ANNUAL REPORT
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Message from the Director

Appropriate soil and land use is vital for climate change adaptation and mitigation. Transforming agriculture to meet the needs of an expanding population and facilitate inclusive, agriculture-led economic growth requires an in-depth understanding of soil. After the oceans, soil is the largest pool of carbon storage, and therefore, it can be seen as a climate regulator with an untapped potential to fight climate change. The bottom line is that if we want to preserve and protect our world, we must invest in sustainable soil and land management.

At ISRIC - World Soil Information, we support decision-making for sustainable soil and land management by increasing soil knowledge and information globally. We use our long-term soil expertise to develop soil information products and services, science-based tools, methods, and community standards. Our capacity-strengthening programme is crucial for the development and application of soil information globally.

In recent years, we have seen an increased interest in soil from governments, funders and the international community. Our efforts to further develop our global products WoSIS and SoilGrids have focussed on increasing the number of supporting data points, improving accuracy through innovative mapping approaches, and developing additional global data layers. We are happy to see the ever-increasing number of users for these global products and the diversity of their applications.

Guided by the increased policy interest of the African Union, we have seen an encouraging and improved cooperation between national institutions, international institutions and funders on the African continent. The Community of Practice for Soil Information Providers, set up and supported by ISRIC, brings together individuals from 28 African countries to develop and share soil information. Additionally, the Soils4Africa project is building an innovative open-access Soil Information System (SIS) for the continent.

Fertiliser is a critical component of intensive and sustainable agricultural systems, allowing greater productivity from existing land under cultivation. The Space to Place initiative will provide improved and localised soil fertility recommendations for the sustainable and cost-efficient use of fertilisers by farmers in Africa. A sound understanding of soil in a specific location is key for developing these recommendations. Complementary to this is the Land, Soil and Crop Information Services (LSC-IS) project, which develops sustainable land, soil, and crop information hubs in agricultural research organisations to eventually benefit 1.2 million farmers in Kenya, Ethiopia, and Rwanda.

The Horizon Europe programme of the European Union allows us to work together with top-level research organisations to advance innovative methods and tools for soil information at scale. For instance, the SoilWise project is developing a data and knowledge repository and an integrated access point for Findable, Accessible, Interoperable and Re-usable (FAIR) soil data. The project Operationalising the International Research Consortium on Soil Carbon (ORCaSa) seeks to establish a consistent, scalable, and standardised methodology for measuring, modelling, monitoring, reporting and verifying net soil carbon stock change to support the EU Green Deal. Further, it aims to establish an International Research Consortium on soil carbon.

Nestled in our building is ISRIC's World Soil Museum and its World Soil Reference Collection and Library. These bring awareness and advocacy to the public and support global institutions, academics, and artists with world-class research and innovation.

The activities and achievements mentioned above were possible thanks to ISRIC's dedicated staff, guest researchers, volunteers, and the Board. We are passionate about our work in soil and strive for collaboration and excellence in the sector to benefit our planet. We would not be able to do our work without the support of the Ministry of Agriculture, Fisheries, Food Security and Nature in the Netherlands, along with many other international funders and partners. It is only with their support that ISRIC can contribute to an increased understanding of soils for sustainable land management.

Rik van den Bosch

Director of ISRIC – World Soil Information

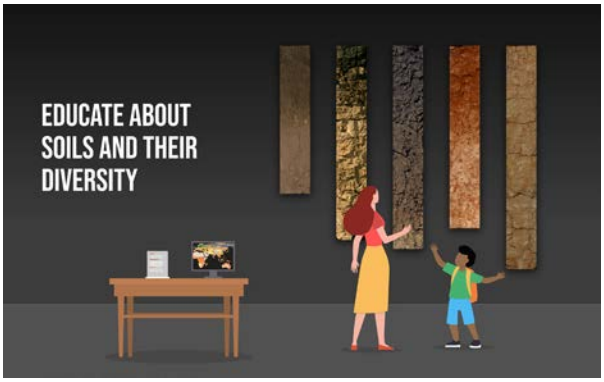
This is ISRIC

Founded in 1966, ISRIC began by assembling and documenting the world's main soil types. In 1989, ISRIC was accredited as the World Data Centre for Soils, and since then, the organisation has developed into a leading global authority in soil information.

Since its beginnings, ISRIC has grown into an independent, science-based foundation that serves the international community as a custodian of global soil information. Based on sound science, the organisation develops and uses consistent approaches, methods and data to build its products and services. It has built a solid reputation for providing global information products on soils and land, technical capacities, and IT infrastructure. ISRIC is dedicated to supply quality-assessed soil information and knowledge to address pressing global issues by providing:

- Innovative and science-based soil data products for global users.
- Standards, tools, capacity strengthening, and direct collaboration for the development and use of soil information products and systems at sub - and - national levels in the Global South.
- Education, research, and awareness raising through the World Soil Museum and the World Soil Reference Collection.

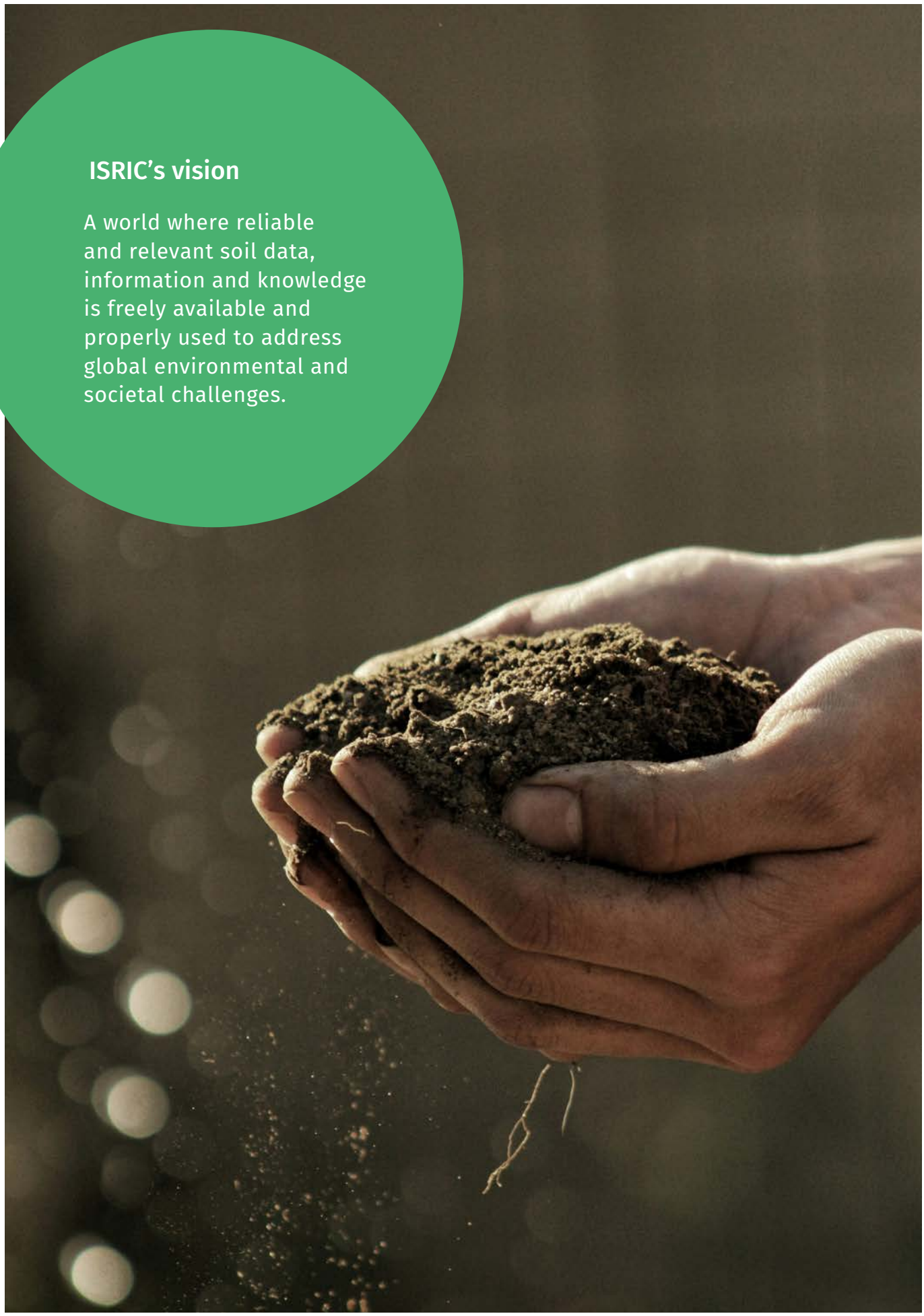
ISRIC's efforts are driven by a strategy which aims to:



Through its activities and strategy, ISRIC increases the availability and use of soil data, information, and knowledge to enable better decision-making for sustainable land management; and democratises the world of soil information by promoting open science principles. This contributes to solving societal challenges in food production, climate change adaptation and mitigation, and biodiversity conservation.

ISRIC's 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.



