ANNUAL REPORT
2020 - 2021

ISRIC
World Soil Information

In our digital world, data is more valuable than ever. We need to answer questions such as: where is land quality getting better or worse? Where are soils storing or releasing the most carbon? To do that, scientists and policymakers need data they can trust. At ISRIC - World Soil Information, this is our passion—working behind the scenes to continually improve the quality of soil data, at a global and national level, so that people can make important decisions about how to manage land.

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Director's message

Land management is key towards a more sustainable and equal world, as it determines our options to adapt to climate change, to preserve biodiversity, to prevent droughts and floods and to boost sustainable intensification of food production. To support sustainable land management, we need data we can trust, informing us where land is degrading or recovering and helping us decide which types of interventions and conservation measures are needed. At ISRIC - World Soil Information, this is our passion—working with our partners to continually improve the quality of soil information, at a global and national level.

We are excited to see an increasing demand for soil information by those engaged in land management. Over the review period, ISRIC has helped with the integration of soil information in national information services in Rwanda, Ethiopia and Kenya in support of climate smart agriculture. We have also developed science-based procedures for formulating more precise fertiliser recommendations to improve on blanket recommendations and contributed to the WOCAT network and services to better support sustainable land management decisions.

Our efforts to further develop our global products WoSIS and SoilGrids have continued with a view to meeting the needs of a diverse user community. Acknowledging that global products cannot be used for local applications because of the limited resolution and accuracy, we have started a community of practice to support national level soil information providers in their endeavour to produce user-oriented soil information products for their countries. We will consolidate and expand this service in the coming years.

In 2021, we completed our role as Soil Data Facility (2017-2021) for the Global Soil Partnership (GSP), under the umbrella of FAO, with key contributions towards developing distributed Global Soil Information System (GLoSIS) and the development of a global soil data exchange standard. On spectrometry, we started a working group focussing on standardisation, community building and capacity building that is now hosted within GLOSOLAN, GSP's Global Soil Laboratory Network. Further, consequent on COVID-related restrictions and in response to the demand of our user community, we increased possibilities to view and enjoy our World Soil Museum

> **Our ability to collaborate is our most valuable asset**

collection online. Many of the activities mentioned above support our functioning as World Data Centre for Soils, certified with the CoreTrustSeal, and accredited as a regular member by the ICS World Data System.

The achievements reported on here could only be reached with the help of our valued partners from national soil institutes, international soil organisations, environmental scientists, land-focused NGOs, sustainability oriented agriculture businesses and policymakers. Further, all of our past and future work rests on the tremendous teamwork between our specialists, supporting staff, guest researchers, PhD students, volunteers, and the board. Our ability to collaborate is our most valuable asset. I am very thankful to the team for their dedication and perseverance, especially in periods of lockdown, restricting human interactions and travelling. I am also thankful to our funding partners who support our ongoing efforts to ensure the world has the best soil information possible at their fingertips. Good soil information is built on good relationships.

Rik van den Bosch
Director

WHO WE ARE

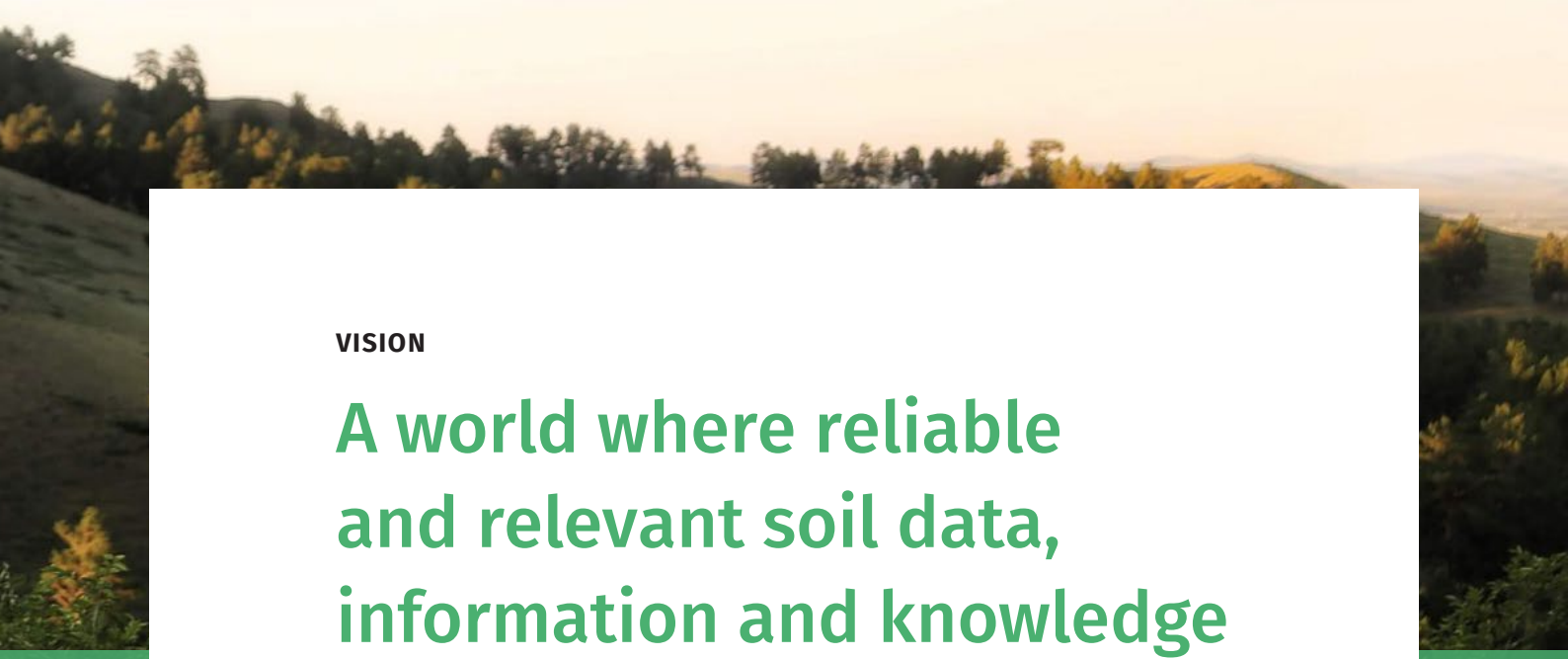
ISRIC – World Soil Information is the World Data Centre for Soils

ISRIC – World Soil Information's remit as World Data Center for Soils (WDC-Soils) is to provide trustworthy soil-related collections and information services that can be used to underpin a wide range of studies of environmental, societal and economic sustainability, in an increasingly inter-operable world.

Since 1989, we have been accredited as regular member of the World Data System (WDS), an Interdisciplinary Body of the International Science Council (ISC, formerly ICSU). The WDS aims to build worldwide 'communities of excellence' for scientific data services. As a WDS member, we provide the building blocks of a searchable common infrastructure for soil data, from which a trustworthy global data system that is both interoperable and distributed can be formed.

We democratise the world of soil information through promoting open science principles: developing open data products, using of open-source software and publishing results in open access journals.

Member organisations of ISC-WDS have a strong and tangible commitment to open data sharing, data and service quality, and data preservation. In this context, we have prepared, or updated, several documents to make our processes transparent: Data and Software Policy, Collection Management Policy, Digital Data Preservation Policy, Data Management Protocol, and Privacy and Personal Data statement.



VISION

A world where reliable and relevant soil data, information and knowledge is freely available and properly used to address global environmental and societal challenges.

MISSION

We help to increase the availability and use of soil data, information and knowledge to enable better decision making for sustainable land management around the world, by:

- Producing information products
- Helping others to do the same
- Providing examples of use
- Educate and raise awareness

Through these activities we contribute to solving societal challenges such as sustainably intensifying food production, climate change adaptation and mitigation, and biodiversity conservation.

