virtual museums specific to soils. Soil collections accessible by appointment were more difficult to add to our inventory. Many universities or soil research centers had accessible soil collections that could be visited only by appointment. We merged open-air museums (e.g., those in South Africa or Tanzania) with permanent exhibitions housed indoors.

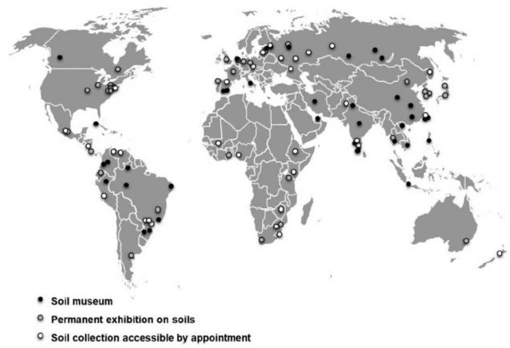

Fig. 1 Worldwide locations of types of soil museums, exhibitions, and collections.

3. Results

3.1 Geographic distribution

The geographical distribution of soil museums around the world is very irregular. Few museums exist in Africa, and they are atypical because three of them are open-air museums. Oceania, Central America, and most of the countries in the Middle East have few museums on soils. All the continents, however, have at least two soil museums or permanent exhibitions. Europe (in a geographical sense), Eastern and South-East Asia have the highest concentration of soil museums and permanent exhibitions related to soils (Fig. 1). Table 1 lists soil-specific museums, Table 2 lists the permanent exhibitions on soils, and Table 3 lists the collections accessible by appointment.

We posit that these tables may interest the readers who would want to visit them, and it provides the readers the “corpus” on which we based our paper. If we overlooked a museum or exhibition, readers may alert us.

Table 1 List of soil-specific museums.

Name	Country/Region	City	Website
Museu de Solos do Estado de Roraima	Brazil	Boa Vista	http://ufrr.br/museusolos/index.php?option=com_content&view=category&layout=blog&id=18&Itemid=272
Museu de Solos do Rio Grande do Sul	Brazil	Santa Maria	http://w3.ufsm.br/msrs/
Museu de Solos do Amazonas (Amazonas Soil Museum)	Brazil	Humaitá	No website
Reference Soils of Pernambuco-Brazil (UFPE)	Brazil	Recife	http://www.colecaomateusrosas.com.br
Museu de Solos do Brasil (Brazilian Soil Museum)	Brazil	Rio de Janeiro	https://www.msbufrrj.org/
Museu de solos de Santa Catarina (Santa Catarina Soil Museum)	Brazil	Lages	No website
Soil Science Collection of the University of Alberta Museum	Canada	Edmonton	https://www.ualberta.ca/museums/museum-collections/soil-sciences-collection
Guangdong Museum of Soil Science	China	Guangzhou	http://www.soil.gd.cn/document.action?docid=57420
Soil Museum of Northwest A&F University	China	Xi-an	https://www.travelchinaguide.com/cityguides/shaanxi/xianyang/nwafu-garden.htm
Institute of Soil Science	China	Nanjing	No website
Museo Nacional de Suelos	Colombia	Bogotá	https://www.igac.gov.co/es/contenido/areas-estrategicas/agrologia/museo-de-suelos
Museo de Suelos Ciro Molina Garcés	Colombia	Palmira	http://circular.unal.edu.co/museumlist/detail/detail/News/museo-de-suelos/ http://www.palmira.unal.edu.co/index.php/lasede/recursos
Instituto nacional de investigaciones de la caña de azúcar cuba—INICA	Cuba	Havana	No website
Estonian Soil Museum	Estonia	Tartu	https://kogud.emu.ee/mullamuuseum/?&lang=eng
Kerala Soil Museum	India	Thiruvanathapuram, Kerala	http://www.keralasoils.gov.in/index.php/institutions-under-the-dept/state-soil-museum
Soil museum-Kerala Forest Research Institute	India	Thrissur, Kerala	http://www.kfri.res.in/soil_museum.asp
Soil Museum	India	Thiruvananthapuram, Kerala	http://www.kau.in/institution/college-agriculture-vellayani
Pedonarium	India	Nagpore	https://www.nbsslup.in
Soil museum	India	Chandigarh	http://www.pau.edu
Museum Tanah	Indonesia	Bogor	http://asosiasimuseumindonesia.org/anggota/74-museum-tanah.html
Soil Museum at Yazd University	Iran	Yazd	https://yazd.ac.ir/en/schools/natural/dept/desert
Soil Museum	Italy	Pertosa	http://www.fao.org/soils-2015/events/detail/en/c/346202/ http://fondazionemida.com/museo-del-suolo
Museo de Suelos	Peru	Loreto, Iquitos	http://www.ilam.org/index.php/es/museo?id=4952
BSWM Soil Museum in Manila	Philippines	Manila	No website
Central Museum of Soil Science named after V.V. Dokuchaev	Russia	Saint-Petersburg	http://www.russianmuseums.info/M150 http://www.saint-petersburg.com/museums/museum-of-soil-science/

