Understanding soil health across landscapes

Leigh Ann Winowiecki
Soil &Land Health Research Leader
CIFOR-ICRAF

GLOSOLAN Plenary Meeting
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UNITED NATIONS DECADE ON ECOSYSTEM RESTORATION 2021-2030
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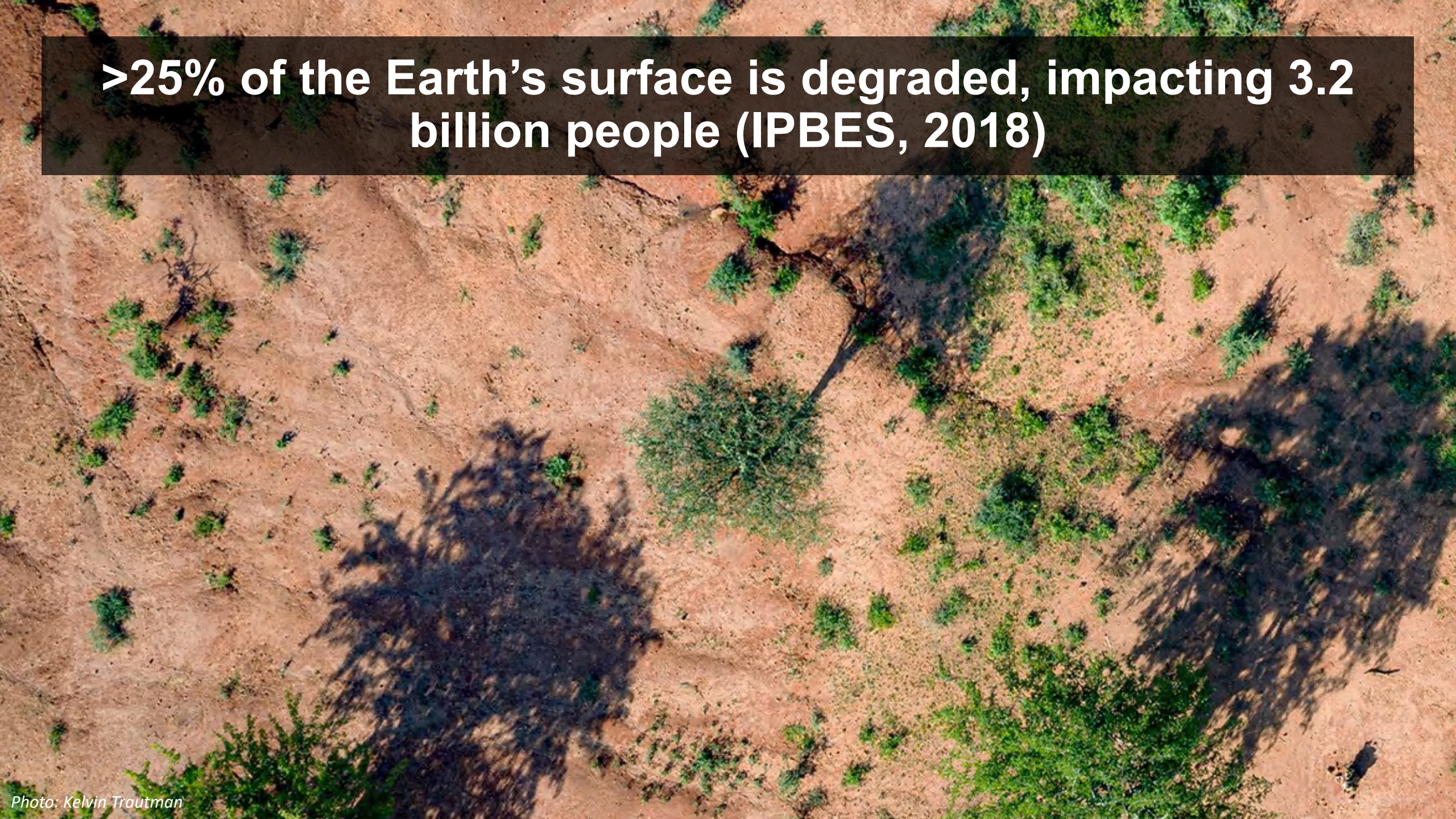
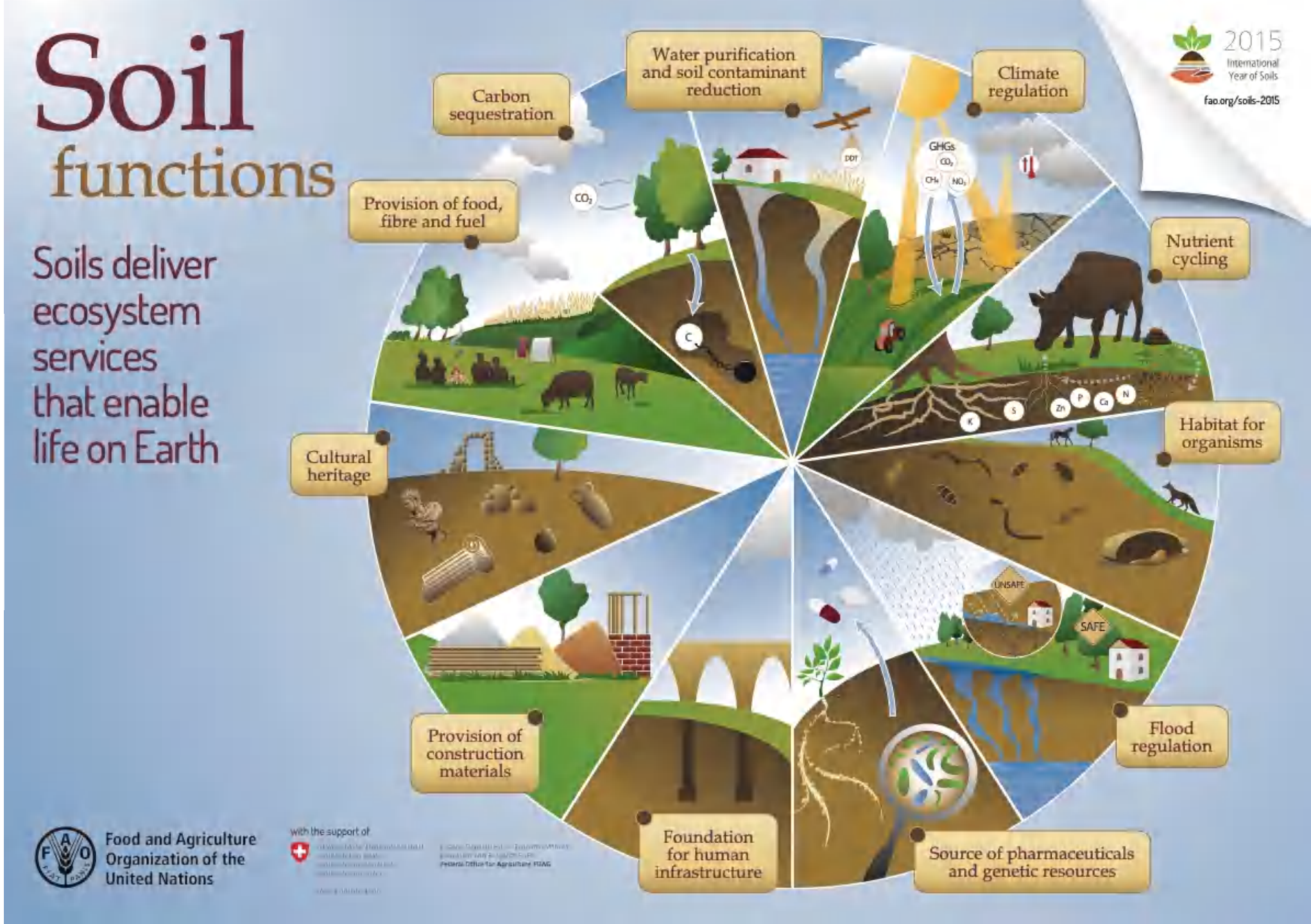