SOIL EDUCATION AND ADVOCACY

The World Soil Museum and World Soil Reference Collection

ISRIC hosts a unique place for soil education and advocacy—the World Soil Museum. Museums are both repositories of works and artifacts, as well as spaces for meeting, knowledge-sharing and building social ties. In ISRIC's World Soil Museum, people are informed about and inspired by the great diversity of soils and their functions. It is a venue for study, education, and edutainment.

The museum reflects ISRIC's efforts since 1966 to establish a reference collection whereby we collect, document, and study the soils of the world. Through this collection, we also contribute to standards for analysis, description and classification, and provide a global overview of soils and their properties.

Starting early 2020, the Covid-19 pandemic had a great impact on society. Doors were closed for a large part of 2020 and 2021. While the number of visitors was low for 2020-2021 compared to previous years, connection to the public was achieved using different media and events in times of visitor restrictions. Online tours were done on request, such as for the National Key Registry of the Subsurface (Basisregistratie Ondergrond).

Welcoming visitors back in 2021

In June 2021, when coronavirus-related regulations began to ease, the first group was received in the museum. Later in November 2021 when restrictions were fully lifted, we welcomed more than 200 students to the museum.

Open Monument Day in September 2021 was a bright spot of the museums' re-opening. Open Monument Day is


WORLD
SOIL
MUSEUM
GAIA
LUMEN

Presentation of the exposition of the Museum of Edible Earth in the World Soil Museum with soil tasting.

an annual celebration of cultural heritage across the Netherlands and Europe when thousands of historical buildings and sites are open to the public free of charge. Open Monumentendag in the Netherlands started in 1987 and is one of the country's premier cultural events.
During our regular opening hours, on Wednesday afternoons, when regulations allowed, we continued our volunteer program and a rotation of four volunteer guides provided tours and assistance to visitors.

Artist-in-residence
The World Soil Museum collaborated with Impulse (Wageningen UR) and the artist masharu of the Museum of Edible Earth to host a special guest exhibit. Masharu installed a temporary exposition of more than 400 edible earth samples in the museum and hosted soil tasting events. Many visitors from diverse backgrounds experienced the exposition and we received significant media attention from diverse outlets including radio coverage on NPO radio 1 and Radio 1 Belgium, television coverage on RTL EditieNL, and national newspaper coverage in Trouw and Parool.

International collaboration
We are a founding partner of the Global Soil Museum Network which is a young group bringing together soil exhibits and educators around the world. For World Soil Day, December 5, in 2020 and 2021 the network coordinated online excursions to various member museums such as the Emirates Soil Museum in the United Arab Emirates and Dokuchaev Central Soil Museum in Russia. The World Soil Museum hosted the events which attracted hundreds of participants and the tour recordings shared on YouTube have more than 1900 views.

ISRIC Soil Reference Collections and Library

The soil reference collection of ISRIC is a unique resource with over 1100 soil monoliths from around 82 countries in the world which provides a reference for identification (classification), comparison, research and education. Part of the collection is displayed in the World Soil Museum with the aim to increase knowledge and respect for the soils of the world; alternatively, the entire collection is accessible via the virtual soil museum. The curation and use of the soil reference collection is guided by an open access collection management policy, published in 2021. Importantly, we are working towards compliance with international Spectrum standards for collection management. Further, we made good progress with the scanning of our thin sections for future online access. This work will be continued in 2022.

The ISRIC World Soil Reference Library, another core-collection, holds over 26,600 documents in total, including soil-related reports, books and maps, the scanning of which is ongoing. Since the end of 2021, about 85% of our maps can be downloaded in high resolution, and over 35% of our reports and books are available online full-text (PDFs). Scanning of ISRIC's library holdings is a continuous process as we regularly receive new additions for the collection.

PROVISION OF GLOBAL AND REGIONAL SOIL DATA AND INFORMATION

ISRIC's flagship soil data and information products: WoSIS and SoilGrids

WoSIS

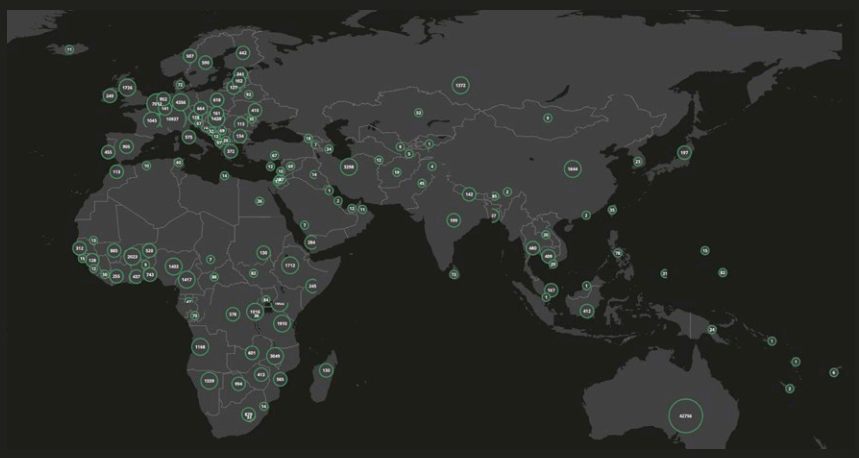
The World Soil Information Service (WoSIS) serves quality-assessed and standardised soil profile data for the whole globe, ultimately aiming for full data harmonisation. Such data have the capacity to underpin digital soil mapping as well as a wide range of broad scale assessments.

Recent use examples include the Soils Revealed platform, the Carbon Map prepared by World Wildlife Fund Canada, ISRIC's own SoilGrids platform, as well as a diverse range of published studies.

In 2020 and 2021, more than 20 new datasets were acquired for WoSIS from a range of data providers. These were cleansed, quality-assessed and processed into WoSIS using a re-factored system (e.g., improved code design without changing the semantics themselves). The resulting set of standardised data represents over 30,000 new point locations. This brings the total number of point data that can be served freely* from WoSIS to over 215,000 profiles, up from 196,000 in 2016.

In conjunction with methodological and technical developments, a new branding for WoSIS was developed to support our ongoing data acquisition efforts. New acquisitions are particularly sought for the northern, high latitude regions.

* Another 40,000 thousand point data are shared with WoSIS under a restricted license and cannot be served.

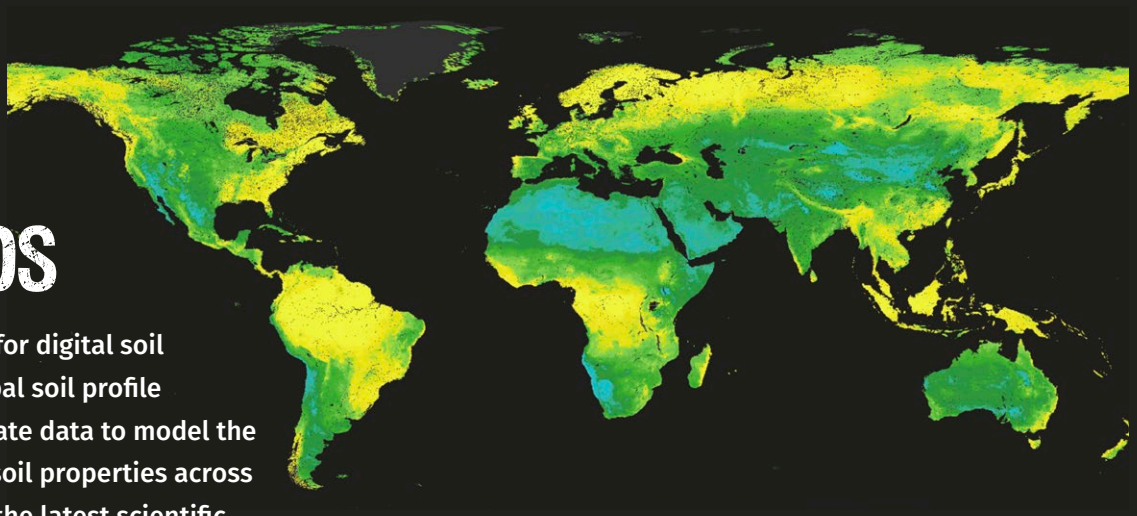


SoilGrids portal showing number of profiles in WoSIS per country.