Continued

Table 1 List of soil-specific museums.—cont'd

Name	Country/Region	City	Website
Williams Museum of Soil and Agriculture	Russia	Moscow	http://www.museum-williams.ru/
East-Siberian Nikolaev Soil Museum	Russia	Irkutsk	http://www.russianmuseums.info/M1921 http://old.biosoil.isu.ru/museum/soilmus/index.htm
Virtual Museum of Soils	Russia	Tomsk	http://www.photosoil.ru/
Soil Museum	Russia	Novosibirsk	https://issa-siberia.ru/museum.html
Museo de Suelos de la Facultad de Ciencias	Spain	Granada	http://edafologia.ugr.es/museovirtual/indice.html http://www.ugr.es/~edafolo/museo_ciencias.php
Museo de Suelos Profesor Roque Ortiz Silla	Spain	Murcia	https://www.um.es/web/museodesuelos/
National Taiwan University (NTU)	Taiwan	Taipei	http://Lab.ac.ntu.edu.tw/soilsc/
Taiwan Agricultural Research Institute (TARI)	Taiwan	Taichung	https://www.tari.gov.tw/sub/links/index.asp?Parser=11,27,279
Soil Museum, Land Development Department	Thailand	Bangkok	https://db.sac.or.th/museum/museum-detail/197
World Soil Museum	The Netherlands	Wageningen	https://wsm.isric.org/ https://www.isric.org/discover/
Emirates Soil Museum	United Arab Emirates	Dubai	http://www.emiratessoilmuseum.org/
Dong Nai Soils Museum	Vietnam	Dongnai Province	No website
Soil Reference and Information Center	Vietnam	Hanoi	http://www.baotangdat.com

Table 2 List of permanent exhibitions relating to soil specimens.

Name	Country/Region	City	Website
El Museo Tecnológico del Agua y del Suelo	Argentina	Viedma	https://rionegro.gov.ar/?contID=20086
The Home Soil	Australia	Sydney	https://www.anzacmemorial.nsw.gov.au/explore-memorial/1701-nsw-place-names
Museum of Earth Science (UFV)	Brazil	Viçosa	http://www.mctad.ufv.br/
Santa Cruz Soil Museum	Brazil	Ilhéus	http://www.uesc.br/projetos/petsolos/index.php?item=conteudo_projetos.php
Soil in the School (UFPR)	Brazil	Curitiba	http://www.escola.agrarias.ufpr.br/index.htm
Soil Lab at the Canada Agriculture and Food Museum	Canada	Ottawa	https://ingeniumcanada.org/agriculture/accueil.php
National Agricultural Exhibition Center = China Agricultural Museum	China	Beijing	http://www.ciae.com.cn/nbg/en/index_nbg.html
The Tropical Agricultural Research and Higher	Costa Rica	Turrialba	No website
Ministerio de Agricultura y Ganadería. Programa Nacional de Regionalización Agraria (PRONAREG).	Ecuador	Quito	No website
Muséum d'Orléans pour la Biodiversité et l'Environnement (MOBE)	France	Orléans	No website
Museum am Scholerberg	Germany	Osnabrück	https://www.museum-am-schoelerberg.de/startseite/
Museum Görlitz	Germany	Görlitz	http://www.senckenberg.de/root/index.php?page_id=17871&preview=true
Soil Research Institute	Ghana	Kumasi	http://sri.csir.org.gh/

Continued

Table 2 List of permanent exhibitions relating to soil specimens.—cont'd

Name	Country/Region	City	Website
Natural Resources Inventory Museum	Japan	Tsukuba, Ibaraki	No website
Water Science Museum	Japan	Tokyo	http://www.mizunokagaku.jp/
Agricultural Science Hall	Republic of Korea	Jeonju-si, Jeollabuk-do	http://www.rda.go.kr/aehBoard/aeh_main.do?prgId=aeh_main&tab=01
Agri-Environmental Resources Learning Center	Republic of Korea	Wanju-gun, Jeollabuk-do	No website
National Museum of Korea	Republic of Korea	Yongsan-gu, Seoul	http://www.museum.go.kr/site/main/home
Museum of Earth Science	Russia	Moscow	http://www.mes.msu.ru/
Open air museums, excellent soil exposures along the Barberton geotrail	South Africa	Barberton geotrail	https://geotrail.co.za/
Open air museums exposition en relation avec le terroir viticole	South Africa	Cape province	https://www.thesouthafrican.com/news/new-vines-in-old-soil-to-commemorate-225-years-of-south-african-heritage/ https://www.wosa.co.za/The-Industry/Terrior/Soil/
Museo de Historia Natural	Spain	Santiago de Compostela	http://www2.usc.es/museohn
Open air museums gorges d'Olduvai	Tanzania	Olduvai gorge	No website
Agricultural Museum Complex	Thailand	Bangkok	https://www.wisdomking.or.th/en/page/7

Museonder	The Netherlands		https://www.hogeveluwe.nl/nl/bezoek-het-park/bezoekerscentrum https://www.hogeveluwe.nl/nl/bezoek-het-park/museonder
The Museum of English Rural Life	UK	Reading	https://merl.reading.ac.uk/
Dirt? Scientists, Book Artists, and Poets Reflect on Soil and Our Environment	USA	Tacoma, WA	https://www.pugetsound.edu/academics/academic-resources/collins-memorial-library/about-collins/artwork-exhibits-in-the-library/dirt/
The Field Museum of Natural History-Underground Adventure	USA	Chicago IL	https://www.fieldmuseum.org/exhibitions/underground-adventure
American Museum of Natural History-Soil and Soil Conservation	USA	New York	https://www.amnh.org/exhibitions/permanent/nys-environment/soil-conservation
Cayuga Nature Center	USA	Ithaca	https://priweb.org/index.php/cayuga-nature-center
Saint Louis Science Center	USA	St Louis	https://www.slsc.org/
Delaware Farm Museum	USA	DuPont Highway Dover	http://www.agriculturalmuseum.org/
The Earth Room	USA	New York. NY	https://www.diaart.org/visit/visit/walter-de-maria-the-new-york-earth-room-new-york-united-states
Soil:Art© Museum—Soil.ed©	USA	New York,NY	https://usi.nyc/divisions/education-outreach/

Table 3 List of soil collection accessible by appointment.