>25% of the Earth's surface is degraded, impacting 3.2 billion people (IPBES, 2018)
Photo: Kelvin Trautman

Healthy soil provides multiple ecosystem services & functions.



The challenge (and opportunity) is to scale locally appropriate soil restoration options with large numbers of farmers across large areas.

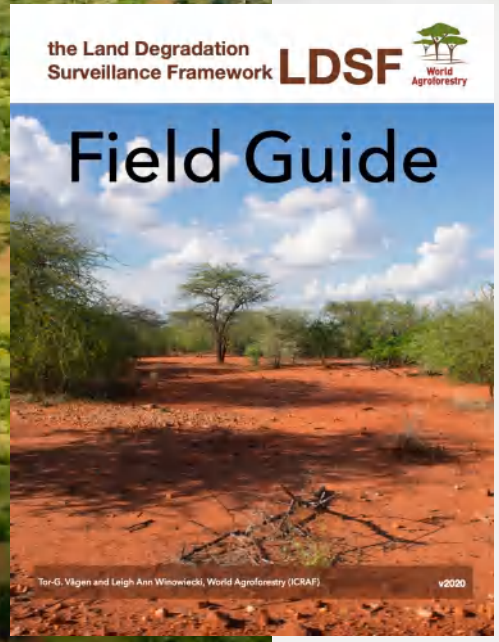
Photo: Kelvin Trautman

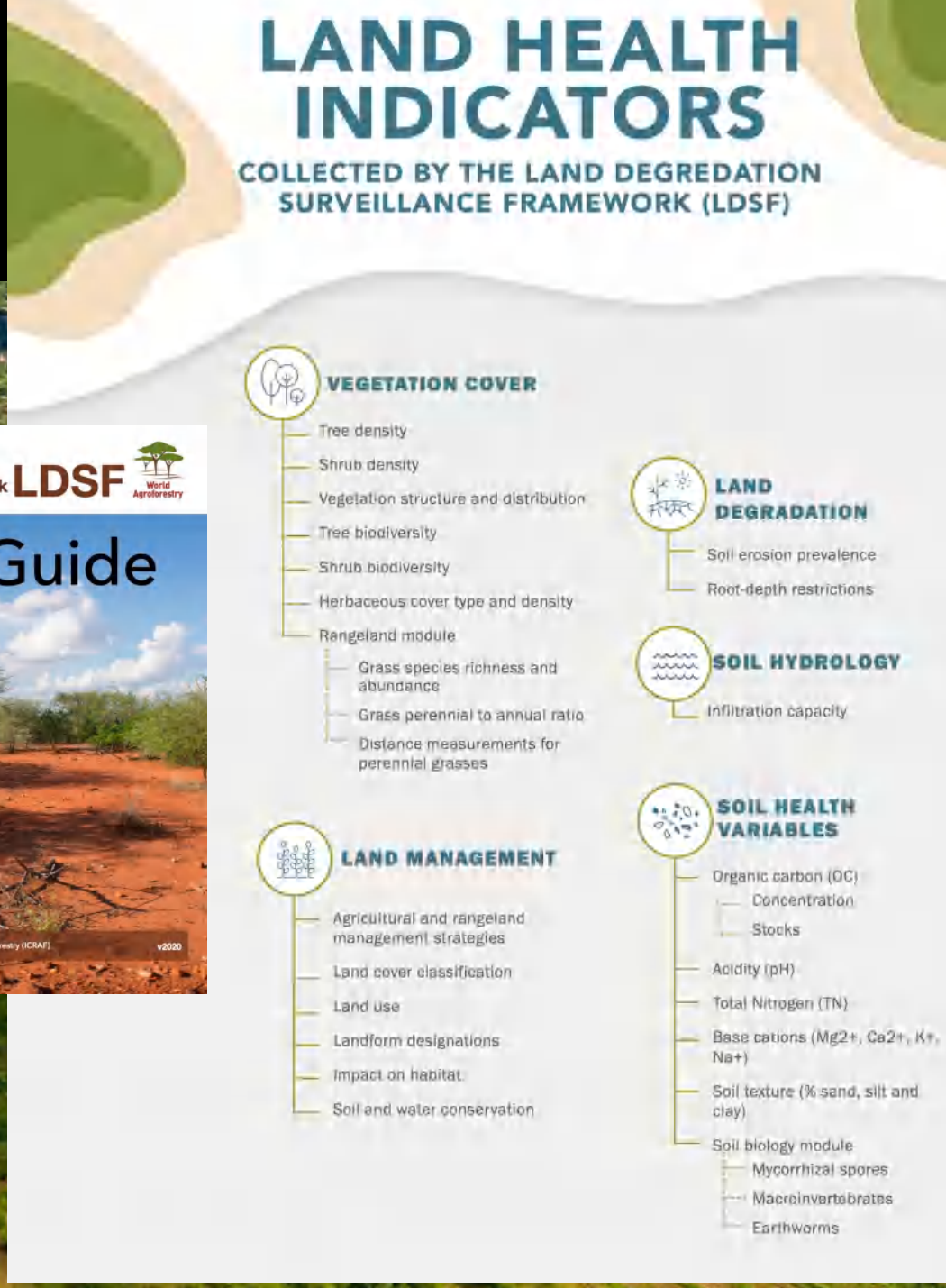
Landscapes are diverse

- This requires a sampling design to capture this variability
- Soil analysis technologies that are cost-effective and robust
- Data analytics that can assess the complex drivers of degradation
- Frameworks that can track changes over time (performance of agricultural and restoration interventions)

Understanding the multiple dimensions of soil health for ecosystem restoration, climate change and food & nutrition security

1) Application of a systematic sampling framework
2) Use of innovative methods for soil analysis
3) Coupled with statistical analysis to generate predictive maps

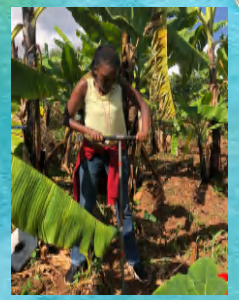




http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

Robust and rapid monitoring systems across diverse landscapes: The Land Degradation Surveillance Framework (LDSF)

http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/



Data-driven network of LDSF sites (each site is 100 km^2, with 160 sampling plots). One systematic framework across multiple projects, donors, initiatives.