PUBLICATION HIGHLIGHT

Two peer-reviewed data papers, discussing the 2016 and 2019 static snapshots of WoSIS, are now among 'Earth Systems Data Science (ESSD) most down-loaded'. The most recent paper is:

Batjes NH, Ribeiro E and van Oostrum AJM. 2020. Standardised soil profile data for the world (WoSIS snapshot 2019). Earth Syst. Sci. Data, 12, 299–320, https://doi.org/10.5194/essd-12-299-2020



SoilGrids

SoilGrids™ is a system for digital soil mapping that uses global soil profile information and covariate data to model the spatial distribution of soil properties across the globe. It considers the latest scientific developments in the field of digital soil mapping, uncertainty analysis and spatial data infrastructures. SoilGrids 2.0 layers, a major update released in May 2020, are used in a variety of applications and by different users.

SoilGrids is a collection of soil property maps for the world produced using machine learning at 250 meter resolution. Predictions are made at six standard depths. SoilGrids uses global models that are calibrated using all available soil observations and a statistical selection of globally available environmental covariates. This results in globally consistent predictions (e.g., no abrupt changes in predicted values at country boundaries). SoilGrids spatial predictions, or layers, are created using a reproducible soil mapping workflow. Therefore, they can be regularly updated as new soil data or covariates become available, novel procedures for quality control, data standardisation and harmonisation are implemented, or the digital mapping procedures themselves are fine-tuned.

PUBLICATION HIGHLIGHT

SoilGrids paper is among 'SOIL most down-loaded papers, All time' articles. SoilGrids 2.0: producing soil information for the globe with quantified spatial uncertainty.

Laura Poggio, Luis M. de Sousa, Niels H. Batjes, Gerard B. M. Heuvelink, Bas Kempen, Eloi Ribeiro, and David Rossiter. SOIL, 7, 217–240, https://doi.org/10.5194/soil-7-217-2021, 2021

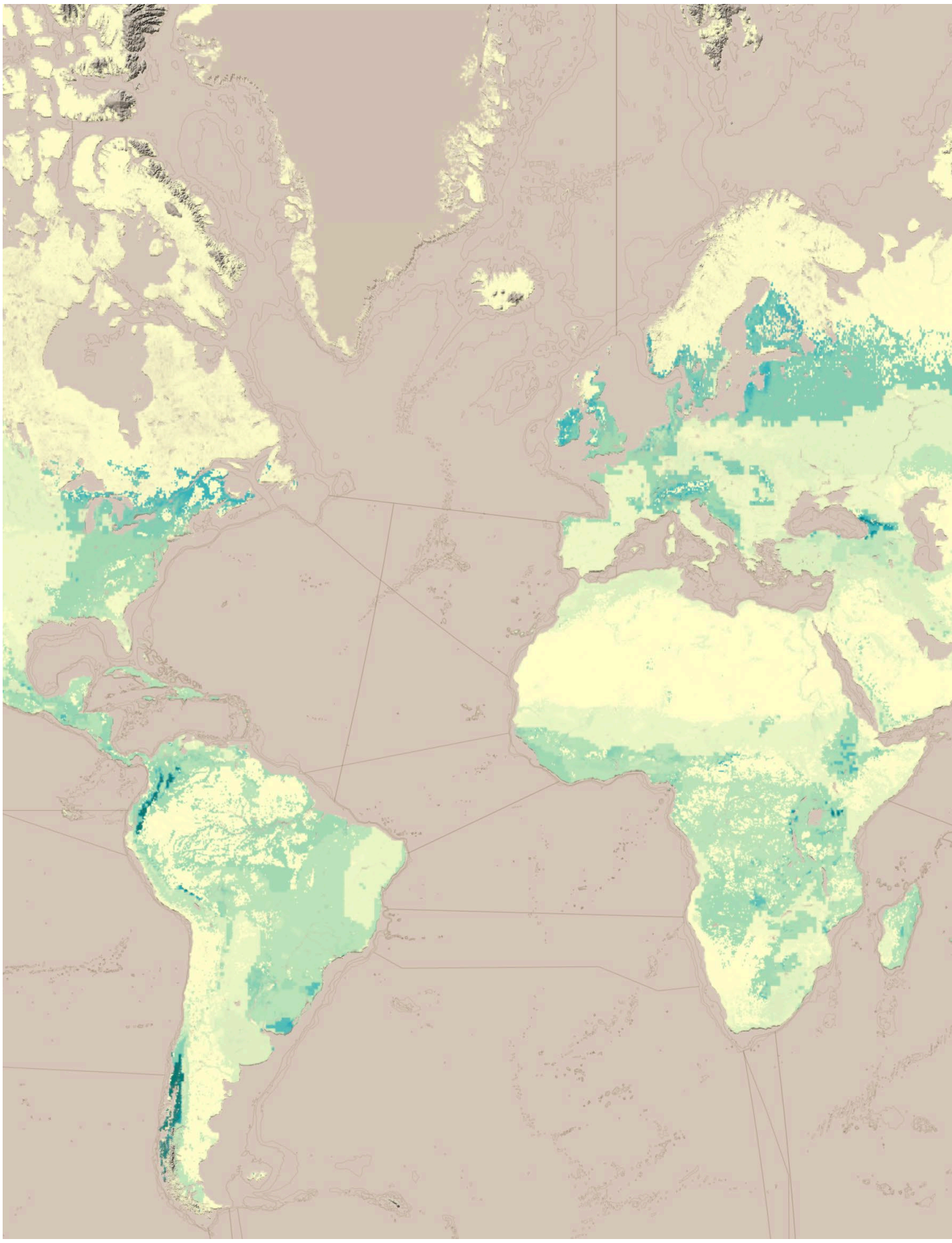
SOILGRIDS USER

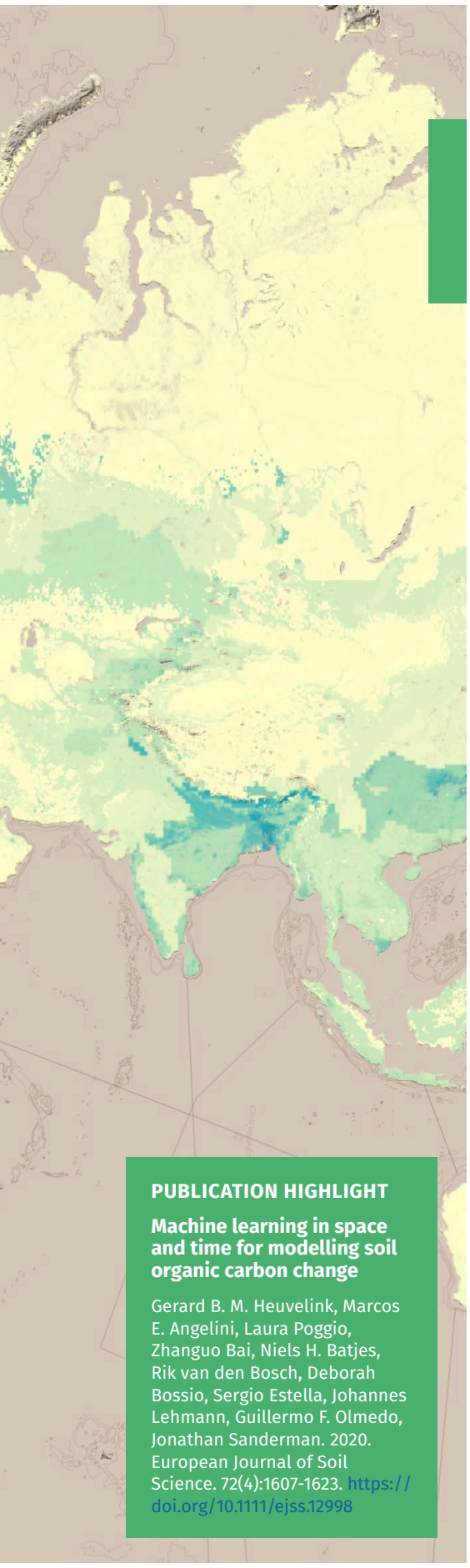
United Nations Convention to Combat Desertification (UNCCD)