Quick overview of 2022 and 2023

In 2022 and 2023, ISRIC worked on an array of soil projects and activities in 17 countries. Highlights include:

- The World Soil Information Service (WoSIS) is an extensive open-source database which now freely serves quality-assessed, standardised soil data for 228,000 geo-referenced profiles, representing more than 6 million soil records. WoSIS provides the world's most extensive and consistent soil information web service.
- The unique SoilGrids maps are derived from soil profile observations from WoSIS and over 400 global environmental data layers using digital soil mapping.
- The Soils4Africa project built a prototype for an open-access Soil Information System (SIS) for the African continent.
- In the framework of the Operationalising the International Research Consortium on Soil Carbon (ORCaSa) project, ISRIC led the review of the soil carbon MRV (Monitoring, Reporting and Verification) initiatives at the international level with a view to provide a framework for future harmonisation.
- The future SoilWise repository for soil data and knowledge for the European Union Soil Observatory will allow better-informed decision-making at EU, national and regional levels towards the 2030 Green Deal goals.
- The establishment of the Africa Soil Information Community of Practice brings together members from 28 countries with the goal of knowledge sharing, collaboration, and innovation in soil information.
- For the Land, Soil and Crop Information Services (LSC-IS) project, more than 240 land, soil, and crop information sources in Ethiopia, Kenya and Rwanda were compiled to eventually benefit the livelihood of 1.2 million farmers.
- The innovative Decision Support Tool developed in the Space to Place project allows farmers to receive on-the-spot recommendations to improve soil fertility and food security.
- The World Soil Museum continues to be ISRIC's pride and joy, with numerous exhibitions attracting over 3,000 visitors, and inspiring residential artists with soil-related artworks.
- The samples of the World Soil Reference Collection provide baseline information for innovative research, such as the development of the first global soil DNA microbial reference database.

"Essentially, all life depends upon the soil... There can be no life without soil and no soil without life; they have evolved together."

Charles E. Kellogg, Soil Scientist, 1938

Why soil?

Soil plays a vital role on earth, and its importance drives ISRIC's work. It is one of our most valuable resources because it holds water, is home to living beings and microorganisms, and plays a crucial role in the earth's ecosystem, the balance of chemical elements, and the composition of matter. Soil affects many areas of life, including agriculture, environmental management, nature protection, landscape architecture, urban applications, and human health and well-being. Without soil, life would not be sustainable.

According to the Status of the World Soil Resources Report (FAO, 2015), 33% of land is moderately to highly degraded due to erosion, salinisation, compaction, acidification and the chemical pollution of soils. Preserving and understanding soil, and collecting data and managing it, are all vital to keeping soil healthy, restoring its quality, and addressing the UN Sustainable Development Goals and the impact of climate change. This is very much a part of ISRIC's mission.

ISRIC works in four thematic areas, and they include:

1. **Provisioning of global and regional soil data and information.**
2. **Supporting national-level soil information providers.**
3. **Applying soil information for sustainable land management.**
4. **Advocating and educating on the diversity and importance of soil.**

Learn more about each thematic area below.

1: Provisioning of global and regional soil data and information

ISRIC provides soil information and data to the global and national soil community and ensures that this is accessible and comparable to suit a range of disciplines, applications, and sectors. Through ISRIC's flagship soil information products (WoSIS and SoilGrids), the organisation collates, quality-assesses, standardises, and provides credible open data to its community using reliable approaches and expertise.

World Soil Information Service (WoSIS)

The World Soil Information Service (WoSIS) is an extensive open-source database management system with application programming interfaces. It draws on soil data shared by numerous data providers, and systematically cleans and standardises the source data using consistent workflows. The cleaned and "shared" datasets are freely available to the international community.

WoSIS-served data can be used for predictive soil property mapping, space and time modelling of soil organic carbon stock change, and various regional to global environmental assessments. The products derived from WoSIS are crucial for creating awareness and informing policymakers, business leaders, and conventions (e.g., the United Nations Convention to Combat Desertification and the United Nations Framework Convention on Climate Change) because they support knowledgeable decisions about the environment, biodiversity, climate change, and human well-being.

ISRIC's impact in 2022 and 2023:

WoSIS serves quality-assessed, standardised data for approximately 228,000 geo-referenced profiles (or points), representing more than 6 million soil records. These include soil chemical properties (organic carbon, total carbon, total carbonate equivalent, total nitrogen, phosphorus, soil pH, cation exchange capacity, and electrical conductivity), physical properties (soil texture, sand, silt, and clay), bulk density, coarse fragments, and water retention, as well as soil classification-related information. Arguably, WoSIS provides the most extensive, consistent soil information web service for the world.

WoSIS system upgrades: The data model was overhauled and the procedures for extracting, transforming, and loading disparate source data were refactored. Further, novel procedures for querying (e.g., dashboards), serving, and downloading profile data were standardised and implemented. All developments are based on open-source software, to ensure the accessibility of the publicly available data.

To access WoSIS, visit the following website.

To explore the public version of WoSIS see the WoSIS Soil Profile Database.

WoSIS – Standardised soil data for the world

WoSIS is a trustworthy source of quality-assessed, standardised soil profile (point) data for the world. The publicly available data are used for a wide range of applications, including ISRIC's own SoilGrids products (see page 13).

According to Web of Science, the "WoSIS snapshots" (for 2016 and 2019) are cited 324 times across various journals, as demonstrated in some examples below:

Hartley, I. P., Hill, T. C., Chadburn, S. E., & Hugelius, G. (2021). Temperature effects on carbon storage are controlled by soil stabilisation capacities. Nature Communications, 12(1), 6713. https://doi.org/10.1038/s41467-021-27101-1

Ivushkin, K., Bartholomeus, H., Bregt, A. K., Pulatov, A., Kempen, B., & de Sousa, L. (2019). Global mapping of soil salinity change. Remote Sensing of Environment, 231, 111260. https://doi.org/10.1016/j.rse.2019.111260

Nenkam, A. M., Wadoux, A. M. J. C., Minasny, B., McBratney, A. B., Traore, P. C. S., Falconier, G. N., & Whitbread, A. M. (2022). Using homosoils for quantitative extrapolation of soil mapping models. European Journal of Soil Science, e13285. https://doi.org/10.1111/ejss.13285

Poggio, L., de Sousa, L., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Riberio, E., & Rossiter, D. (2021). SoilGrids 2.0: Producing soil information for the globe with quantified spatial uncertainty. SOIL, 7(1), 217–240. https://doi.org/10.5194/soil-7-217-2021

Schillaci, C., Perego, A., Valkama, E., Märker, M., Saia, S., Veronesi, F., Lipani, A., Lombardo, L., Tadiello, T., Gamper, H. A., Tedone, L., Moss, C., Pareja-Serrano, E., Amato, G., Kühl, K., Damatirca, C., Cogato, A., Mzid, N., Eeswaran, R., Rebelo, M., Sperandio, G., Bosino, A., Bufalini, M., Tunçay, T., Ding, J., Fiorentini, M., Tiscornia, G., Conradt, S., Botta, M., & Acutis, M. (2021). New pedotransfer approaches to predict soil bulk density using WoSIS soil data and environmental covariates in Mediterranean agro-ecosystems. Science of The Total Environment, 146609. https://www.sciencedirect.com/science/article/pii/S0048969721016776

Sothe, C., Gonsamo, A., Arabian, J., & Snider, J. (2022). Large-scale mapping of soil organic carbon concentration with 3D machine learning and satellite observations. Geoderma, 405, 115402. https://www.sciencedirect.com/science/article/pii/S0016706121004821

Tao, F., Huang, Y., Hungate, B. A., Manzoni, S., Frey, S. D., Schmidt, M. W. I., Reichstein, M., Carvalhais, N., Ciais, P., Jiang, L., Lehmann, J., Wang, Y.-P., Houlton, B. Z., Ahrens, B., Mishra, U., Hugelius, G., Hocking, T. D., Lu, X., Shi, Z., Viatkin, K., Vargas, R., Yigini, Y., Omuto, C., Malik, A. A., Peralta, G., Cuevas-Corona, R., Di Paolo, L. E., Luotto, I., Liao, C., Liang, Y.-S., Saynes, V. S., Huang, X., & Luo, Y. (2023). Microbial carbon use efficiency promotes global soil carbon storage. Nature, 618(1), 981-985. https://doi.org/10.1038/s41586-023-06042-3

Turek, M. E., Poggio, L., Batjes, N. H., Armindo, R. A., de Jong van Lier, Q., de Sousa, L., & Heuvelink, G. B. M. (2023). Global mapping of volumetric water retention at 100, 330 and 15,000 cm suction using the WoSIS database. International Soil and Water Conservation Research, 11(2), 225-239. https://www.sciencedirect.com/science/article/pii/S2095633922000636

SoilGrids

SoilGrids is a system for global digital soil mapping that uses global soil profile information and environmental layers to model the spatial distribution of soil properties across the globe.

Volumetric water content at -33KPa from SoilGrids 2.0 (Turek et al, 2023).