Name	Country/ Region	City	Website
Soil monolith Center of Boku	Austria	Vienne	No website
Museu de Ciência do Solo FCA/UFGD	Brazil	Dourados	No website
Brazil (Embrapa)[a]	Brazil	Embrapa	No website
Ethiopia—National Soil Service Laboratory[a]	Ethiopia	Addis Abeba	No website
Tamil Nadu Soil Reference Centre	India	Coimbatore	http://www.tnau.ac.in
University of Agricultural Sciences (UAS) Bangalore[a]	India	Bangalore	No website
Kenya—Kenya Soil Survey[a]	Kenya	Nairobi	No website
Soil-geological collection	Latvia	Jelgava	http://www.llu.lv
Faculty of Geography and Earth Sciences of the University of Latvia	Latvia	Riga	No website
Mali—Laboratoire Sol-Eau-Plante[a]	Mali		No website
Mexico - Instituto de Recursos Naturales, CONABIO[a]	Mexico		No website
(Comisión Nacional para el Conocimiento y Uso de la Biodiversidad), Colegio de Postgraduados[a]	Mexico		No website
Soil monolith displays at Massey University	New Zealand	Palmerston North	No website
Nicaragua—Universidad Nacional Agraria[a]	Nicaragua	Managua	No website
Nigeria - University of Ibadan[a]	Nigeria	Ibadan	No website
Pakistan - Soil Survey of Pakistan, Ministry of Food, Agriculture and Investment[a]	Pakistan		No website

Table 3 List of soil collection accessible by appointment.—cont'd

Name	Country/ Region	City	Website
Peru - Instituto Nacional de Recursos Naturales—INRENA[a]	Peru	Lima	No website
A.N. Panasenko soil museum	Russia	Ulianovsk	http://www.fao.org/soils-2015/events/detail/en/c/327795/
Soil Museum	Russia	Voronezh	http://www.bio.vsu.ru/soil/vgu_muzeym.html
Soil Museum Professor V.V. Nikitin	Russia	Perm	No website
Soil-geological museum	Russia	Rostov-na-Dony	http://www.dongau.ru/studencheskaya-zhizn/muzei/pochvenno-geologicheskiy-muzey-imeni-dekana-agronomicheskogo-fakulteta-professora-valeriya-stepanovi.php
Botanic Museum	Russia	Valdivistok	https://www.dvfu.ru/museum/botanical_museum/
Soil-Geological Museum	Russia	Saratov	No website
Soil-Geological Museum	Russia	Saint-Petersburg	No website
Monolith display at the Institute for Soil, Climate and Water (ARC-ISCW)	South Africa	Pretoria	http://www.arc.agric.za/arc-iscw/
Monolith display at the South African Sugarcane Research Institute (SASRI)	South Africa	Durban	https://sasri.org.za/
Centre d'Interpretació dels Sòls del Pirineus	Spain	Lleida	http://www.icgc.cat/L-ICGC/Agenda2/Centre-d-Interpretacio-dels-Sols-dels-Pirineus

Continued

Table 3 List of soil collection accessible by appointment.—cont'd

Name	Country/ Region	City	Website
National Chung Hsing University (NCHU)	Taiwan	Taichung	No website
Cornell Soil Health Laboratory	USA	Ithaca, New York	No website
Venezuela - Universidad de Zulia, Maracaibo[a]	Venezuela	Maracaibo	No website
Venezuela (CIRS, UCV-Facultad de Agronomía, Maracay)[a]	Venezuela	Maracay	No website
Zimbabwe—Chemistry and Soil Research Institute, Harare[a]	Zimbabwe	Harare	No website

[a]S. Mantel, pers. comm

3.2 Development of soil museums and exhibitions

The first soil museum opened in 1902 (Fig. 2) in Russia ("Central Soil Museum of Dokuchaev" in St. Petersburg). This museum presented the first collection of soils, and the exhibit remains active. It was constituted by Vasili Vasilyevich Dokuchaev, universally considered (perhaps alongside German-American Eugene Woldemar Hilgard) the "father" of pedology (Evtuhov, 2006; see also Churchman, 2010; Landa and Brevik, 2015). Previous soil collections had been formed in 1885 in Nizhny Novgorod (Russia) as a result of field works of V.V. Dokuchaev and N.M. Sibirtsev in this region (Vernadsky, 1900). Subsequently, a similar soil collection was opened in 1891 by V.V. Dokuchaev in Poltava (Ukraine). Both collections were not preserved and are not shown in Fig. 2. Since then, many countries have been inspired by the idea of presenting the soils of their country to the general public. On the occasion of temporary exhibitions, these museums sometimes exchange soil items between them, but few have a permanent exhibition containing soils foreign to their country.