The UNCCD encourages use of SoilGrids for assessing land degradation, specifically in reporting on Sustainable Development Goal (SDG) 15 'Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.' SDG Indicator 15.3.1 requires calculating the proportion of land that is degraded over total land area. This includes looking at change in soil organic carbon stocks and UNCCD recommends in the absence of a national soil organic carbon (SOC) database, use of the SOC 0-30 cm product derived from SoilGrids250m v.2 as a stand-in for baseline SOC stock.

One major addition achieved with SoilGrids 2.0 was the inclusion of uncertainty information. The primary soil properties considered were acidity, organic carbon concentration, nitrogen, cation exchange capacity, sand, silt, clay, coarse fragments and bulk density. Complex soil properties such as soil carbon density and soil carbon stocks (0-30cm) were also produced. The mean prediction for each property and depth was made available on Google Earth Engine (GEE). Further, a new portal for SoilGrids and WoSIS data was released incorporating all relevant Open Geospatial Consortium (OGC) standards and latest accessibility options.

In 2021, we worked on soil water content layers (for three pressure heads), and these were pre-released in December 2021. More work was done behind the scenes to model soil depth and to improve soil carbon stocks predictions. Results should be available in 2022.





PUBLICATION HIGHLIGHT

Machine learning in space and time for modelling soil organic carbon change

Gerard B. M. Heuvelink, Marcos E. Angelini, Laura Poggio, Zhanguo Bai, Niels H. Batjes, Rik van den Bosch, Deborah Bossio, Sergio Estella, Johannes Lehmann, Guillermo F. Olmedo, Jonathan Sanderman. 2020. European Journal of Soil Science. 72(4):1607-1623. https://doi.org/10.1111/ejss.12998

PROVISION OF GLOBAL AND REGIONAL SOIL DATA AND INFORMATION

Soil Organic Carbon Information Products

Soil is the largest store of terrestrial carbon on earth. Conserving and improving carbon (held in soil organic matter) through thoughtful soil use and land management can help to mitigate climate change, combat degradation of soil and water quality, and address food security by improving soil health. Policy makers and other stakeholders require reliable data and tools to support informed decisions concerning possible actions aimed at mitigation and adaptation.

Space-time SOC modelling

Soil organic carbon (SOC) varies both across a landscape and over time. Monitoring the change of SOC over the years is particularly important for climate change mitigation studies. Many soil organic carbon maps already show how SOC varies across a landscape but visualising how it changes over time is less common. The Soils Revealed platform shows SOC change over both space and time and was created in partnership with The Nature Conservancy, Cornell University, and Woodwell Climate Research Center and launched on World Soil Day, December 5, 2020.

The interactive platform shows global maps of the predicted annual topsoil SOC stock at 250 m spatial resolution between the years 2000 and 2018 and provides summary statistics and time series of the SOC stock change for all countries. Soils Revealed also shows maps indicating how much soil organic carbon was lost or gained as a result of human influence in the last 12,000 years, as well as maps of expected SOC stock change over the next 20 years, under different scenarios. The method used for modelling SOC stock change was based on the Intergovernmental Panel on Climate Change (IPCC) Tier 1 accounting approach.

Together with the Instituto Nacional de Tecnología Agropecuaria (INTA) in Argentina, we also developed and applied a machine learning methodology for space-time mapping of SOC stock change in Argentina for the 1982-2017 period. ISRIC is exploring whether this methodology can also be applied to the entire world.

ESA WORLDSOILS

Since 2020, ISRIC has a role in the WORLDSOILS programme, part of the European Space Agency's (ESA) Earth Observation Strategy 2040. WORLDSOILS is ESA's Earth Observation Envelope Programme backbone. As part of the above strategy, ESA includes a 'science for society' element. This component is achieved by activities, like WORLDSOILS, which transfer scientifically proven earth observation research results into pre-operational products that meet the most important needs of user organisations and public authorities. The main roles of ISRIC are:

1. modelling soil organic carbon for permanently vegetated soil,
2. integrating models for bare and permanently vegetated soil,
3. prototyping predictions for up-scaling in close collaboration with the GMV company, and
4. developing the data dissemination platform.

Phase 1 of the project was successfully completed in 2021 and Phase 2 is ongoing.

Horizon 2020 CIRCASA project

CIRCASA (Coordination of International Research Cooperation on Soil Carbon Sequestration in Agriculture) developed international synergies concerning research and knowledge exchange in the field of carbon sequestration in agricultural soils at European Union and global levels. ISRIC contributed to the development of a knowledge information system aimed at hosting knowledge on carbon sequestration in agricultural soils, as well as a literature review on options for measuring, reporting and verification of soil carbon change to realise the potential of soil carbon

sequestration for atmospheric greenhouse gas removal. Further, we produced an updated SoilGrids map, at 250 m spatial resolution, of soil organic carbon concentrations with quantified uncertainty for inclusion in CIRCASA's online collaborative platform.

During the implementation of CIRCASA, the scope for an International Research Consortium was identified resulting in the 2021 approved Horizon Europe project called OrCASA (Operationalising International Research Cooperation on Soil Carbon).

Mongolia: soil organic carbon mapping

Together with the Central Asia Soil Science Society, ISRIC developed maps of the soil organic carbon content and soil pH for Mongolia. Underpinning these maps were 1423 measurements on soil organic carbon and pH from a survey organised within the framework of the 'National Program to Combat Desertification.' This survey aimed to determine the primary soil quality indicators for desertification assessment in Mongolia and it was conducted based on the state network of the Meteorological and Environmental Research Agency starting in 2012.

Samples were collected from 1500 monitoring points every 5 years. The resulting data were combined with two sets of satellite imagery comprised of about 220 layers including maps of climate indicators, land cover and vegetation, terrain morphology in a statistical modelling framework. Soil maps were generated with statistical models trained with each of the sets. As a next step, we will compare the results of the two models, with both point-wise evaluation metrices and assessment of spatial patterns. The project also produced detailed scripts and code to be used by our partners in Mongolia.

PROVISION OF GLOBAL AND REGIONAL SOIL DATA AND INFORMATION

Collaborating for better international and national soil information

Horizon 2020 Soils4Africa

The Soils4Africa project, funded by the European Union under the Horizon 2020 framework programme, aims to develop a Soil Information System (SIS) to support sustainable intensification of agriculture by providing up-to-date and consistent soil information at continental scale. Existing soil databases for Africa at the continent scale often are compilations of datasets generated for different purposes, and therefore based on a variety of methods for soil sampling and analysis. These factors limit data interoperability and pose challenges for accurate assessment of soil quality indicators and quantification of risks at continental scale. Further, the available data are seldom shared as open data.

Starting in June 2020, the Soils4Africa project defined use cases with stakeholders and established soil quality indicators to support the use cases as a basis for the SIS. The project produced a map of agricultural land in Africa, as a basis for the soil sampling framework, and developed a methodology for implementation of the SIS.