SoilGrids soil property maps are derived from soil point data served from WoSIS. Using state-of-the-art machine learning methods, SoilGrids generates global maps of soil properties at medium spatial resolution (250 m cell size) at six standard depths. The inputs for the maps include soil observations from about 240,000 locations worldwide and over 400 global environmental layers describing vegetation, terrain morphology, climate, geology and hydrology.

ISRIC's impact in 2022 and 2023:

The SoilGrids website had almost 12,000 unique visits. On average, 16 unique visits are documented daily, demonstrating its relevance to target audiences in the soil, environment and climate change sectors.

Improving soil global mapping data for users. SoilGrids is a platform for an audience seeking soil information for various applications. To respond to user and data needs, ISRIC focussed on:

- The development of soil-water content information at three pressure heads. The global layers are available on the website since 2023. The results were published as a peer-reviewed journal article (Turek et al, 2023).
- Improvements to the SoilGrids mapping workflow and data serving platform, using the latest technologies for serving geospatial data.
- Exploratory work for global soil functional indicators layers, such as the presence and absence of high organic carbon content, and defining soil depth data to complement the soil carbon stock layer.

To access the SoilGrids products, visit the following website.

SoilGrids – A trustworthy source

SoilGrids is a trustworthy source for scientists and academics. According to Web of Science, SoilGrids is cited 684 times. The platform is widely used for global studies across disciplines (ecology, farming, environment, etc.) and in various prestigious journals as listed below:

Lessmann, M., Ros, G., Young, M., & de Vries, W. (2022). Global variation in soil carbon sequestration potential through improved cropland management. Global Change Biology, 28(3), 1162-1177. https://doi.org/10.1111/gcb.15954

Noon, M., Goldstein, A., Ledezma, J., Roehrdanz, P., Cook-Patton, S., Spawn-Lee, S., Wright, T., Gonzalez-Roglich, M., Hole, D., Rockström, J., & Turner, W. (2022). Mapping the irrecoverable carbon in Earth's ecosystems. Nature Sustainability, 5(1), 37-46. https://doi.org/10.1038/s41893-021-00803-6

Tedersoo, L., Mikryukov, V., Zizka, A., Bahram, M., Hagh-Doust, N., Anslan, S., Prylutskyi, O., Delgado-Baquerizo, M., & others. (2022). Global patterns in endemicity and vulnerability of soil fungi. Global Change Biology, 28(28), 6696-6710. https://doi.org/10.1111/gcb.16398

Soils4Africa

Soils4Africa is a continent-wide project to systematically collect new soil data and build an open-access Soil Information System (SIS) for Africa. The project is funded by the Horizon 2020 programme of the European Union.

Access to good-quality data is essential for making well-informed decisions. In collaboration with 17 partners, Soils4Africa will provide an open-access information system that includes soil data gathered and analysed through a standardised methodology for future soil monitoring across Africa's agricultural land. The project defined a set of use cases for the SIS and is developing soil quality indicators to support these.

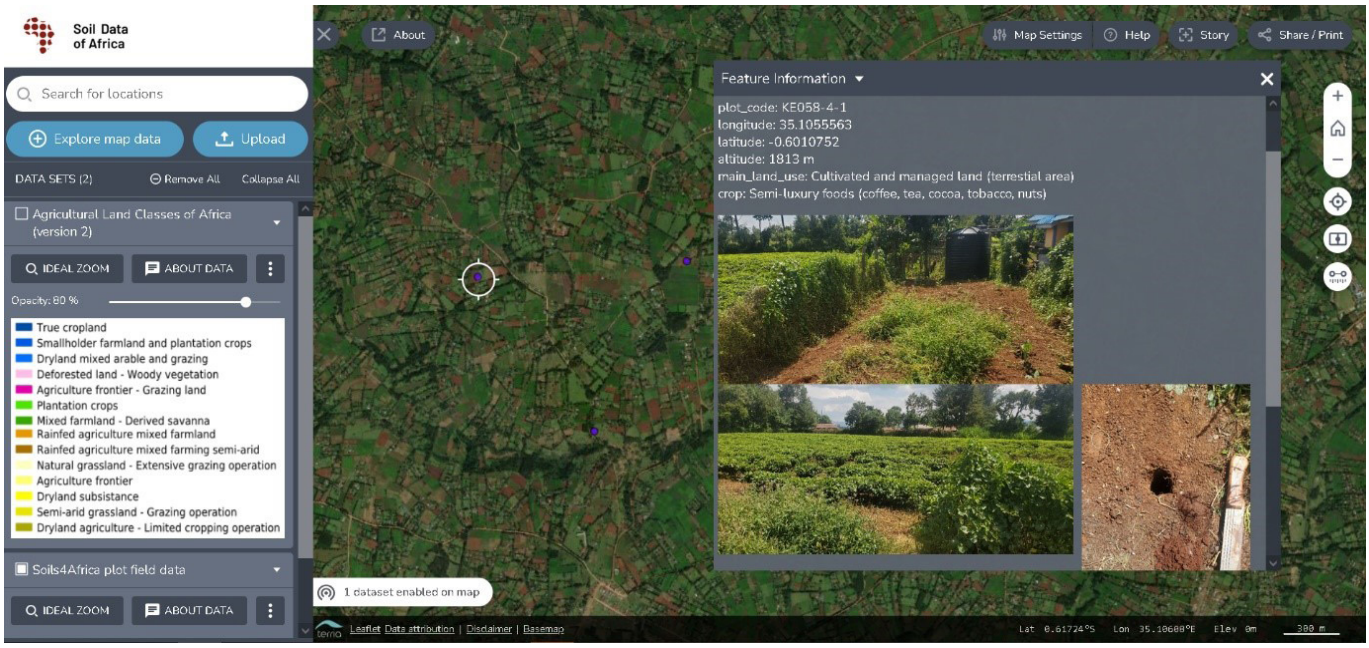
The SIS is designed to efficiently organise, analyse, manage and disseminate soil data and information on the African continent from national to continental scale.

Demonstration of the field sampling technique at the Soils4Africa Annual Project Meeting in Ghana (May 2023).

Upon completion (estimated in 2025), the populated SIS will serve as a baseline assessment of soil conditions in Africa's agricultural land, support sustainable agricultural production, and be useful for many stakeholders (researchers, policymakers, governments, and non-governmental organisations).

ISRIC's impact in 2022 and 2023:

Development of the SIS: Significant progress in four areas was made concerning the development and fine-tuning of various components of the SIS. First, a relational database capable of storing soil field and laboratory data was deployed, and it is supported with workflows automatically loading data from the field data collection systems into the database. Second, a web interface was developed to assist users with data discovery in the database. Third, a geospatial data catalogue was set up that allows users to explore over 50 continental data layers relevant to sustainable agriculture. The catalogue is supported by a webGIS through which users can visualise and explore a large set of geospatial data layers. A fourth component is a data dashboard which provides an overview of soil data collected from agricultural land on the continent. All SIS components comply with international standards for soil data storage and exchange. ISRIC currently hosts the prototype SIS, but at the end of the project the operational system will be transferred to an African organisation.



The webGIS of the soil information system shows information collected at the soil sampling sites across Africa.

Development of the sustainability and funding strategies for the SIS: A sustainability strategy for the SIS was developed, and it identified the emerging development of the Soil Initiative for Africa (SIA) as the logical landing place for the SIS. The SIA offers a long-term plan to enhance the health and resilience of Africa's soil across all agricultural sectors by boosting agricultural productivity, improving water availability, increasing resilience to climate change, transforming smallholder farms into profitable businesses, and encouraging sustainable practices in commercial farming through knowledge and technology transfer. One of SIA's thematic components is to develop reliable continental soil information, demonstrating the relevance of the approach and outcomes of the Soils4Africa project for future agricultural sustainability efforts in Africa.

Why is the Soils4Africa project so important?

Conducting agricultural research in Africa presents a myriad of challenges, ranging from infrastructural limitations to socio-economic and environmental factors.

Soils4Africa is a unique project with standard and uniform methodologies for soil monitoring and assessment across the continent. The assessment is conducted by sampling soil, analysing it and then translating the findings into useful data products for a variety of users. The soil analysis is conducted in one laboratory in Africa, which also serves as repository for the soil samples.

The project includes a strong capacity-strengthening component. By the end of 2023, the Soils4Africa project trained more than 280 field surveyors and country supervisors on the use of new tools, protocols and standard operating procedures for soil sample collection and field assessment. The tools are user-friendly, accessible, and available in different formats and languages on the project website.

Source: Soils4Africa field campaign coordination and field surveyors and country supervisors from Cameroon, Kenya, Nigeria, Malawi.

Field registration of soil samples in Ethiopia. ©Stephan Mantel

> *"The Soils4Africa project is unique in that the sampling methodology is digital and uniform throughout the nations involved. The design of the Survey Data Management Tool makes supervision and monitoring of fieldwork effective. The sampling methodology ensures that areas of interest are well covered and represented. The validity of the results is assured for the sustainable applications of the outputs, and the templates will be very useful for future mapping or land use monitoring."*
>
> Olufunmilayo T. Ande
> Soils4Africa Country Supervisor
> Institute for Agricultural Research and Training
> Ibadan, Nigeria.