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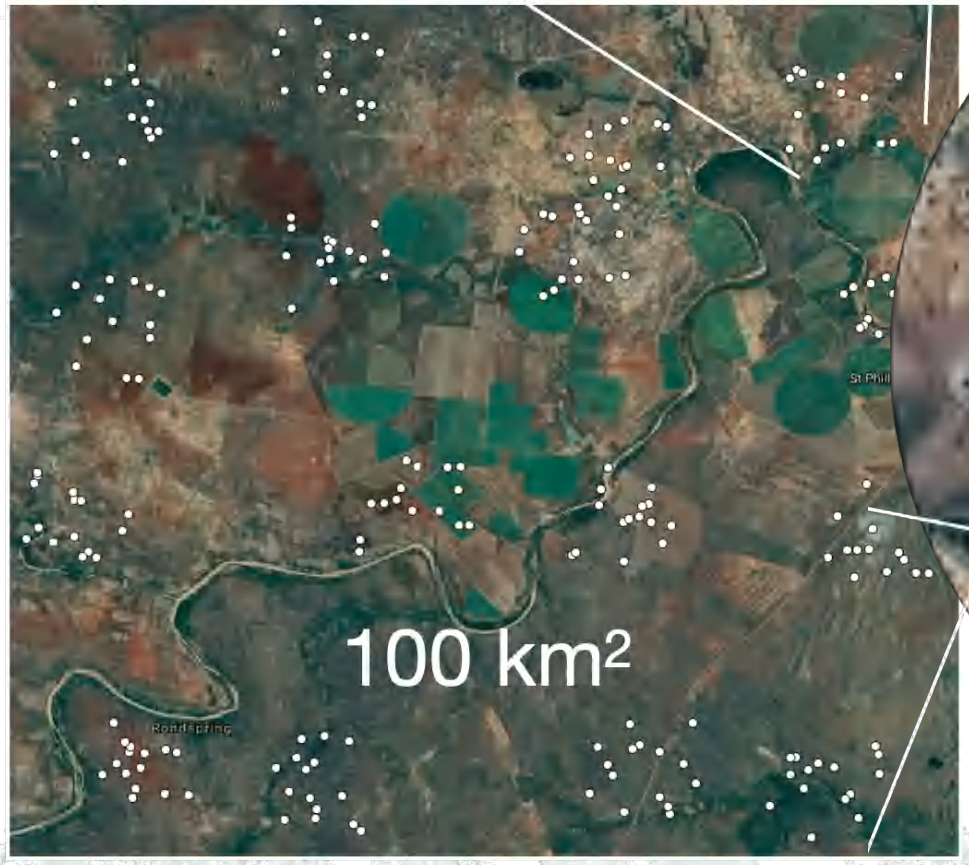