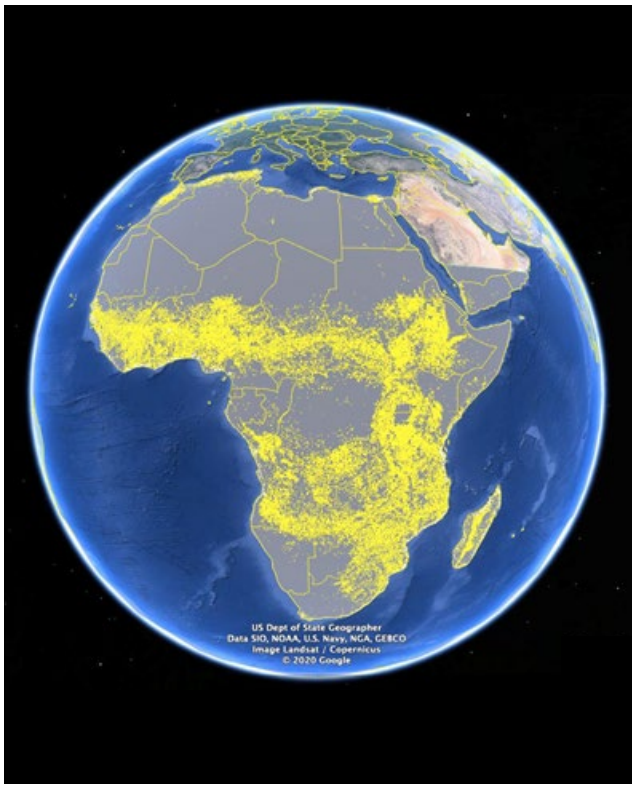
The project developed a soil sampling design for application at a continental scale and produced uniform guidelines and protocols for collecting soil data in the field and their subsequent dispatch and analysis in one central laboratory (ARC-Soil, Pretoria). These materials are directly useable by different stakeholders including national and international agencies and NGOs, governments, policy makers, researchers from both African soil institutions and international groups including other H2020 research projects, with immediate and potentially great impact. All project outputs are accessible on the project website.

The project has established connections with key high-level stakeholders in Africa, including LEAP-4FNSSA (Long-term Europe-Africa Research and Innovation Partnership for Food and Nutrition Security and Sustainable Agriculture) and CAADP-PP (African Union's Comprehensive Africa Agriculture Development Programme Partnership Platform), and received endorsement of a number African agricultural organisations for its efforts so far.

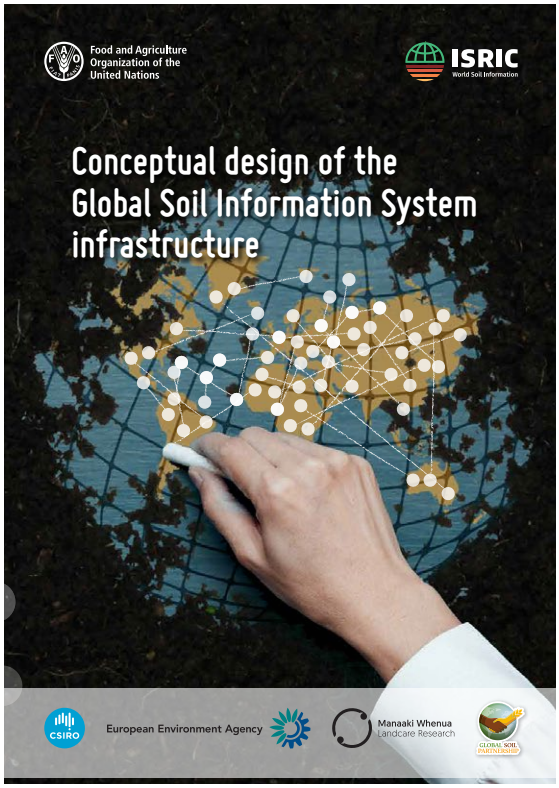
In view of Covid restrictions, Soils4Africa's field campaign to collect soil samples at 20,000 locations in Africa will start in 2022, building on the developed guidelines and protocols.

Global Soil Partnership: summary of our contributions

The United Nations' Food and Agriculture Organisation hosts the Global Soil Partnership (GSP), a globally recognised mechanism established in 2012 with the mission to position soils in the global agenda and to promote sustainable soil management. From June 2017 until September 2021, ISRIC supported the GSP in the role of 'Soil Data Facility' to assist technical implementation of global soil data sharing and to help countries set up their own soil information systems. During the last two years of ISRIC's mandate as Soil Data Facility to the GSP we changed course from an advanced custom technological solution for a Global Soil Information System (GloSIS), towards a more practical solution based largely on existing software with clear instructions, testing and deployment. Based on ques-



Mask of agricultural area created by Soils4Africa for continental Africa, overlain in Google Earth on the map of Africa (©Google Earth)



tions and suggestions by countries it was clear that easy-to-operate software was needed first to serve data as-is, without going to data standardisation and/or harmonisation immediately. For this, we developed an easy-to-install version of GeoNode as in-country soil information system. Simultaneously, we set up an instance of GeoNetwork as Discovery Hub or central portal at www.glosis.org. Existing soil information systems or portals of eight countries were connected to it and made findable through the provision of metadata.

Parallel to this effort we continued with the development of a global soil data exchange standard or ontology for GloSIS, to allow future exchange of standardised soil data. Results were discussed and further elaborated with a group of experts around the globe. These experts are connected to GSP as well as other groups, for example ESIP Soil Ontology in the USA. This work will be continued in 2022 within the context of the European Joint Programme SOIL project.

On soil spectroscopy, we started a working group focussing on standardisation, community building, and capacity building. The working group is hosted within the GSP's Global Soil Laboratory Network (GLOSOLAN) and co-led by the United States Department of Agriculture's Natural Resource Conservation Service Charles E. Kellogg Soil Survey Laboratory (USDA-NRCS-KSSL), ICRAF World Agroforestry, and Innovative Solutions for Decision Agriculture (iSDA). The working group was successful in bringing together the community, starting standard operating procedures for mid-Infrared soil spectral lab measurements, writing two concept notes on a Global Soil Spectral Calibration Library and Estimation Service (GSCLES) as well as GSCLES Capacity Building, which have been endorsed by the GLOSOLAN spectroscopy working group.

The working group sent out a questionnaire on the needs of soil laboratories worldwide and received about 100 responses from 60 countries. The synthesis report, published in 2021, was subsequently used for defining follow up activities. Our role as co-chair ended in 2021; nonetheless, ISRIC remains pro-active in the GLOSOLAN Spectroscopy group itself as well as other communities with a focus on serving spectral data.

Soil Intelligence System for India

The Soil Intelligence System developed within the context of the CSISA project (Cereals Systems Initiative

for South Asia), funded by the Bill & Melinda Gates Foundation, supports people in the agriculture sector to make better decisions by providing accurate, spatially referenced digital soil and crop information at a larger scale. To achieve this, the system integrates remote sensing, digital soil mapping, technological changes in soil testing like spectroscopy, and new statistical tools. The initiative was implemented in the states of Andhra Pradesh, Bihar and Odisha, under the partnership of the International Maize and Wheat Improvement Centre (CIMMYT), ISRIC, Cornell University and the International Food Policy Research Institute (IFPRI).