Operationalising the International Research Consortium on Soil Carbon (ORCaSa)

The Operationalising the International Research Consortium on Soil Carbon (ORCaSa) EU H2020 project aims to enhance global collaboration and data sharing among researchers focusing on soil carbon management and its role in climate change mitigation and adaptation. By bringing together various stakeholders, including scientists, policymakers, and land managers, ORCaSa seeks to establish standardised methodologies for measuring, monitoring and verifying soil carbon stocks and greenhouse gas flux changes. The project's goals include providing effective strategies for carbon sequestration in soils, promoting sustainable land use practices, and informing policies that support soil health and ecosystem resilience. Through innovative research and a focus on actionable solutions, ORCaSa contributes to high-level global efforts in mitigating and adapting to the impacts of climate change while fostering environmental sustainability. This notable project, focussing on the earth's well-being, is supported by the Horizon Europe initiative.

A picture of the participants in the ORCaSa project kick-off event at the EU Joint Research Centre in Ispra, Italy (26-28 October 2022).

ISRIC's impact in 2022 and 2023:

Establishment of ORCaSa. In 2022, the ORCaSa consortium focussed on project set-up, establishing the International Research Consortium (IRC) on Soil Carbon, and fostering buy-in from stakeholders.

Towards a standardised MRV framework. One aim of ORCaSa is to develop a standardised framework to monitor, report, and verify (MRV) soil organic carbon stock changes. ISRIC co-organised one webinar and two international workshops in 2023, bringing together a network and community of scientists and experts across Europe and beyond to review and gather information on MRV initiatives, methodologies, limitations and recommendations. Partially with input from this community, a technical report on MRV approaches and methodologies was prepared in an activity led by ISRIC. Building on this comprehensive review, in the next

phase, coordinated by the French National Research Institute for Agriculture, Food and the Environment (INRAE), ORCaSA will develop a “cookbook” for users and a MRV prototype applicable in agriculture, different contexts and at different levels of complexity.

Further, ISRIC provided feedback and advice concerning the development on an online platform that collects knowledge and information on soil carbon and makes it available to the public. The platform will drive cooperation and knowledge sharing on soil carbon at an international level. The development of the platform is led by the French Agricultural Research Centre for International Development (CIRAD) and will be launched in 2024.

Cereal System Initiative South Asia (CSISA 4.0)

A CSISA workshop in Patna, Bihar, to discuss the progress of developing digital soil maps (September 2023).

The Cereal Systems Initiative for South Asia (CSISA) is led by the International Maize and Wheat Improvement Center (CIMMYT). It is a science-driven and impact-oriented regional initiative to increase the productivity of cereal-based cropping systems in Bangladesh, India, and Nepal to improve food security and farmers’ livelihoods. The initiative has now expanded to the next phase (CSISA 4.0).

ISRIC’s contribution to the CSISA 4.0 project was to support the development of soil information products and analytical approaches for improving land productivity and transforming soil health management initiatives, which will be adapted and deployed by the National Agricultural Research and Education System.

A view of rice fields and hills on the outskirts of Bhaktapur, Nepal. ©Giulio Genova

ISRIC's impact in 2023:

Twelve maps with supporting documentation of soil fertility properties were produced for the state of Bihar. The maps at 100 m spatial resolution, the first of their kind for the region, aim to inform fertiliser policies in the state. The maps were generated by a machine learning algorithm trained to produce digital soil maps using vast soil observational data and satellite imagery. The maps were produced with a semi-automated, reproducible digital soil mapping (DSM) workflow that facilitates future updates. The maps became part of the state's BIHAN app, which the government of Bihar uses as a tool for agricultural extension.

Facilitating the allocation of fertiliser subsidies: The DSM-generated maps can be used by the Bihar Government to optimise the allocation of fertiliser subsidies to farmers. For example, they are used to identify areas with a zinc deficiency in soil, and as a result, subsidies can be directed specifically to regions in need. This targeted approach optimises resource use, minimises waste, and reduces unnecessary expenditure.

Area-specific land reclamation schemes: The Bihar Government plans to develop a policy for land reclamation schemes guided by DSM, focusing on addressing soil degradation and promoting sustainable land management practices.

Streamlining soil health monitoring: With the insights provided by the DSM, the Bihar Government has decided to reduce the volume of soil samples collected under the Soil Health Card Scheme. This decision will make soil health monitoring more efficient and ensure accurate and actionable data for sustainable agricultural practices.

SoilWise

The SoilWise repository will provide a common entry point (platform) for information, data and knowledge exchange on soils for European countries, the European Commission, and other stakeholders, to guide soil and spatial policy towards the 2030 Green Deal goals and achieve healthy soils by 2050. The platform aims to encourage informed decision-making across sectors (land managers, policymakers, researchers, and industry).

Metadata in SoilWise will be made FAIR (findable, accessible, interoperable, and reusable), while respecting data ownership, access policies and privacy. The open data and knowledge metadata repository itself will be built using existing and new (mostly open source) technologies.

Within the consortium, ISRIC will lead the a) co-design of the SoilWise repository and provide knowledge and experience on soil data, standards, information systems, and applications, b) develop tools and a strategy to ensure "data FAIRness", and c) engage stakeholders to ensure a user-driven design and maximise impact and outreach.

Impact in 2023:

The project brings together experts from the data, soil data, and soil science domains. Since nominally common concepts sometimes differ, considerable effort was put into understanding the user stories, terminology, and needs for the repository. This resulted in usage scenarios and requirements for the SoilWise Repository.

ISRIC's expertise in establishing recognised standards for handling and interpreting soil data

ISRIC's mission is to serve the international community with information about the world's soil resources to help address major global issues and to ensure that this information adheres to defined, international standards. With its partners, ISRIC is maintaining and developing new standards for handling and interpreting soil data. For example, the GloSIS global soil data exchange standard is supported by the EJP SOIL project and ISRIC and in collaboration with the SIEUSOIL project. In 2022 and 2023, significant progress has been made on developing vocabularies, codelists and a semantic web implementation of the GloSIS standard.

ISRIC is proactive in various working groups of the International Union of Soil Science (IUSS): the Soil Information Standards Working Group, the World Reference Base Working Group, the Digital Soil Mapping Working Group, and in working groups of the Open Geospatial Consortium (OGC), the Global Soil Partnership (GSP): the International Network of Soil Information Institutes (INSII), the Global Soil Laboratory Network (GLOSOLAN), and is a member of the CoreTrustSeal Trustworthy Data Repositories assembly of reviewers.

As indicated by RDA-CODATA, the "ability of the research community to share, access, and reuse data, as well as to integrate data from diverse sources for research, education, and other purposes requires effective technical, syntactic, semantic, and legal interoperability rules and practices." An important aspect here is that data should comply with FAIR principles and be "findable, accessible, interoperable, and reusable." ISRIC's Spatial Data Infrastructure follows open-source and FAIR standards, and tools are developed and integrated as much as possible in all ISRIC projects and the community the organisation works with.

For soil description, an open-access field work tool was developed and made available through ISRIC – World Soil Information: Soil Description DevTool. The licensed Soil Description DevTool is powered by an Open Data Kit (ODK) form. The tool works through smartphones and is used by professionals in the field who will describe soils using the United Nations' Food and Agriculture Organisation (FAO) 2006 Guidelines for Soil Description standard.

2: Supporting national-level soil information providers

ISRIC supports national institutions in understanding the importance of soil information and the elements to be considered in setting up a Soil Information System (SIS). ISRIC is committed to developing actionable soil information to support decision-making in sustainable soil, land management and environmental conservation efforts. ISRIC provides soil information products, science-based tools, methods, standards, and capacity strengthening to meet the needs of stakeholders.

The Africa Soil Information Community of Practice

ISRIC assists national partners in Africa by building national and regional-level soil data and information systems, networking, and facilitating a Community of Practice (CoP) for soil information users and providers. The programme initially started in 28 African countries. By 2026, ISRIC aims to have all African states as members of the African Soil Information Community.

Figure 1: Countries highlighted in green represent African members of the CoP in 2023.

The CoP covers all parts of the soil information workflow, from user consideration and data collection, to data and information dissemination to various sectors and users.

The CoP is a dynamic platform for collaboration, knowledge sharing, and capacity building among soil professionals (government agencies, research institutions, non-governmental organisations, etc.) involved in soil data collection, analysis, and dissemination. The CoP also addresses specific national priorities, challenges, and policy objectives in agriculture and sustainable land management.

ISRIC's impact in 2022 and 2023:

ISRIC conducted a needs assessment community survey in several African countries. This survey was essential for ensuring that the programme identifies and addresses gaps and challenges in soil information, or seeks opportunities for setting up soil information systems in African countries. The assessment was responsive, relevant, and impactful in meeting stakeholder needs (e.g., the demand for establishing a CoP) and, in the long term, contributing to sustainable land management and environmental conservation efforts.