Since the appearance of the first museum on soils, the number of soil museums has been increasing. The number of museums and permanent exhibitions on soils stagnated until the 1990s; then, it steadily increased to a new plateau between 2006 and 2011. A noticeable increase is from 2015 to 2019 (see Section 4). Permanent exhibitions on soils were not necessarily created on the same date as that of a museum's creation.

The number of soil collections accessible by appointment is obviously underestimated because many universities have small soil collections, such as representative monoliths, for their students and research visitors. Thus, their complete inventory remains very difficult to access. The dossier that we could develop, however, lists the most important known collections. Some are accessible virtually on the web, for example, the "Virtual Museum of Soils" of the Tomsk State University (Russia), the "Museo de Suelos de la Facultad de Ciencias" of the University of Granada (Spain), and the "Museo de Historia Natural" of the University of Santiago de Compostela (Spain).

3.3 Visitors to soil museums and exhibitions

Fig. 3 shows the average attendance of the museums for which data are available. The number of visitors per year was accumulated by country or region. Most of the museums' attendance ranged from approximately 1000 to 10,000 visitors per year, whereas three "outlier" countries (Canada, South Korea, and the United States) had an attendance ranging from more than 100,000 to almost 10,000,000 visitors per year. These three outlier countries correspond to big and highly visited museums in which some rooms are dedicated to soil. Notably, in South Korea, two museums are

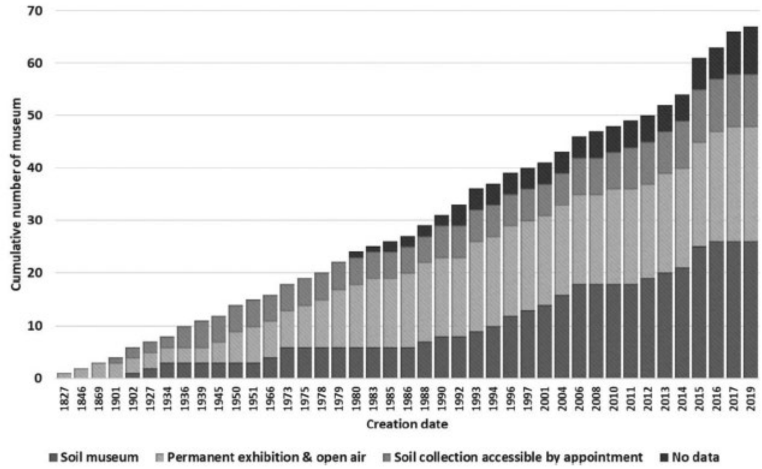

Fig. 2 Change over time of the number of the types of museums on soils worldwide in the four ways.

strictly on soil exhibitions and receive 80,000 visitors annually. Overall, the median value of museum attendance is 4530 visitors per year.

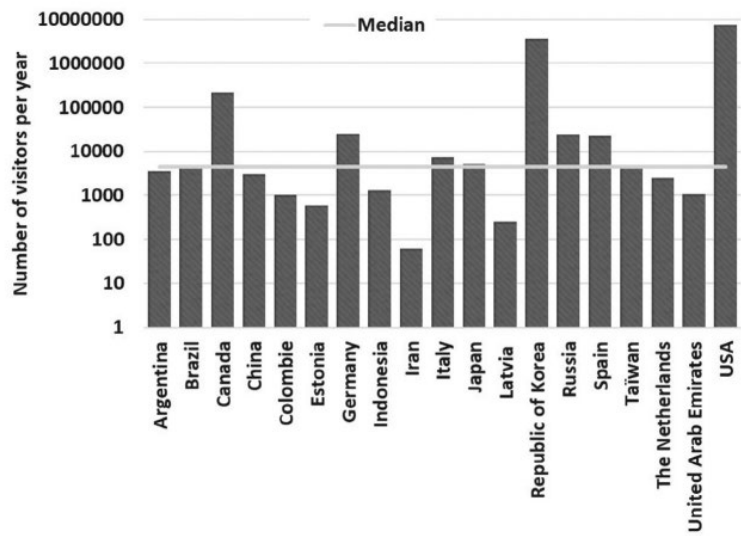

Fig. 3 Number of visitors who visited soil science museums per year per country or region (out of 38 museums for which data are available). The y axis depicts a log scale.

Comparison of the attendance to soil museums relative to the attendance of the 62 most-visited museums in the world (e.g., the Louvre, National Museum of China, and Metropolitan Museum of Art), is shown in Fig. 4. The sum of soil museum visitors in each country remains much lower than that of the most-visited museums in the country. However, as aforementioned, in some countries, the sum of all visitors is close to the highest number of visitors to a museum in the country.

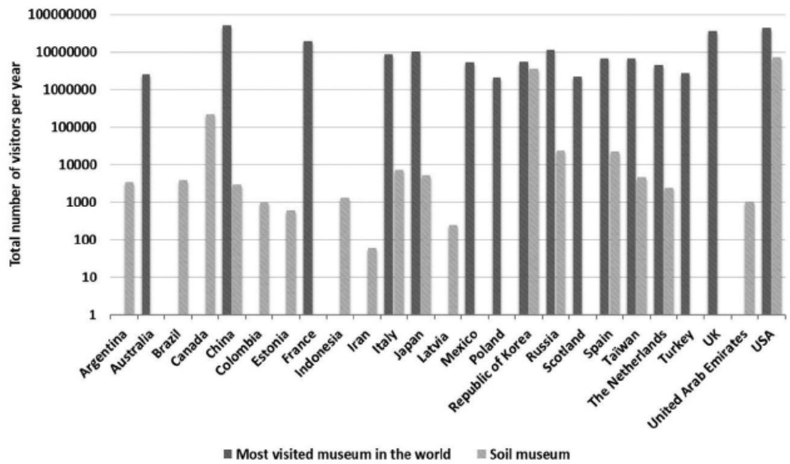

Fig. 4 Number of visitors per year to the most-visited (non-soil) museums in the world (source: Wikipedia), and number of visitors per year to soil museums (total number of visitors per country or region). The y axis depicts a log scale.