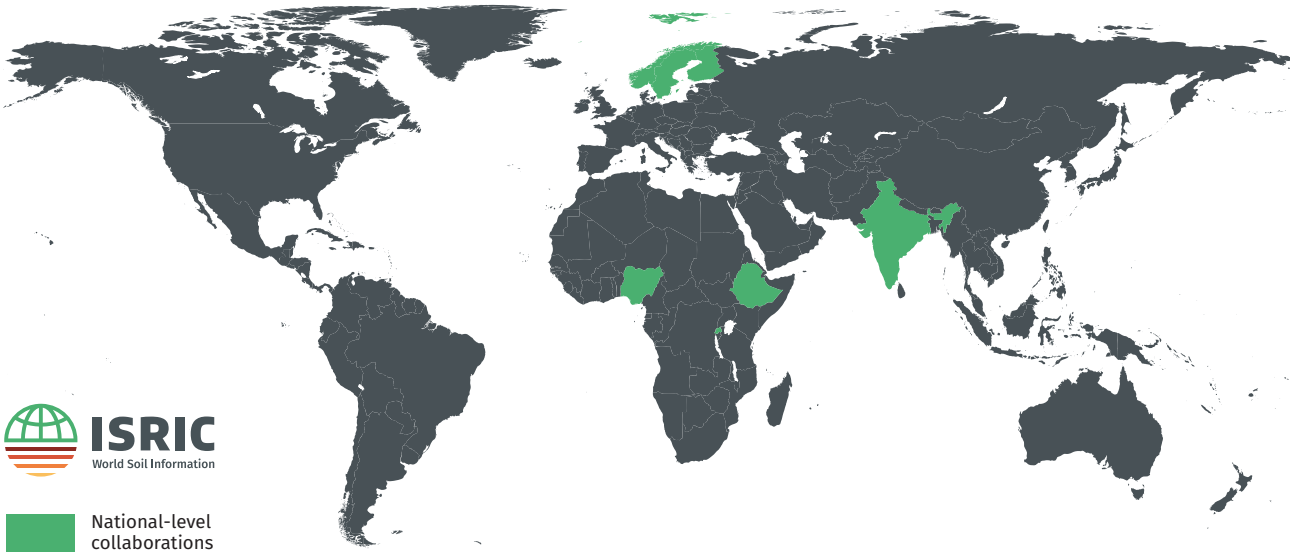
ISRIC led the predictive mapping and developed digital maps of soil fertility parameters, including macro- and micronutrients, at different scale levels for the states of Andhra Pradesh and Bihar. Further it developed a geoportal that serves these maps. The portal allows for easy access to the data layers by third parties. Together with Dr Dick Brus of Wageningen University, we elaborated a methodology for efficient sample size determination for future soil monitoring cycles in India based on soil data from past sampling cycles.

SUPPORTING NATIONAL LEVEL DECISION SUPPORT

We cultivate a community of practice for soil information professionals

Demand for soil information is steeply increasing at international, national, and sub-national levels in order to address climate change, sustainably intensify agricultural production, and improve land and water management. Acknowledging that global products cannot be used for local applications because of their limited resolution and accuracy, we support national level soil information providers in their endeavour to produce user oriented soil information products for their countries.

SOIL INFORMATION WORKFLOW



We do this by cultivating a community of practice for soil information professionals. A community of practice (CoP) is a group of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly. Our area of practice is soil information provisioning, and we aim to better connect and support others who work in this field, particularly national soil information institutes. Being a practitioner in the field of soil information systems involves working in these categories along the 'soil information workflow'.

In 2021, we prepared a concept for building new connections and resources to serve members of the community. In our CoP, we target national-level entities because they are best placed to develop high resolution and high accuracy soil information products for their territories. The approach builds on our current projects, trainings and professional relationships with national-level institutes. See map for work carried out in 2020 and 2021 in alignment with the community of practice concept.

India

On February 18, 2021, Prof. Gerard Heuvelink provided a training about 'Applications of Remote Sensing in Digital Soil Mapping' to the Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-Kashmir) in India. The training was attended by soil scientists from many Indian institutions including officers from the Department of Agriculture. His presentation was part of a 21-day programme designed by SKUAST-Kashmir's Remote Sensing and Geoinformatics Lab to build capacity for Indian soil scientists around the applications of remote sensing and geographic information system technology for natural resource management.

Nigeria: Collaborative agreement

In 2021, the Nigeria Institute of Soil Science (NISS) and ISRIC established a collaborative agreement to work closely together. The collaboration aligns with the NISS Action Plan which includes five pillars of action on key work such as strengthening of the Nigeria Soil Information System. Together, NISS and ISRIC will mutually strengthen one another by contributing to an active community of practice on soil information workflows and joint development of soil information applications such as soil fertility advice or land degradation assessment. Future activities between the two institutions could include researcher exchanges, joint research, exchange of academic information, and joint

Field registration of soil samples in Ethiopia. Image credit: Stephan Mantel.

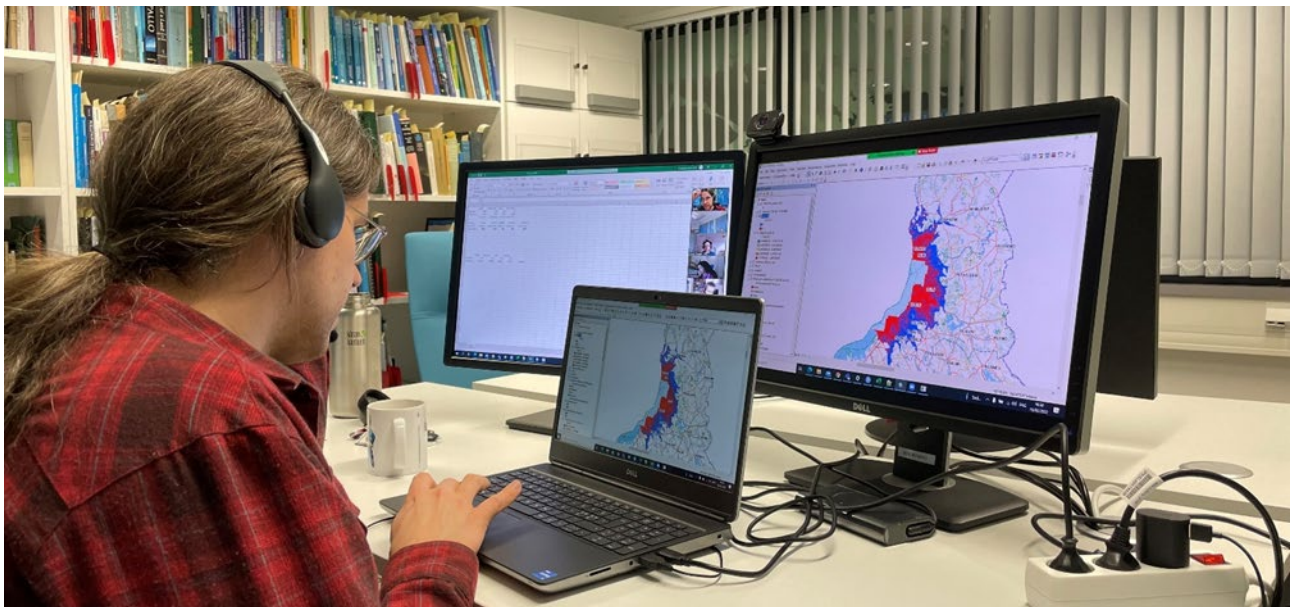
publications. One initial activity, in October 2021, was our colleague Johan Leenaars delivering a guest lecture to the Soil Science Society of Nigeria and the Nigeria Institute of Soil Science on the topic: 'Compiling a Nigerian Soil Profile database for agricultural development.'

Ethiopia: BENEFIT

Under the REALISE programme (Realising Sustainable Agricultural Livelihood Security in Ethiopia), ISRIC helped carry out a survey and mapping of soil resources. In collaboration with the BENEFIT programme, a partnership between the governments of Ethiopia and the Netherlands and the Ethiopian Ministry of Agriculture, ISRIC guided the survey and mapping of the soil resources at semi-detailed scale of 15 food insecure woredas or districts. A geomorphic base map covering the entire country at 50m resolution was produced and shared with the Ethiopian Ministry of Agriculture. World Reference Base soil classes were mapped using an innovative approach which included the prediction of disaggregated diagnostics and qualifiers. An ISRIC team performed a field correlation with selected national teams in different woredas.