ISRIC hosted a community meeting in May 2023 with 126 participants from 28 African countries. The community meeting served as a springboard in soil information system development on the continental level. It focused on topics such as digital soil modelling and mapping, soil spectroscopy and spectrometry, remote sensing and GIS in soil survey, and soil information application (in integrated soil and nutrient management, fertiliser application, climate change and soil carbon sequestration-related applications). Additional knowledge and exchange were shared on policy and decision-making, and identifying challenges in resource limitations, capacity, skills and data availability. A positive outcome of the meeting was demonstrated in the enthusiasm for national, regional, and international collaboration, which will foster knowledge sharing, technological advancement, innovation and lessons learned. The CoP will provide a space to develop standards and harmonise soil information across African countries.

Establishment and expansion of the CoP. During 2022 and 2023, 27 active and passionate advocates from nine African countries volunteered as CoP ambassadors. They played a pivotal role in fostering a sense of connection, engagement, and information in the COP online community, which includes a newly built knowledge-sharing and interaction platform and social media. Through their efforts, these ambassadors inspire others to actively participate, share insights, and contribute to the collective growth of the vibrant community. The CoP also developed a strategy for community building and to realise its efforts. Eventually, the community established its activities in November 2023, and today, it has a full-time Community Manager to manage and develop its activities and strategic direction, in collaboration with ISRIC team members.

Soil information workflow

The soil information workflow was developed by the entire ISRIC team to comprehensively describe and categorise all steps of the soil information workflow, from user needs assessment to data collection, lab analysis, archiving, organisation, modelling and mapping, application and serving of soil data and information.

These steps are a logical workflow but can also be revisited separately for more simple or extensive elaboration and implementation, for example, in the context of setting-up or improving a soil information system. This can be at a national, international, local or project level.

The categorisation of the soil information workflow is used to form communities in ISRIC's Community of Practice and to structure ISRIC's Resource Library, including resources provided by the Soil Information Systems Review: a process toward strengthening national soil information systems, which is a project led by CABI and funded by the Bill and Melinda Gates Foundation. It also provides guidance to soil practitioners and is a communication tool to stakeholders.

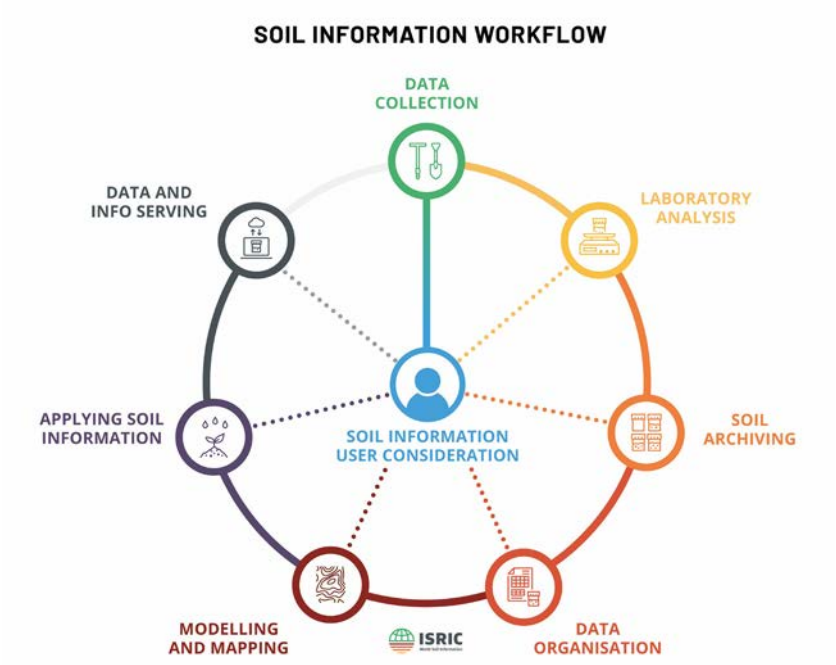


Figure 2: Soil Information workflow components.

A needs assessment sheds light on the limitations in soil information in Africa

In April 2023, 126 soil information practitioners, researchers, and enthusiasts from 28 African countries participated in a need assessment survey for a community of practice (CoP).

The survey gathered an understanding of who would be interested in the CoP and aimed to identify areas of potential exchange in the soil sector and gaps in existing networks.

The assessment results demonstrated a high demand and need for the CoP, as all respondents were enthusiastic about its international collaboration and the space it will provide to foster expertise.

The survey identified several needs in the sectors from practitioners. The respondents stated that the most valuable activities a CoP could offer professionals are knowledge, expertise development, the latest advancements in soil innovation, and trainings or workshops. Additionally, the assessment revealed that the most significant challenges experienced by respondents in soil information included resource limitations (such as laboratory analysis, facilities, equipment, financing, and IT infrastructure), knowledge and skill building, data availability and quality, and making soil information data useful.

In May 2023, all survey respondents were invited to a meeting to discuss the survey results and to provide further insight, perspectives, and needs from professionals concerning the potential CoP. T**he survey results and the meeting became the catalyst for highlighting the need for the CoP** and responding to the identified gaps in soil information. As a result, the information gathered from the survey and the meeting became the core of the CoP's strategy, structure and activities.

The CoP will expand innovative ideas for soil information system development emerging from geographically diverse locations, co-develop standards for soil information workflow, and strengthen interdisciplinary connections between field-based scientists, computer-based soil scientists and other disciplines. The community of practice will also solicit and respond to community members' professional needs and interests, facilitate the network, and seek valuable information and training to share with members. The CoP is a safe, transparent space for interaction and knowledge development.

Membership is open to professionals, researchers, and people creating soil data and information products in Africa. To join the community, fill in the form, and stay tuned for the impact stories from CoP members in 2024.

Resource library

The online resource library provides accessible, comprehensive, and high-quality educational and technical soil information resources and tools for global users and the CoP members. It is an open-access library that targets a diverse audience of readers, learners, academic researchers and professionals seeking specific knowledge and practices concerning soil information. The library fosters learning and provides reliable information on the soil information workflow (see Figure 2 above).

ISRIC's results in 2022 and 2023:

Building the library. In 2022 and 2023, ISRIC focused on the design and development of the online library, which is expected to be launched in 2024. Considerable thoughtful work went into creating and designing the library's prototype and metadata framework, as well as the resources and tools related to the "soil information workflow" (see Figure 2) and categorisation under different soil information system workflow domains.

3: Applying soil information for sustainable land management

ISRIC provides information services (e.g., models, apps, platforms, and websites) and capacity strengthening for applying soil information to sustainable land management. Sustainable land management comprises measures and practices to protect, conserve, use, and restore degraded land and ensure soil fertility management.

ISRIC's approach combines spatial soil information with environmental spatial data and uses these data to support decision-making in sustainable land management. All of ISRIC's internal and external projects are complementary and contribute to realising efficient soil and land management use. Notably, ISRIC's work in land management is always done in collaboration with specialists in land rehabilitation and development, food security, climate adaptation and mitigation, and land use planning.

Types of information devices for soil and land management

ISRIC works with an array of technologies that have a wide range of practical application for sustainable land management and help inform decision-making. These include:

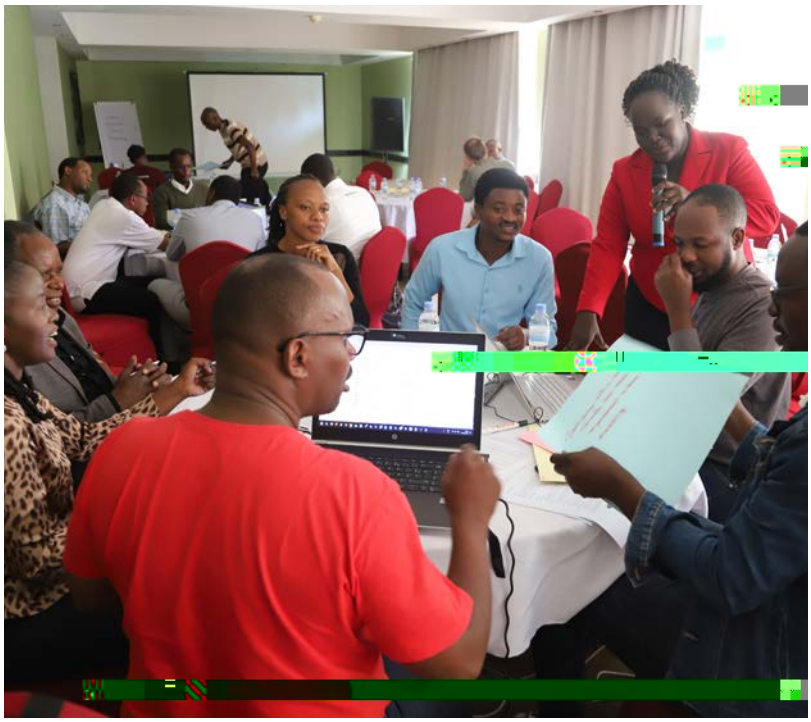
- Platforms and apps such as Land Soil Crop Hubs (LSC-IS), Land Potential Knowledge System (LandPKS), Soil Quality App (SQAPP), and Decision Support Tools for soil fertility and crop nutrition (as under development in Space to Place project) that analyse the land, soil, crop and climate data to determine and recommend fertiliser-use, land capability, land use planning, climate-smart agriculture (including carbon sequestration), and land management.
- ISRIC is a consortium partner of the World Overview of Conservation Approaches and Technologies (WOCAT), which has developed the Global Database on Sustainable Land Management (GDSLM). The GDSLM is the primary database recommended by the United Nations Convention to Combat Desertification (UNCCD).