3.4 Museum content and presentations

For the content of these museums, we observe a great diversity of objects and animations (Fig. 5). More than 85% of museums have soil monoliths from the host country's regions (Sa´nchez Espinosa, 2005), or from abroad, and they are generally associated with the landscapes and ecosystem services they can render.

Soils museums are increasingly providing "fun" activities including interactive animations for children and/or adults, guided tours, or conferences. Some museums use advanced technologies to improve the attractiveness to the public: augmented reality applications, videos, animations, 3D models, interactive games, and hands-on discovery. Such museums have particular activities: presentations of the soils of various regions, collections of fertilizers, presentations of the tools of the pedologist, documented procedures for manufacturing monoliths (Barahona and Iriarte, 1999) or soil peelings

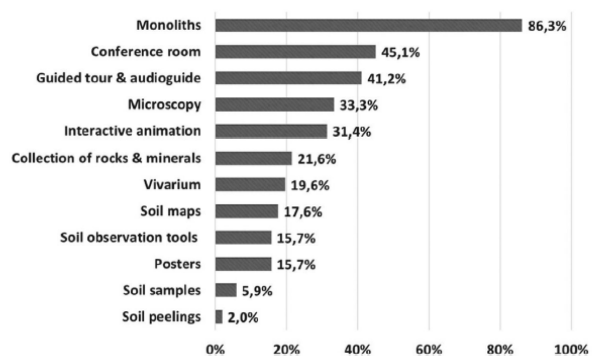

Fig. 5 What is in the soil museums?

(Stoof et al., 2019), and animations related to aspects of pedogenesis including how soils form and evolve with time.

Nearly all museums have soil monoliths (Fig. 6). A soil monolith is a blocky vertical soil section extracted from the field. The extraction technique makes it possible to preserve the characteristics of the soil, for example, its structure or pedality, color, and differentiation into soil horizons. The monolith is generally extracted from a soil pit or freshly prepared road cutting (section), and the further work of preparing and preserving it is performed in the laboratory. The methods for making soil monoliths and soil lacquer peels, often called “soil peelings” (Stoof et al., 2019), were described by van Baren and Bomer (1979). These two methods provide different results and are relatively easy to perform depending on soil conditions.

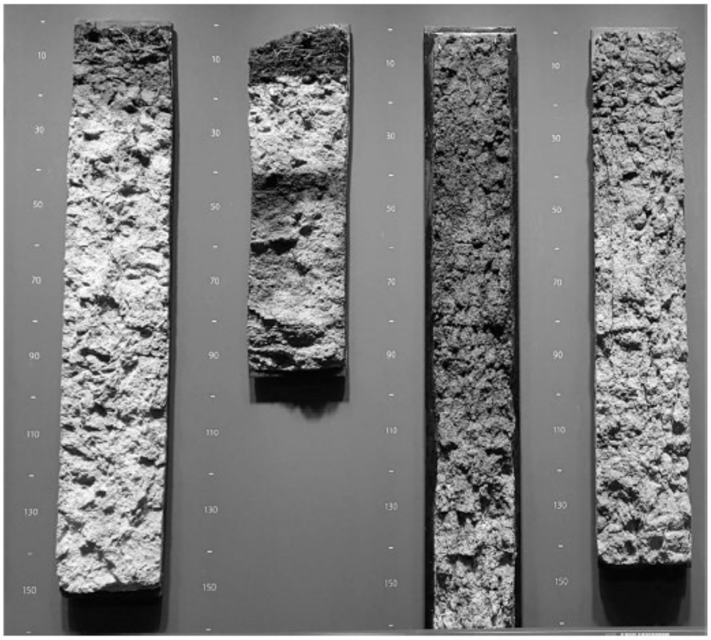

Fig. 6 Examples of soil monolith collections at the ISRIC World Soil Museum, Wageningen, the Netherlands (©Manon Caubet).

A soil monolith is a visual object that transmits to the general public a vision of changes in soil morphology with depth. Indeed, most of the general public consider “soil” a surface material (topsoil or typically an A horizon) and are not aware of the variety of shapes, colors, and textures that occur in the deeper horizons, upper and lower subsoils, and underlying parent material(s).

Very few museums, however, curate monoliths from other countries.
Generally, the soils exposed are from the country in which the museums are situated, and most museums obtain and prepare the monoliths by themselves.