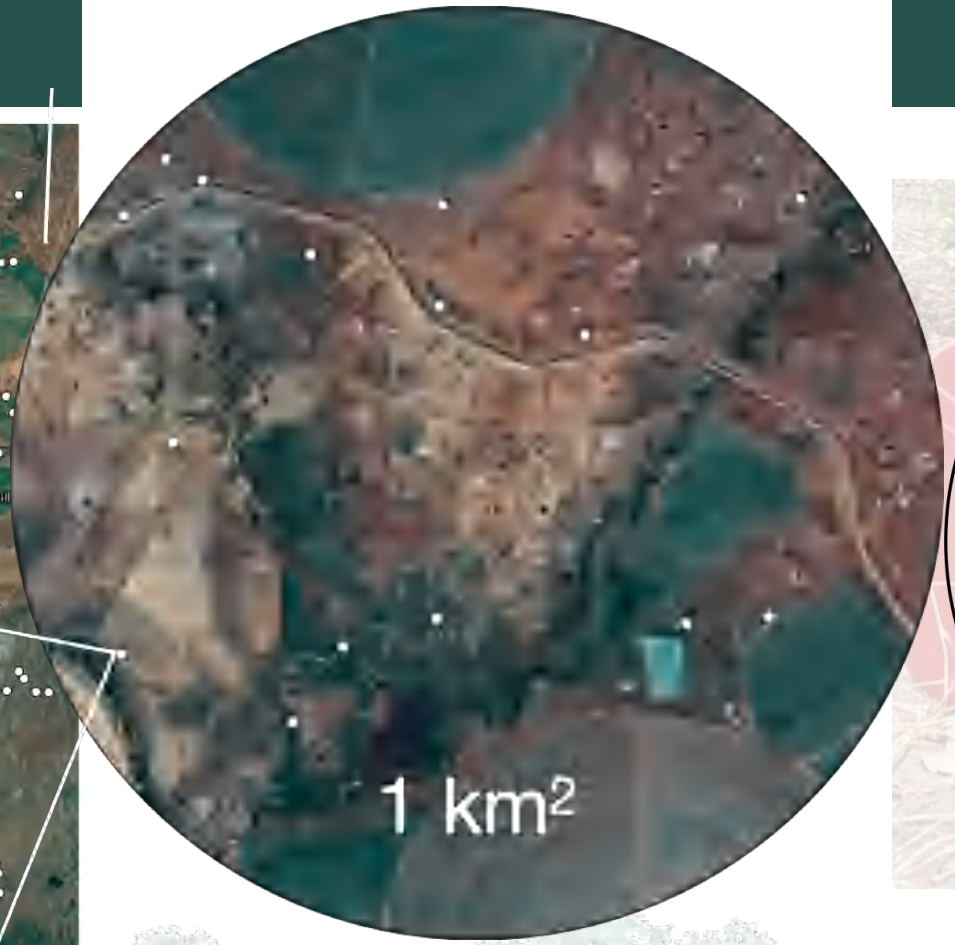
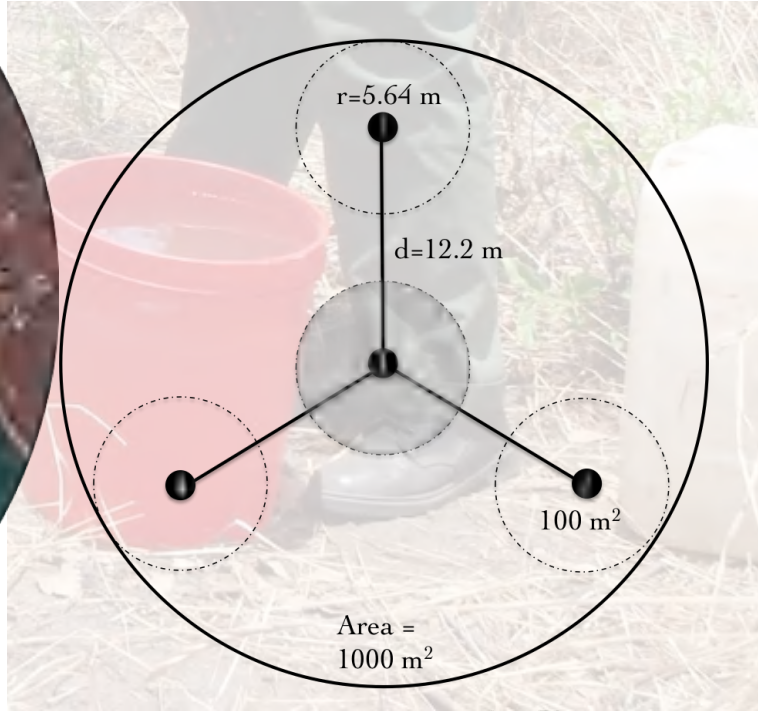
LDSF: Nested Sampling Scales