Land, Soil and Crop Information Services (LSC-IS) to support Climate-Smart Agriculture (DeSIRA)

The LSC-IS project develops sustainable land, soil, and crop information hubs in national agricultural research organisations in Kenya, Ethiopia, and Rwanda. The hubs will exchange knowledge and information between stakeholders and contribute to rural transformation and climate-smart agriculture in target countries. The data hubs, currently populated with consolidated data from various existing sources and portals, will facilitate access to information for agricultural decision-makers, extension staff, and farmers at the national, regional, and local levels. This project is jointly funded by the European Union's Development Smart Innovation through Research in Agriculture (DeSIRA) program, The Netherlands' Ministry of Foreign Affairs and a contribution from ISRIC.

The LSC-IS initiative targets different types of information users including policy bodies, knowledge organisations and development partners, organisations working with farmers such as local landscape and watershed management bodies, local public rural extension, non-governmental organisations, the private sector, farmer organisations, and farmers themselves. LSC-IS focuses on users at national, regional and local level and aims to reach approximately 400,000 farmers in each target country.

> *"Improving soil fertility management and reducing land degradation continues to be a priority for the EU. It is through such programmes as DeSIRA LSC-IS that support is being extended. The generation and appropriate dissemination of land, soil and crop information is crucial for effective decision-making and innovation."*
>
> Mr. Stephen Wathome, Agriculture, Job Creation and Resilience Section
> Delegation of the European Union to Kenya



Participants during the national training workshop on the LSC Hub in Kigali, Rwanda (December 2023).

> *"Our transformation journey is still long, but having a functional information hub is a first step towards farmers accessing information and data. The hub requires the commitment of all relevant government officials to make sure that it is functional for farmers by encouraging its use, maintaining it, and entering data regularly so farmers can benefit."*
>
> Mr. Francois Uwumukiza, Senior Policy Advisor for Economic Cooperation, The Embassy of the Kingdom of The Netherlands in Rwanda.

Key features of the LSC Hubs

Embedded national-level information hubs

In Ethiopia, Kenya and Rwanda, land, soil and crop information from many sources is being consolidated into information hubs, or portals, where this information can be accessed, downloaded and visualised. LSC hubs are integrated in national agricultural and data systems and owned by national agricultural research organisations.

Technology-driven decision tools

LSC hubs take advantage of the latest data technology so that people who need knowledge about land, soil and crops have access to the best information possible. These hubs support agricultural decision-making and innovation.

Co-development to improve accessibility

LSC hubs are co-developed with user groups. The feedback from users shapes the content and the way data is presented in the hubs.

Focus on impact and climate-smart agriculture

LSC hubs are tested and applied by a variety of agricultural sector professionals including agricultural extension staff. This improves soil fertility and land and water management practices that help the agricultural sector adapt and build resilience to climate change and improve food and nutrition security.

ISRIC's impact in 2022 and 2023:

Building a solid hub: In 2022 and 2023, LSC-IS focused on the preparatory work of the needs assessment, which resulted in the hub's design, prototype, and launch. The project also ensured the hub's practicality and long-term functioning by gathering stakeholder feedback.

Training Rwanda and Kenya on soil data management and digital soil mapping. The primary focus of the training **in Rwanda** was to develop a new set of high-resolution digital soil maps, which will improve recommendations for soil fertility and soil erosion. This effort is a continuation of a series of trainings on soil data standardisation and digital soil mapping, which were provided to the Rwanda Agriculture Board, the Rwanda Ministry of Agriculture and Animal Resources, the Rwanda Space Agency, and the International Union for Conservation of Nature. **In Kenya**, the Department of Remote Sensing and Resource Surveys, the Forest Service and the Meteorological Department came together to understand FAIR data principles, the benefit of standardised metadata, tools for metadata (to create, import, convert, and validate data), and workflows for data management.

Annual project meeting in the Netherlands. In May 2023, partners of the LSC project gathered in Wageningen, the Netherlands, for an annual meeting and project reflection moment to gather insights on each country hub and identify project improvements. Because of previous Corona restrictions, it was the first in-person meeting since the project's inception. This convening supported relationship building and collaboration between professionals from all project countries.

Creating awareness and advocacy for scale. Experts from the project countries presented the LSC and advocated for the opportunity for LSC Information Services to be scaled in the region at the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) Agriculture Ministerial Conference.

Mid-term evaluation for learning and improvement. In September 2023, an external consultant conducted a mid-term evaluation, which concluded that the LSC-IS project's strategies and activities improved the availability of actionable information and the livelihoods of thousands of farmers and stakeholders in Kenya, Rwanda, and Ethiopia. The evaluation recommended extending the project for one year until the end of 2025.

Compiled more than 240 available land, soil, and crop information sources in Ethiopia, Kenya and Rwanda. This data consists of national and global spatial vector data (point, line, polygon), gridded maps and related metadata.

Space to Place

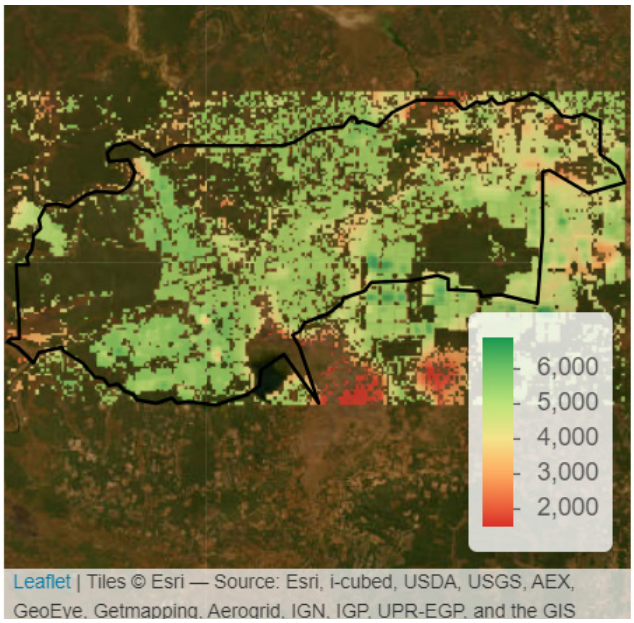
Space to Place is a project led by the International Fertilizer Development Centre (IFDC) and funded by the United States Agency for International Development (USAID) Bureau for Resilience and Food Security. The Pan-African initiative collaborates with various organisations to enhance fertiliser use efficiency, targeting four to five million smallholder farmers in sub-Saharan Africa.

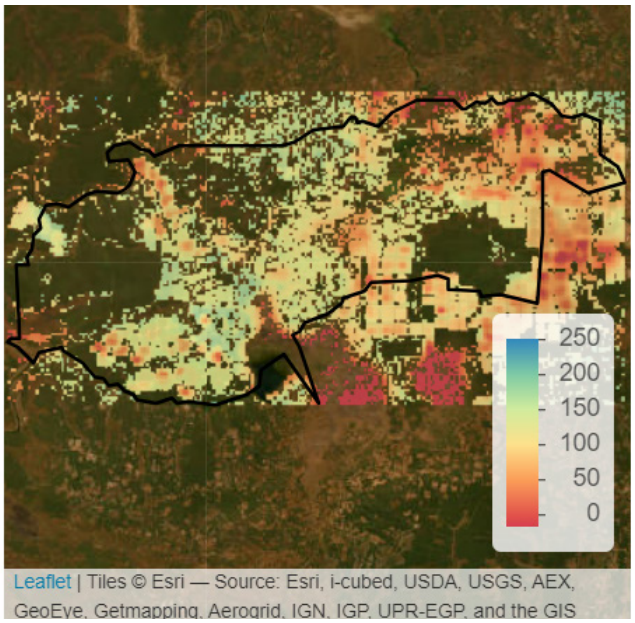
Space to Place is developing a scalable Decision Support Tool (DST), based on fertiliser trial data generated by the project and publicly available input data and maps. This will improve soil fertility management and agriculture decision-making at local to regional scales. This DST applies to various farming systems in diverse geographies and thus improve crop production and reduce agriculture input costs. Space to Place brings partners together, reducing the need to reinvent the wheel multiple times in separate countries.

The impact of global disruptions on fertiliser supply chain

Crop cultivation depends largely on the use of fertilisers. The Russia-Ukraine conflict has led to disruptions in markets for key crops, fertiliser supply chains and trade, and this has resulted in the shortage of fertilisers, increased fertiliser prices, and market crashes. These vulnerabilities threaten food security and have negatively impacted African farmers and countries, because of the high demand, cost, and lack of fertiliser. As a result, there is a growing interest in cost-efficient fertiliser solutions.