By contrast, the most diverse museum in the countries represented in our survey is the ISRIC World Soil Museum located in the Wageningen University campus in the Netherlands. This museum has 1100 soil monoliths derived from 75 countries across the world. In a sense, soil monoliths are objects or works of art from nature, as famously espoused by Hans Jenny in his invited “Vatican lecture” on the image of soil in landscape art (Jenny, 1968), among others (e.g., Churchman and Landa, 2014).
Fig. 7 shows the country or region of origin of the monoliths exhibited in the various museums of the world (the monoliths are not necessarily exposed in their country of origin). As expected, Russia has the largest number of soil monoliths exhibited across the world’s museums. Most of these Russian monoliths are shown in different museums in Russia but are also observed in the Netherlands, Latvia, and Estonia. Russia is also the country with the oldest monoliths. Some small countries or region
(e.g., the Netherlands, Taiwan, Latvia, and Estonia) have very large numbers of monoliths compared with their size or region (land area). Notably, in Latvia, there are collections on the premises of two

universities. These collections are open to the public but do not have museum status. Japan is an outlier in having a large number of soil monoliths, considering its relatively modest country area. We also distinguish a cluster of large countries—Brazil, Canada, China, Russia, USA—represented by approximately 200 to 300 monoliths, whereas another very large country—Australia—is characterized by very few monoliths.

The African continent, despite its extensive soil research and teaching infrastructure (Rozanov and Wiese, 2018), had few soil museums. The Kenyan collection of approximately 36 monoliths is largely (approximately 30 monoliths) in storage at the Kenya Soil Survey at Kabete in Nairobi. Only six other monoliths are on display at the University of Nairobi. In South Africa, approximately 100 monoliths are distributed between research institutions and universities, and a few dozen are in private collections. The collections in other African countries are also not organized into formal museum settings.

Quite often, posters help explain the role of soil as central to global issues such as climate change adaptation and mitigation, contribution to ecosystem services, biodiversity of soil organisms, threats to soils (soil degradation), and food security (agricultural production and soil fertility). In many cases, posters also explain the origin of soil and its evolution through weathering and soil-forming processes (pedogenesis). Many museums also have rock and mineral collections that are very attractive to the public and play an important role in the understanding of soil genesis processes.

4. Discussion

The increase in number of soil museums over time (Fig. 2) shows distinct periods. After a limited increase at the beginning of the 20th century, the number of soil museums reached a plateau until the 1960s. Next, a notably higher plateau was reached from the late 1960s to the late 1980s. This increase could be because of the agricultural revolution that occurred during this period, involving the expansion of mechanization, the accelerated use of fertilizers and other external inputs, the use of conventionally bred varieties of crops, and general soil and crop improvement techniques such as artificial drainage or irrigation. Indeed, during this period, soils were mainly considered support for increasing agricultural production and increasing food production. Moreover, as stated by Hartemink and McBratney (2008), “Soil science has always had strong ties with agriculture and soil science

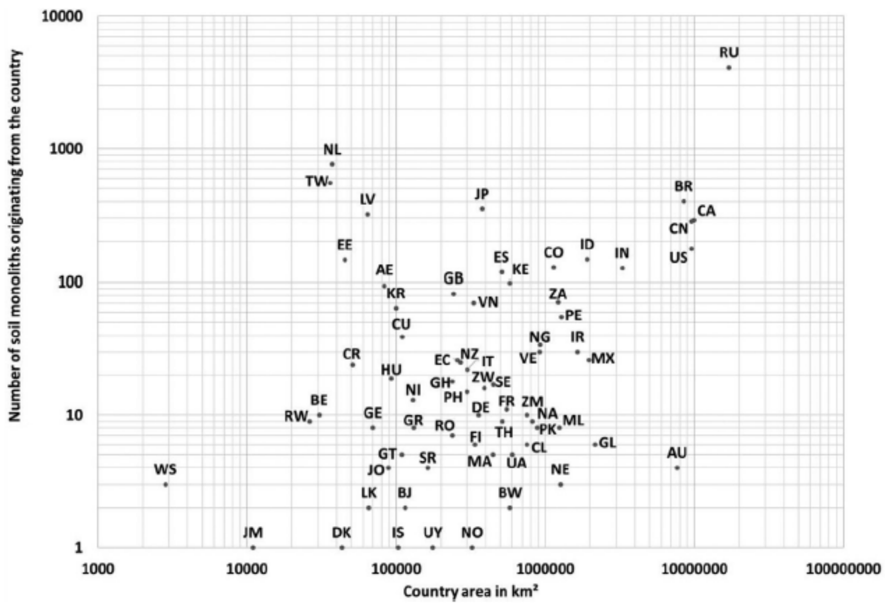

Fig. 7 Number of monoliths exhibited in soil museums of the world versus the size of the country or region from which the monoliths were excavated, on a log-log scale. Abbreviated names correspond to the ISO 3166-1 alpha-2 two-letter country or region codes (AE: United Arab Emirates; AU: Australia; BE: Belgium; BJ: Benin; BR: Brazil; BW: Botswana; CA: Canada; CL: Chile; CN: China; CO: Colombia; CR: Costa Rica; CU: Cuba; DE: Germany; DK: Denmark; EC: Ecuador; EE: Estonia; ES: Spain; FI: Finland; FR: France; GB: United Kindom; GE: Georgia; GH: Ghana; GL: Greenland; GR: Greece; GT: Guatemala; HU: Hungary; ID: Indonesia; IN: India; IR: Iran; IS: Island; IT: Italy; JM: Jamaic; JO: Jordan; JP: Japan; KE: Kenya; KR: Republic of Korea; LK: Sri Lanka; LV: Latvia; MA: Marocco; ML: Mali; MX: Mexico; NA: Namibia; NE: Niger; NG: Nigeria; NI: Nicaragua; NL: The Netherlands; NO: Norway; NZ: New Zealand; PE: Peru; PH: Philippines; PK: Pakistan; RO: Romania; RU: Russia; RW: Rwanda; SE: Sweden; SR: Suriname; TH: Thailand; TW: Taiwan; UA: Ukraine; US: USA; UY: Uruguay; VE: Venezuela; VN: Vietnam; WS: Samoa; ZA: South Africa; ZM: Zambia; ZW: Zimbabwe).

knowledge has made large contributions to the increase in agricultural production," but numerous other global issues have returned soils to the global research agenda (e.g., Bouma, 2009).