Unbiased sampling







Site Level (10km * 10km)

Cluster Level
16-1km² per site

Plot Level
10-1000m² per cluster

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Soil sampling in the LDSF

Soil samples are taken from each subplot (n=4) and composited at the plot level at two depths

- 160 topsoil (0-20 cm) samples per site
- 160 subsoil (20-50 cm) samples per site

All soil samples are analyzed using mid-infrared spectroscopy

Reference soil samples (10%) are analyzed using wet chemistry for pH, **organic carbon & total nitrogen (using dry combustion)**, base cations, texture, etc)

Predictions are made using the spectra and wet chemistry data 1) 70% for calibration model and 2) 30% for validation models

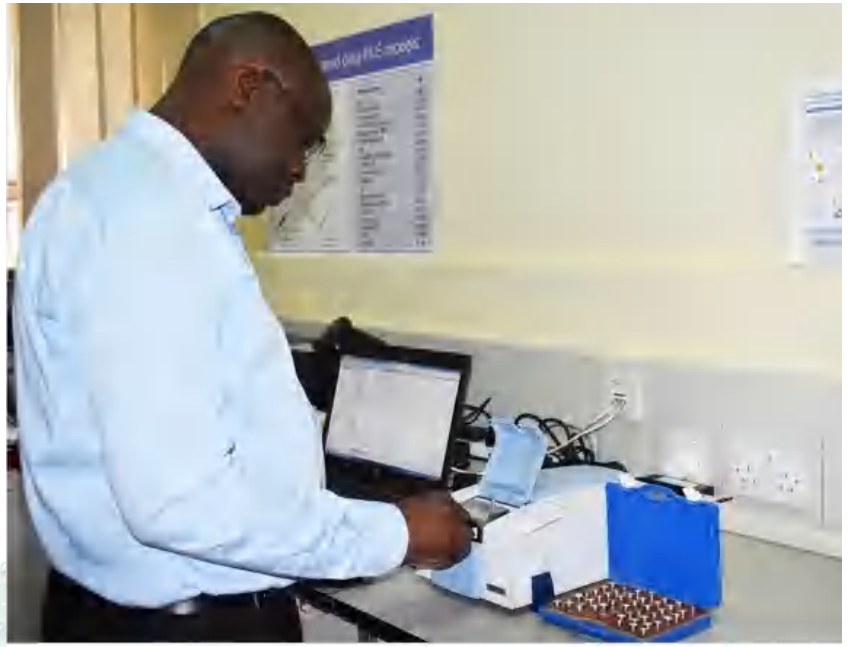
Soil cumulative mass samples (0-20,20-50,50-80,80-110 cm) for carbon stock calculations

This landscape scale sampling is enabled by soil spectroscopy

Shining a light on soils for land restoration

- MIR &NIR spectroscopy for accurate, robust, low-cost analysis of multiple properties, simultaneously
- **Can be used to analyze plants, compost, manure, fertilizers, liquids and yes soil!**
- Enables landscape scale sampling- which was previously limited by costs of analysis
- This has transformed research and **requires NEW skills of soil scientists**
- ICRAF has invested **>20 yrs to build a consistent spectral library (database) for a number of spectrometers**
- Investment in spectral data analytics

https://wle.cgiar.org/solutions-and-tools/science-driven-solutions/shining-a-light-on-soils-for-land-restoration/