The DST provides targeted site-specific soil fertility and crop-nutrition recommendations from up-to-date soil information. This means that recommendations for soil management are tailormade, hyper-localised and in accordance with specific farming conditions.





Screenshots from the DST prototype showing a map of a) fertilised maize yield and b) fertiliser P recommendation (NPK).

ISRIC's impact in 2022 and 2023:

Establishing the "Space and Place". In 2022, the project focused on building its program and prototype DST for Madagascar and Ethiopia. By the end of 2023, a Space to Place prototype was developed for Zambia, Tanzania, Malawi, and Uganda. The DST is currently being developed for Tier 1 to include legacy data, while Tier 2 will include local legacy data and trial data; and thereby provide results that will be tested and validated.

Building a database for the DST. A data need assessment and legacy data collection strategy was created for the DST. Legacy data collection efforts in Zambia, Malawi, Uganda are in progress.

Building block for development: Trial data collection protocols were developed for trial data collection in the target countries. The trial data will contribute to the model engine of the final DST.

Importance of strategic partnerships

The Space to Place project is collaborating with various key players in soil fertility management including large private sector parties such as fertiliser producers (OCP Group, Meridian, International Raw Materials).

The ambition is that through expanded partnership, the Space to Place approaches and soil data and soil fertility recommendations can be harmonised and upscaled to other African countries.

Innovation in soil analysis

Space to Place offers crop farmers an affordable, up-to-date, location specific soil assessment service that can be used anywhere and at any time.

Space to Place translates available scientific models and concepts used for analysing soil for crop cultivation into a web environment and an operational Pan-African tool, to be eventually used on a mobile phone.

Traditionally, preparing site-specific soil fertility recommendations with available soil data and maps was resource intensive. Space to Place combines existing maps and data ("Space") with selected, geo-referenced research trial data, user-sourced information on soils, and farm management decisions ("Place"). Using advanced crop-soil models, farmers will be able to assess soil characteristics and site-specific soil-fertility recommendations and solutions. This will essentially optimise crop growth and saves resources.

4: Advocating and educating on the diversity and importance of soil

ISRIC promotes education, awareness, advocacy, understanding, and appreciation of the nature and diversity of soils and their management worldwide. The World Soil Museum is an important instrument for these activities. It reflects the efforts of ISRIC since 1966 to collect, document, and study the soils of the world, to contribute to standards for analysis and to describe, classify and provide a global overview of soils and their properties. Managed under one project, the museum contributes to soil education and information in three ways – **a scientific museum, a reference collection, and a library.**

The World Soil Reference Collection and Library are scientific resources. The museum, where education and advocacy are conducted, showcases the World Soil Reference Collection. The library complements the museum and the Reference Collection and safeguards soil survey information, maps, and reports that are otherwise often poorly accessible and tend to become less available or lost over time.

The World Soil Museum

The World Soil Museum is one of a kind, with over 1,000 profiles of soils from all over the world. The museum is recognised internationally for its extensive physical collection of soils from around the globe, which places it in a unique position. See an introduction to the World Soil Museum here.

Soil information is provided in the museum through panels and digital media. ©Mike Bink.

The museum raises awareness about the importance of soil as a base for societal issues. It informs visitors, both onsite and online about soils from around the world, their properties and management, the knowledge derived from them, and understanding what they represent. The museum provides information, evidence-based insights, inspiring visitor experiences, and engagement with soils in the context of their formation, management, and global themes.

Visitors can learn about soils' role in life and ecosystems and understand their enormous variation worldwide. Notably, the museum specifically targets soil education and awareness towards the youth to enhance their soil literacy, engagement, and knowledge of sustainability and climate change.

Museum visitors

On average, the museum has about 3,000 visitors annually. The visitor groups include the following:

Visitor groups	Year: 2023	Year: 2022
General public	37%	21%
Pupils (primary and secondary schools)	3%	5%
Students (colleges, universities)	32%	47%
Researchers	4%	2%
Professionals	20%	24%
Policy makers	3%	0.50%
Journalists/media	1%	0.50%
Total	100%	100%

Visitor groups at the World Soil Museum in 2022 and 2023.

In 2022 and 2023, most museum visitors were students from higher education, public, and professionals. The museum also welcomed international students from France, Switzerland, Germany (multiple universities), Belgium, Netherlands (multiple universities), and China.

Recently, with soils higher on the policy agenda, the museum experienced a growing interest from policy, research, and decision-makers. As a result, various delegations were received, such as from the Ministry of Agriculture of Ethiopia, the President of the Executive Board of Wageningen University & Research, Rectors from Indonesian Universities, Heads and Policy Officers from the European Commission, Embassy Ambassadors to the Netherlands from twelve countries, Research Centre Directors from Egypt, the President of Moldova, and Middle East and North African regional researchers.

President Maia Sandu of the Republic of Moldova explores the soils in the museum with the Chair of ISRIC's Board, Prof. Dr. Jakob Wallinga.

Since 2018, visitors from 85 nationalities have visited the museum. They came from the following countries:

Nationalities of museum's visitors in 2018-2023.

The museum's digital presence amongst students, universities, and researchers is growing, resulting in an increased demand for virtual tours. Recognising the importance of making the museum more accessible, stimulating and engaging to potential users around the world, one of its future goals is to make more information digitally available for international audiences.

Museum capacity

The museum and library are run with the support of volunteers who commit their time and expertise to ensure the space is operational, visitors are informed, exhibitions are maintained and updated, library sources are digitised, and soil samples are preserved. The volunteers provide customised tours in different languages depending on the group, audience background and interest.

By its nature, the World Soil Reference Collection requires continued attention and quality investment. This includes scrutinising reference data, assessing and documenting the reference collection, and acquiring and disposing of soil reference collection objects. ISRIC will continue to enhance online access to the reference collection and associated educational resources.

The World Soil Museum provides a unique and enriching experience to audiences. Ongoing support from partners and volunteers ensures the museum's continued success.

ISRIC's reach in 2022 and 2023

There is an increased demand for museum virtual tours. Many schools, universities, researchers, and students visit the museum online, access the virtual tours, or explore the museum's maps and data. They also request online tours and lectures from the museum. For instance, as part of the module "Soil Classification and Mapping," an online tour and lecture on soils were given to students at Leeds University.

The "Art of Soil". Since 2017, the World Soil Museum has been collaborating with artists to highlight how soil and art are connected and to provide new perspectives on the importance and diversity of soils. In 2022, the World Soil Museum hosted a four-part online series called "Peatland Exchanges." The series was initiated by the museum's artist-in-residence Kate Foster, in partnership with Wageningen University Research's Home Turf Project and WetFutures. The environmental artist Kate Foster used drawings, shadow play, excavated soil, and other mediums to focus on Peatlands. Her ecological concern led to collaborative art-science projects, the involvement of grassroots restoration projects, and advocacy on Peatlands. Learn more about the Peatland Exchange here.

Celebrating World Soil Day. A video message from the World Soil Museum honouring World Soil Day 2022 was released (view it here). Additionally, on 5 December 2023, the museum hosted a one-hour online interactive program titled "Soil and Water: A Source of Life." If you missed the event, you can view it here.

Soils on Mars exhibition. This fascinating exhibition (13 September – 1 December 2023) explored the biological and environmental potential of life on Mars, and whether the nature of its soil and surface material could support and cultivate life. Emke Mooney from Wageningen University curated the exhibition in collaboration with ISRIC, and highlighted the work of Ecologist Wieger Wameling - who started his first experiments to grow crops on Martian soil a decade ago. An interesting and witty article about the exhibition appeared in Resource Magazine and is available here.

Public interest in the museum. The World Soil Museum is featured in two articles in Atlas Obscura. These articles were written by Mary Rose Abraham, and include: "World Soil Museum: A Dutch museum preserves the world's most diverse collection of vertical slices of soil" and "Soil Scientists Dig Deep to Understand the 'Skin of the Earth' - Atlas Obscura."

Exterior view of the World Soil Museum located on the Wageningen campus.

World Soil Reference Collection - Sample soil for research and innovation

The acquisition for the World Soil Reference Collection started in 1966. The primary purpose was to show and characterise representative examples of soils worldwide. Since then, the collection has become an unmatched resource for research and education.

The collection contains 1,000 soil profiles from more than 80 countries worldwide, with some (inherited) samples dating back to 1926. These preserved soil profiles, or monoliths, are vertical, 3D sections of the soil that tell a story about the soil's formation, history, landscape, environmental conditions, composition, layering, and structure.

The soils are described, sampled, and analysed in accordance with uniform and standard international methods. The data are accessible through the ISIS database and the collection explorer of the World Soil Museum. The data are also accessible through the World Soil Information Service (WoSIS) - a large open-source soil database.

The reference soils have a vast potential for research and improving soil data because they are derived from past environmental conditions and processes or historical events in human history, which can be compared to the current state of soil analysed. They also provide clues about formation, variation, functions, and human influence and baseline data for new predictive models (for example, for climate change).