Norway, Sweden and Finland: HazArctic

Between June and December 2021, ISRIC provided scientific and technical guidance on digital soil mapping to the geological surveys of Norway, Sweden and Finland. The focus was on mapping occurrence of acid sulphate soils in the Arctic region under the project 'HazArctic – Geo-Bio Hazards in the Arctic Region'. A one-week intensive training on digital soil mapping methodologies and workflows was provided to ten scientists of the geological surveys in June. This was followed by a series of technical working sessions later in the year.



A member of the HazArctic team creating a map of acid sulfate soil occurrences in the study area in Finland using online guidance by ISRIC. Image credit: Anton Boman.

Our collaboration with the three Nordic countries will be concluded in 2022 with a hands-on workshop to produce final map results.

Rwanda: RwaSIS

In 2020, ISRIC partnered in the Bill and Melinda Gates Foundation-funded project 'Rwanda Soil Information System' (RwaSIS). ISRIC's role was to provide capacity building on soil data compilation and standardisation as well as digital soil mapping to staff of the Rwanda Agricultural Board (RAB). The first one-week training course, given in September 2020, focussed on methods and workflows for bringing legacy soil data from disparate sources to a common, standardised format. This course was followed by a hands-on training session in January 2021 that resulted in a standardised soil dataset for Rwanda containing data from over 5,000 locations. The capacity building effort will be continued in 2022 with two more training courses on digital soil mapping methods and workflows for RAB staff.

Spring School

In addition to targeted national partnerships and trainings, we also provide an annual opportunity for anyone interested in improving their skills on soil assessment or digital soil mapping at the ISRIC Spring School. In 2020 the Spring School was postponed due to the coronavirus pandemic and in 2021 the weeklong course was adapted to be offered online for the first time given ongoing pandemic-related travel restrictions. Sixty-four participants representing 28 countries attended the 'Hands-on Digital Soil Mapping' and 'World Soil Assessment' courses offered during Spring School. The 'Hands-on Digital Soil Mapping' course provided a rigorous program with many applied exercises about methods and software for soil data management, analysis and mapping within the R environment, including geostatistics and machine learning. The 'World Soil Assessment' course provided participants with a robust understanding of international standards for soil classification and assessment including guided small group exercises.

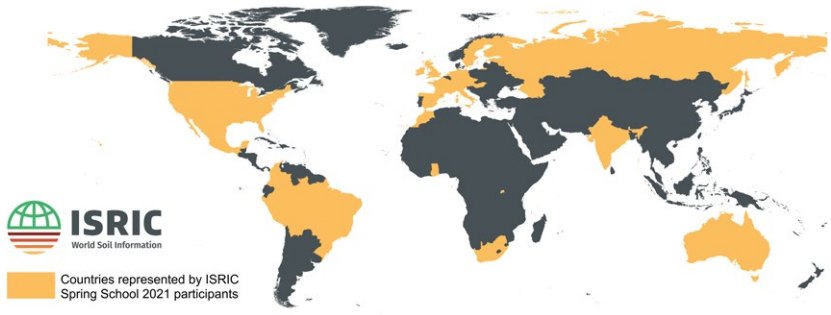


Image credit: Elie Ntirengaya

SUPPORTING NATIONAL LEVEL DECISION SUPPORT

We support the application of soil information for sustainable land management decisions

In 2020 and 2021, the sustainable land management (SLM) workstream was defined as part of ISRIC 's overall strategy. Through SLM, ISRIC aims to generate societal impact of its services. To generate societal impact, we actively engage with actors in the field of SLM to develop information products and services in support of decision making, best practices and applications. These are typically services based on soil data and other spatial data combined with modelling which provide land management decision-making support.

Partnering to create Land, Soil and Crop Information Services (LSC Hubs)

In 2021 the project 'Land, Soil and Crop Information Services to support Climate-Smart Agriculture (LSC Hubs)' started. The project aims to develop sustainable land, soil, crop information hubs in national agricultural research organisations in Ethiopia, Kenya and Rwanda to enhance the effectiveness of national agricultural knowledge and innovation systems and contribute to rural transformation and climate-smart agriculture in East Africa.

The project targets: policy bodies, knowledge organisations and development partners, organisations working with farmers including local landscape and watershed planning and management bodies, local public rural extension, NGOs, private sector, farmer organisations, and farmers themselves.

Project partners include Wageningen Research, ISRIC and the International Livestock Research Institute (ILRI). National partners are the Ethiopian Institute of Agricultural Research (EIAR), Kenya Agriculture and Livestock Research Organisation (KALRO) and Rwanda Agriculture Board (RAB).

The 4-year project is jointly funded by the European Union's Development Smart Innovation through the Research in Agriculture (DeSIRA) program, The Netherlands' Ministry of Foreign Affairs and a contribution from ISRIC.

www.isric.org/projects/land-soil-and-crop-information-services-lsc-support-climate-smart-agriculture-desira

Innovating with Land Potential Knowledge System (LandPKS)

In 2021, ISRIC was requested by the United States Agency for International Development (USAID) and United States Department of Agriculture (USDA) to take up responsibility for the hosting and further development of the LandPKS international tool consisting of a mobile app, data portal and knowledge hub with training and instruction materials. This tool facilitates collection of data on soil characteristics, land cover and land use in the field. It also blends collected data in the field with existing mapped data in order to develop accurate localised advisories on fertilisation and land suitability.

The request was translated into a 2-year project (June 2021-June 2023) signed with the International Fertilizer Development Corporation (IFDC) and funded by USAID. The project is a collaborative effort between the current LandPKS team of USDA Agricultural Research Service and the University of Colorado, IFDC and ISRIC. In 2021 the project worked on its inception phase, preparing overview of the current system, user needs and expectations and detailing the project workplan. The project aims to develop into a long-term working relationship between ISRIC and USAID, through its Soils Consortium, and IFDC.

https://landpotential.org

Guiding the World Overview of Conservation Approaches and Technologies (WOCAT) Network

The WOCAT Network and database are a foundational element of ISRIC's own sustainable land management programme, which aims to embed our soil information services in applications that are socially relevant and demonstrate societal impact. Through WOCAT, ISRIC supports the development of a global database of sustainable land management (SLM) technologies and practices, various tools related to Land Degradation Neutrality, and decision making for SLM.

ISRIC was a founding member of the WOCAT Network in 1992. Since then, WOCAT expanded to a global network of over 1300 institutional members that together have documented more than 1500 sustainable land management practices in its database, which can be used as a resource to select SLM measures for specific agro-ecological conditions.

In 2020 and 2021, ISRIC contributed to the restructuring of the WOCAT management structure to ensure greater ownership of the WOCAT partners and increased impact. Also, ISRIC started the modernisation

of WOCAT's spatial data infrastructure. ISRIC's activities are part of a two-year project with the University Bern, Centre for Development and Environment (CDE) and International Centre for Agricultural Research in Dry Areas (ICARDA), with funding from GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH) and Swiss Development Cooperation (SDC).

www.isric.org/news/isric-continues-wocat-support-30th-year

Soil description in soil pit on trial site in Cordoba, Spain.

Supporting improved crop varieties

The European Union Horizon 2020-funded project InnoVar ('Next-generation variety testing for improved cropping on European farmland') introduces innovations in crop variety testing using data science, genomics, phenomics and machine learning. ISRIC contributes to the project with acquisition, management and analyses of data on the environment (weather, soils) at InnoVar trial sites. We are carrying out field characterisation and sampling on 15 trial sites across Europe. Due to the Covid-19 pandemic travel restrictions, we adapted our work plan to contract local soil experts from the region of the trial sites for field work. Protocols were developed to ensure harmonised data. We developed an open-access tool for soil description to facilitate data entry during the fieldwork.