The big increase in number of soil museums from the late 1980s to the early 2010s may correspond to a stronger awareness of the diversity of soil functions far beyond the mere primary production of crops and livestock (e.g., climate change mitigation and adaptation and the Kyoto protocol (1990); erosion, desertification, and the UNCDD convention; waste recycling and human health; the extension of soil sealing by cities and infrastructures; the protection of biodiversity; and more generally, the role of soils in delivering ecosystemservices and goods (Dominati et al., 2010;Millennium Ecosystem Assessment, 2005). Subsequently, a new, sharp increase has been observed since 2015. The United Nations officially endorsed 2015 as the International Year of Soils (Brevik, 2014) (later expanded to Decade of Soils, by the International Union of Soil Sciences) and December 5 as World Soil Day. Additionally, in 2015 the first publication by the FAO of the first World's Soil Resources Report was published (Intergovernmental Technical Panel of Soils-ITPS et al., 2015a, 2015b), which was the first comprehensive assessment of global soil resources, resulting from the collaborative effort of more than 200 scientists. The report highlighted serious concerns such as soil nutrient imbalance, accelerated soil erosion, soil acidification, soil salinization, soil sealing, and soil loss of organic matter (Montanarella et al., 2016). During the same period, increasing numbers of soil-related papers were published in high-impact factor journals, highlighting that international soil governance faces great challenges (e.g., Amundson et al., 2015;

Borrelli et al., 2015; Montanarella, 2015). In addition, in December 2015, in Vienna, the International Union of Soil Sciences proclaimed the Decade of Soils (2015–2014), as a continuation of the efforts made during the International Year of Soils 2015.

The distribution of soil monoliths' origin can be interpreted as follows.
-Russia is the largest country by area in the world and has long experience in the discipline of pedology. Russia has four very large and well-known soil museums (i.e., the Central Museum of Soil Science, named after V.V. Dokuchaev; Williams Museum of Soil and Agriculture; East- Siberian Nikolaev Soil Museum [Bychkov and Lopatovskaya, 1999], and Soil Museum at Novosibirsk), and most of these museums exhibit soil monoliths from Russia.
-The large number of soil monoliths in countries such as Latvia and Estonia may be partly because of the influence of the former Soviet Union on soil science communication and the diversity of soils within the country.
-The Netherlands and Taiwan have rather small land areas, much historical experience in soil science, and substantial pressure from their governments to use land efficiently. The location of the ISRIC World Soil Museum in the Netherlands may also partly explain the high density of Dutch soil profiles in the world.
A notable anecdote on the long history of soil science (especially pedology) and soil exhibition in Russia was provided by the Russian pavilion in the Universal Exhibition of Paris, 1900. The Russians brought a block of eight tons of a Chernozem (a very dark soil rich in organic matter and very fertile, today referred as a Mollisol in Soil Taxonomy; Wilding and West, 2012), effectively a giant pedon, to illustrate the richness of Russian agricultural and natural resources. Some people said that the large pedon was exhibited to promote the famous Russian financial credit system. Irrespective of this claim, a small part of the pedon was kept over time, and a monolith of this original Chernozem pedon is currently exhibited in the hall of the National Soil Information Centre of France, the INRA InfoSol unit based in Orl_eans,
France.

To better explain numerous soil functions to the general public, we suggest that temporary or permanent exhibitions are added to the in popular museums with a connection to science or the environment, as has been done in the National Museum of China (Beijing), the Natural History Museum
(London), the American Museum of Natural History (New York), the
National Museum of Natural History (Washington), the China Science and Technology Museum (Beijing), the Shanghai Science and Technology Museum (Shanghai), the Gansu Provincial Museum (Lanzhou), the London Science Museum (London), the "Mus_ee d'Orsay" (France), the
National Museum of Natural Science (Taichung), the Chongqing Museum
Of Natural History (Chongqing), the National Museum of Nature and Science
(Tokyo), the Houston Museum of Natural Science (Houston), and the "Cit_e des Sciences et de l'Industrie" (France). By adopting such approach, soil scientists in other countries may "capture" members of the general public who did not visit a museum to specifically learn about soils.
The collections accessible only by appointment are generally intended for students and professors (early childhood, school years, and high school) for training or for visiting geoscientists (Aparin et al., 2007). Additionally, many smaller temporary exhibitions on soil and traveling exhibitions (e.g., in the United States, Switzerland, and France) are not listed here. Some museums contain objects related to soil, such as lake sediments (Lake Biwa Museum, Japan , Olduvai Gorge open-air museum, Tanzania), or related to agriculture and agronomy (many countries have a national museum on agriculture). These museums indirectly participate in sharing soil knowledge and

creating awareness for the general public. Furthermore, such soil displays appear in different contexts, bringing together the understanding of soil in landscape evolution.