Soil samples prepared for DNA extraction and sequencing.

ISRIC's impact in 2022 and 2023

First global soil DNA microbial reference database. In 2023, a project commenced to analyse soil reference samples for soil DNA. The project is a collaboration between ISRIC, the Netherlands Institute of Ecology, the Chinese Academy of Science, the Agricultural Genomics Institute at Shenzhen and the Chinese Academy of Agricultural Sciences. ISRIC will provide 4,655 soil samples for this project. This analysis will build a microbial reference database of the soils for the first time, and will add to the environmental, morphological, physical and chemical data already available for each sample.

What types of research are Reference Collection Soils used for?

- Verifying national and global datasets.
- Comparing different methods of reference sample analysis.
- Developing rules for soil property estimation.
- Providing the basis for classification.
- Understanding the impact of land management, acid rain, pollution and climate change.
- Analysis of heavy metal content, DNA, and pollen.

The World Soil Reference Library

The World Soil Reference Library is a repository of over 25,000 records of soil legacy information, 10,000 maps, and 17,000 books and reports. Legacy soil information (i.e., survey information) is valuable as it provides geographic and time-specific records of soil and landscape conditions. These sources tend to become inaccessible over time or are completely lost. The library safeguards these valuable documents. Current digital soil mapping methods use digital data on soil observations, including legacy data and covariate (environmental) data layers. Soil sampling campaigns are expensive and resources for new sampling are often unavailable or limited. The archiving, digitising and online disclosure of soil survey reports and maps ensures that information is stored and accessible in the long term.

The library's collection is open to the public. Most of it has been digitised and is available online. About 70% of the maps can be downloaded in high resolution, and over 35% of the reports and books are available online and in full text (PDFs). The scanning of library holdings is a continuous process as the library regularly receives new additions to the collection.

Scientific research

ISRIC is a science-based organisation rooted in and contributing to the science behind soil information.

During 2022-2023, ISRIC generated over 70 publications, including 26 papers in peer-reviewed international scientific journals, 13 technical reports, five articles in professional journals, eight conference abstracts, one book chapter, and one editorial in a peer-reviewed journal.

Notable journal papers include:

- A multivariate approach for mapping a soil quality index and its uncertainty in southern France.
- Accounting for analytical and proximal soil sensing errors in digital soil mapping.
- Global mapping of volumetric water retention at 100, 330 and 15 000 cm suction using the WoSIS database.
- How can pedology and soil classification contribute towards sustainable development as a data source and information carrier?
- How well does digital soil mapping represent soil geography? An investigation from the USA.
- Multivariate random forest for digital soil mapping.
- Spatial predictions of maize yields using QUEFTS – A comparison of methods.
- Statistical analysis of nitrogen use efficiency in Northeast China using multiple linear regression and Random Forest.
- Statistical modelling of measurement error in wet chemistry soil data.
- Validation of uncertainty predictions in digital soil mapping.

A more exhaustive list of our publications can be found here.

ISRIC's people

At ISRIC, our work with employees and on projects is transparent. ISRIC prides itself on providing a working environment and culture that fosters excellence, respect, and integrity, whilst ensuring work pleasure and employee satisfaction. ISRIC works passionately to achieve the organisation's strategy through initiative and proactivity among colleagues.

ISRIC would not be able to achieve its goals or project success without the dedicated staff and volunteers, who are the driving force behind the organisation's culture and mission and who ensure that all projects and initiatives run smoothly and successfully.

In 2022 – 2023, ISRIC had a total of 34 staff members from 15 countries, and 13 "affiliated" colleagues, which included PhD candidates, volunteers and guest researchers. They are all appreciated and acknowledged:

Staff

Rik van den Bosch
Director

Andries Bosma
External relations manager

Bas Kempen
Operations manager and Senior digital soil mapping expert

Judy Willems
Management support officer

Niels Batjes
Senior soil science expert
Coordinator WDC-Soils

Laura Poggio
Senior digital soil mapping and remote sensing expert

Emily Toner
Community manager

Chrow Khurshid
Community manager

André Kooiman
Senior sustainable land management expert

Stephan Mantel
Head of World Soil Museum
Sustainable land management expert

Gerard Heuvelink
Professor pedometrics and digital soil mapping

Mary Steverink-Mosugu
Senior project coordinator

Ulan Turdukulov
Senior spatial data infrastructure expert

Zhanguo Bai
Senior soil and land degradation assessment expert

Luis Calisto
Database development expert

Fenny van Egmond
Soil sensing and soil information expert

Thaïsa van der Woude
Project coordinator

Ditte Trojaborg
Project coordinator

Johan Leenaars
Soil fertility expert

Maria Ruiperez Gonzalez
Digital soil mapping and GIS expert

Giulio Genova
Digital soil mapping expert

Francis Silatsa
Soil information expert

Jorge Mendes de Jesus
Spatial data infrastructure expert

Luis Duque Moreira De Sousa
Geoinformatics expert

Lieven Claessens
Soil fertility expert

Paul van Genuchten
Spatial data infrastructures expert

Mara Grandia
Museum and education officer

Ingrid Haas
Webmaster

Betony Colman
Junior GIS expert

Diana Collazos Cortes
Junior GIS expert

Islambek Urazov
Junior spatial data infrastructure expert

Jelle Janssen
Research assistant

Cynthia van Leeuwen
PhD candidate

Erika Henskens
Secretary

Volunteers

Ad van Oostrum
Ans Brom
David Rossiter
Godert van Lynden
Kees van Diepen
Livija Petrovic
Piet Anker
Willem Dragt

Managing Board

ISRIC's Managing Board plays a crucial role in the success of ISRIC. As the organisation's governing body, it oversees ISRIC's strategy, operations, effectiveness, recruitment, finances and accountability.

ISRIC's Board members have diverse academic and technical expertise. Board members include:

- **Prof. Dr. P.C. de Ruiter**, Professor Emeritus, Wageningen University and Research (WUR) and University of Amsterdam, The Netherlands (2022 Chair, left the Board and was succeeded by Prof. Dr. J. Wallinga in December 2022)
- **Prof. Dr. J. Wallinga**, Wageningen University and Research (WUR), The Netherlands (2022 and 2023, Chair)
- **Dr. F. Senf**, Director of Operations, Environmental Sciences Group, Wageningen University and Research (WUR), The Netherlands (2022 and 2023, member)
- **Prof. Dr. R.N.J. Comans**, Soil Chemistry, Wageningen University and Research (WUR), The Netherlands (2022 and 2023, member)
- **Dr. Ir. J.E.M. Baartman**, Associate Professor, Soil Physics and Land Management, Wageningen University and Research (WUR), The Netherlands (2022 and 2023, member)
- **Prof. Dr. Ir. A. Veldkamp**, Rector Magnificus, University of Twente, The Netherlands (2022 and 2023, member)
- **C. Nab**, Business Controller, Wageningen University and Research (WUR), The Netherlands (2022 and 2023 member)

PhD candidates

ISRIC specifically collaborates with Wageningen University through the appointment of a special professor and membership of ISRIC staff in a Wageningen University graduate school. As part of this collaboration, multiple PhD-research projects are being conducted, and they include:

- **Anselme Kouamé**: A multi-model approach to identifying the causes of Ghana's variable maize yield responses. [status - ongoing]
- **Bertin Takoutsing**: Digital soil mapping using uncertain soil measurements to support sustainable agricultural intensification in West and Central Africa. [status – ongoing]
- **Cynthia van Leeuwen**: The development and use of a soil database with quantified uncertainties. [status – ongoing]
- **Eric Asamoah**: Machine learning for fertiliser recommendation in Ghana. [status - ongoing]
- **Mirjam Breure**: Models for predicting nutrient availability in soils from sub-Saharan Africa. [status - completed]
- **Musefa Redi Abegaz**: Generating quality-assessed land-soil-crop information to support climate-smart agriculture in Ethiopia. [status – ongoing]
- **Qiuhong Huang**: Using mechanistic models, machine learning and geostatistics to model the relationship between potato yield and soil nutrients in China. [status - ongoing]
- **Stephan van der Westhuizen**: Enhancement of the use of machine learning in digital soil mapping. [status – ongoing]
- **Yingxia Liu**: Statistical analysis and modelling of crop yield and nitrogen use efficiency in China. [status – completed]

Guest researchers

- **Ad van Oostrum**: supported ISRIC by advising on soil analytical methods and by testing methods to quantify errors in laboratory measurements.
- **Ashanafi Abduljelil**: from Addis Ababa University, Department of Geography and Environmental Studies, Ethiopia, joined ISRIC through a CLIFF-GRADS fellowship to support his research on prediction of soil physical properties in Ethiopia, from April to October in 2023.
- **Azamat Suleymanov**: from Ufa Institute of Biology, Department of Soil Science, Russia, joined ISRIC through a CLIFF-GRADS fellowship to support his research on digital mapping of soil degradation processes, from January to July in 2022.
- **David Rossiter**: supported ISRIC as an in-house strategic consultant and as an occasional research collaborator.

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