Developing more precise soil fertility management

In partnership with OCP (Office Chérifien des Phosphates) Africa, new and more precise fertiliser recommendations were developed in Mali and Senegal to improve upon blanket recommendations. Five out of the six new fertiliser recommendations developed for and tested by OCP Africa proved to significantly outperform the default blanket recommendations with on average 60-120% extra grain yield responses. This outperformance was absent on an area with salt-affected soils in Senegal. We concluded that the higher effectiveness was firstly explained by the site-specificness of the recommendations and secondly by the inclusion of micronutrients (See ISRIC's 2018-2019 Annual Report for additional details on this project with OCP Africa).

TAPESTRIES: Tracking Agriculture Productivity and the Environment: Soil and Terrain Rehabilitation for Integrated Ecosystem Services

ISRIC participated in a project that focusses on sustainable land management in Ethiopia aimed at developing tools for land planning, decision making, monitoring and impact assessment of Sustainable Land Management Plans. The project, called 'TAPESTRIES: Tracking Agriculture Productivity and the Environment: Soil and Terrain Rehabilitation for Integrated Ecosystem Services', is led by the Farming Systems Ecology group (FSE) of the Department of Plant Sciences of Wageningen University and is a collaboration between GIZ, FSE, German Aerospace Center (DLR), ISRIC and Ethiopian partners such as the Bureau of Agriculture and Mekelle University. We compiled information for building an erosion component for the FarmDESIGN model, based on the Revised Universal Soil Loss Equation.

ISRIC People

ISRIC Staff (listed in alphabetical order of first name)

Andre Kooiman
Senior sustainable land management expert

Andries Bosma
External relations manager

Bas Kempen
Senior digital soil mapping expert

Emily Toner
Community manager

Erika Henskens
Secretary

Fenny van Egmond
Soil sensing expert

Gerard Heuvelink
Professor pedometrics and digital soil mapping

Giulio Genova
Digital soil mapping expert

Godert van Lynden
Deputy director *(Retired in 2020)*

Ingrid Haas
Webmaster

Jan van Kleef
Workshop and collections assistant
(Retired in 2021)

Jelle Janssen
Research assistant

Johan Leenaars
Soil science expert

Jonathan Atkinson
Project coordinator

Jorge Mendes de Jesus
Spatial data infrastructures expert

Judy Willems
Secretary

Laura Poggio
Senior digital soil mapping and remote sensing expert

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Geoinformatics expert

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Mary Steverink-Mosugu
Senior project coordinator

Niels Batjes
Senior soil science expert and Coordinator WDC-Soils

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Spatial data infrastructures expert

Rik van den Bosch
Director

Stephan Mantel
Sustainable land management expert and Head of World Soil Museum

Ulan Turdukulov
Senior spatial data infrastructures expert

Yolanda Karpes-Liem
Secretary *(Retired in 2020)*

Zhanguo Bai
Senior soil and land degradation assessment expert

Board

Prof. Dr. P.C. de Ruiter
Professor Emeritus, Wageningen University and Research (WUR) and University of Amsterdam, The Netherlands (2020 and 2021, Chair)

Prof. Dr. R.N.J. Comans
Soil Chemistry and Chemical Soil Quality, Wageningen University and Research (WUR), The Netherlands (2020 and 2021, member)

Dr. Ir. J.E.M. Baartman
Assistant Professor, Soil Physical and Land Management, Wageningen University and Research (WUR), The Netherlands (2020 and 2021, member)

Prof. Dr. Ir. A. Veldkamp
ITC, University of Twente Enschede, The Netherlands (2020 and 2021, member)

M. Roos MSc
Director of Operations, Environmental Sciences Group, Wageningen University and Research (WUR), The Netherlands (2020 and 2021 member, left the board in July 2021; succeeded by Dr. F. Senf in February 2022)

Machteld Roos receives flowers during her farewell as a board member.

PhD candidates

Name and topic / Thesis title	Status (Dec. 31, 2021)
Cynthia van Leeuwen The development and use of a soil database with quantified uncertainties	ongoing
Stephan van der Westhuizen Enhancement of the use of machine leaning in digital soil mapping	ongoing
Eric Asamoah Machine learning for fertilizer recommendation in Ghana	ongoing
Mirjam Breure Models for predicting nutrient availability in soils from sub-Saharan Africa	ongoing
Bertin Takoutsing Digital soil mapping using uncertain soil measurements to support sustainable agricultural intensification in West and Central Africa	ongoing
Yingxia Liu Statistical analysis and modelling of crop yield and nitrogen use efficiency in China	ongoing
Luc Steinbuch Model-based Bayesian geostatistics for multi-scale mapping of soil and agronomic variables	Completed on 22 April 2021

MSc students

Name and topic / Thesis title	Completion date
Chloé Girka Digital soil mapping with uncertain data	February 2021
Tom van Ebbenhorst Tengbergen Critical evaluation and improvement of cross-validation strategies for accuracy assessment of digital soil maps	February 2021
Lisanne Schoneveld Added value of synthetic profiles with particular reference to soil organic carbon predictions in SoilGrids	May 2020
Merel Jager Influence of local data and local calibration on SoilGrids predictions	May 2020

Guest researchers

Maria Eliza Turek from the Federal University of Paraná (Brazil) received a CLIFF-GRADS scholarship to support her research at ISRIC on 'global mapping of volumetric water retention' (October 2020 – April 2021).

Giulio Genova from University of Bozen-Bolzano and the EURAC Research Institute for Alpine Environment joined ISRIC from September 2020 to February 2021 to advance efforts to apply deep learning to digital soil mapping.

David Rossiter supported ISRIC in many ways, among others as an in-house strategic consultant, contributions to the annual ISRIC Spring School, and occasional research collaborator (e.g., statistical evaluation of spatial patterns of SoilGrids).

Ad van Oostrum supported ISRIC by advising on soil analytical methods and by testing methods to quantify errors in laboratory measurements.

In commemoration

Mateen Ahmad†, our valued colleague from 1991 to 2009 worked on the preparation of soil monoliths.

Wout Bomer†, our esteemed colleague from 1979 to 2010 provided support with respect to documenting the soil monolith collection, digitisation of the slide collection; responsible for graphical design and photography.

Scientific Research

ISRIC is a science-based organisation which is rooted in and contributes to the science behind soil information. In 2020 and 2021, we published 42 papers in 27 peer-review international scientific journals.

Notable publications include:

Angelini, M. E., Kempen, B., Heuvelink, G. B. M., Temme, A. J. A. M. and Ransom, M. D (2020), Extrapolation of a structural equation model for digital soil mapping. Geoderma 367, 114226.

Leenaars, J. G. B., Elias, E., Wösten, J. H. M., Ruiperez-González, M. & Kempen, B. (2020), Mapping the major soil-landscape resources of the Ethiopian Highlands using random forest. Geoderma 361, 114067.

Richer-de-Forges, A. C., Lowe, D. J., Minasny, B., Adamo, P., Amato, M., Ceddia, M. B., dos Anjos, L. H. C., Chang, S. X., Chen, S., Chen, Z. S., Feller, C., García-Rodeja, E., Goulet, R. C., Hseu, Z. Y., Karklins, A., Kim, H. S., Leenaars, J. G. B., Levin, M. J., Liu, X. N., Maejima, Y. and 22 others (2020), A review of the world's soil museums and exhibitions. Advances in Agronomy 166, 277-304.

Rossiter, D.G. (2021), Are soil phenoforms the new normal? Soil classification and soil mapping in the Anthropocene. Soil Security 5, 100017.

Smith, P., Soussana, J-F., Angers, D., Schipper, L., Chenu, C., Rasse, D.P., Batjes, N.H., van Egmond, F., McNeill, S., Kuhnert, M., Arias-Navarro, C., Olesen, J.E., Chirinda, N., Fornara, D., Wollenberg, E., Álvaro-Fuentes, J., Sanz-Cobena, A. and Klumpp, K. (2020). How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biology 26, 219-241.

A more exhaustive list of our publication history can be found here.

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