In addition to museums and institutional collections, private collections of soil monoliths also play an important role in public awareness. For example, the soil monoliths on display in wine tasting areas in the Cape Province of South Africa (e.g., Babylonstoren, Morgenhof, Neethlingshof estates) offer a direct link between soil quality and the wines produced on these estates within the terroir concept adopted in South Africa from France in the beginning of the XXI century as part of wine marketing strategy.

The attractiveness of soil museums is sometimes increased by the use of modern technology to present the soil in a new light or through games. Interactive animations are very popular among children. Soil museums, however, remain mainly tools for raising awareness and education about soils; they do not collect data on what people think in addition to simply disseminating information to them. Thus, we contend that public dialogue and deliberation as suggested by Bell (2008) would be worthwhile.

The soil science community must be open to developing new perspectives by investigating and initiating transdisciplinary projects. Art, history, anthropology, sociology, psychology, economics, and religious studies represent just a few fields for expanding the scope of soil protection and raising soil awareness (Feller et al., 2015). We should engage and reconnect people with soil, and art is one way of communicate the complex visual, cultural, and symbolic dimensions embodied in the soil (Feller et al., 2015). Both science and art are critical and necessary for raising soil security by soil awareness. Some museums are using the arts with soils to attract the general public. There are exhibitions of pictures painted with soil pigments and sculptures made with clay.

The general trend over the past few decades is a steady increase in the number of soil museums and exhibitions over time. The momentum seems set to continue with the opening in 2020 of the “Mus_eum d’Orl_eans pour la Biodiversit_e et l’Environnement “(MOBE, Orl_eans, France), whose permanent exhibition will contain a new section on soils and the construction of a new soil museum in Naples (Italy).

A matter of great concern is the virtual void of soil museums and permanent public exhibits in Africa. Some of the 54 African countries have adequate human capital in soil science (Rozanov and Wiese, 2018) to manage the challenge of science popularization through various means including the establishment of soil museums and soil exhibits in existing natural history museums and national parks. The national soil science societies should consider promoting such activities.

5. Conclusions

Soils play a vital role through all the services they provide. Soils are at the nexus of global concerns such as food and water security, climate change, soil degradation, biodiversity protection, and human health. An important communication effort to society should, therefore, be provided by soil specialists and be sustained. The soil museums, by presenting the various soils of the country and related topics, improve the connection of the population to the soil and the environment.

The distribution and the contents of soil museums partly reflect the history of soil science and pedology and the progressive emergence of new issues regarding the importance of soils. Although relatively numerous, soil museums and soil exhibitions remain sparse in some parts of the world, and their attendance is very diverse, from approximately 1000 to 10,000 visitors per year.

The classical means of presenting soils is through monolith exhibitions.

These displays allow viewers to see the diversity of soil profile features normally hidden underground, such as the contrast and the beauty of the colors of their horizons. Thus, presenting monolith in museums is logical. Soil scientists preparing soil displays in museums and exhibitions may also be considered artists because of how they choose the most beautiful and most contrasting soils to illustrate their variability. Notably, this selectivity constitutes a type of bias because soil scientists tend to prefer to show amazing, distinctive soils. However, the main objective of soil museums is not only to provide a representative collection but also to attract people's attention and to raise soil awareness by showing objects that speak to everyone. Soil science and art is a means to engage and reconnect people with soil.
Furthermore, as stated by Megonigal et al. (2010), "the primary goal of public soils education should not be to teach, but to inspire." However, one important dimension of the soil museums is the multidisciplinarity (e.g., placing soils in their landscape, highlighting the ecosystem services provided by the soils and thereby showing the multi-functionality of soils). As illustrated by Amato et al. (2015) "this is an important issue for soil, a complex system studied by many specialists but still without a proper collaboration across disciplines, and in a way oriented towards communication and sharing."

Acknowledgments

We thank the people who have guided us in our search for information on museums around the world including those who provided contact details for people familiar with these museums. We warmly thank Cristine Morgan (USA), Ghaedi Hojat (University of Tehran, Iran), Juan Jose Iba´n˜ez (Spanish National Research Council - CSIC, Madrid, Spain), Alessandro Rosa (Universidade Tecnolo´gica Federal do Parana´, Brazil), Edoardo AC Costantini (CREA-ABP Agrobiology and Pedology Research Center of Florence, Italy), David Rossiter (ISRIC), Abdolkarim Ghaedi (Payame noor University, Iran), Rimantas
Vaisvalavi_cius (Institute of Agroecosystems and Soil Sciences, Aleksandras Stulginskis University (ASU), Lithuania), Einar Eberhardt (The Federal Institute for Geosciences and Natural Resources, Hannover, Germany), Megan Balks (University of Waikato, Hamilton, New Zealand), Pascal Boivin (HEPIA, Switzerland), Agnes Llado`s (Centre d'Interpretacio´ dels So`ls del Pirineus, Lleida, Spain) and Roque Ortiz Silla (University of Murcia, Spain).

Part of this work has been supported by LE STUDIUM Loire Valley Institute for Advanced Studies through its LE STUDIUM Research Consortium Programme.

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The Technical Corner

This is a new column open to any and all members who want to discuss technical issues, equipment, new methodologies, observations, any of the discussions that we would typically have at field days and training sessions which, because of the Covid-19 Pandemic, have not been available to us at this point in time. The Executive Committee is hoping that this column will encourage the ongoing dialogue that has made AOP gatherings so very informative. We may also find that these materials can be used for training the next generation of soil scientists. Would you like to be next?