Elvis Weullow of the ICRAF Soil and Plant Spectroscopy Lab demonstrating how to use th Spectrometer. Photo: World Agroforestry/Ann Wavinya

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At ICRAF, you may have noticed that our publications are focused more on application, but we always report the validation results: Spatial Gradients of Ecosystem Health Indicators across a Human-Impacted Semiarid Savanna

Table 1. Summary of soil properties and model results for the for the mid-Infrared spectroscopy predictions.

Soil property	Range measured (range predicted)	R^2	RMSEP†
Soil organic C (g kg^{-1})	1.75–30.31 (2.41–28.10)	0.98	1.3
pH	5.32–8.28 (5.52–8.07)	0.95	0.2
Sand (%)	6.4–78.3 (9.2–72.7)	0.94	5.0
Clay (%)	12.6–76.8 (15.6–74.2)	0.97	3.6

† RMSEP, root mean squared errors of prediction.

Vågen, T., L. A. Winowiecki, W. Twine, and K. Vaughan. 2018. Spatial Gradients of Ecosystem Health Indicators across a Human-Impacted Semiarid Savanna. J. Environ. Qual doi:10.2134/jeq2017.07.0300

https://dl.sciencesocieties.org/publications/jeq/articles/0/0/jeq2017.07.0300

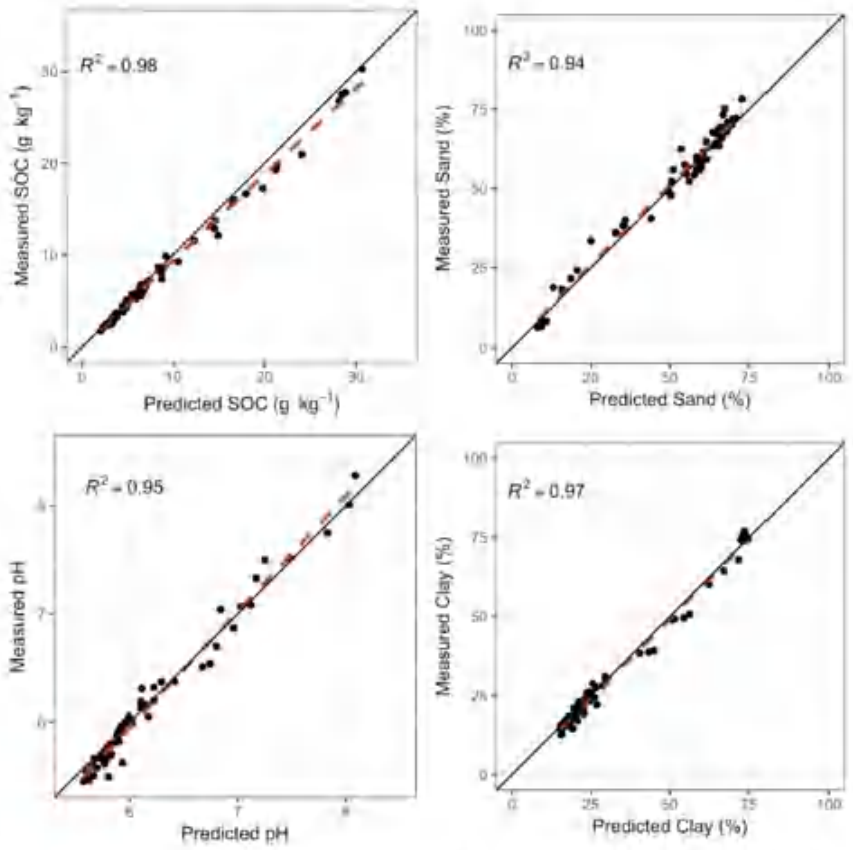

Fig. 3. Prediction results for soil organic carbon (SOC), pH, and texture according to mid-infrared spectral data from the two study sites combined. The red dashed lines represent the regression lines, and the 1:1 abline is the solid black line.

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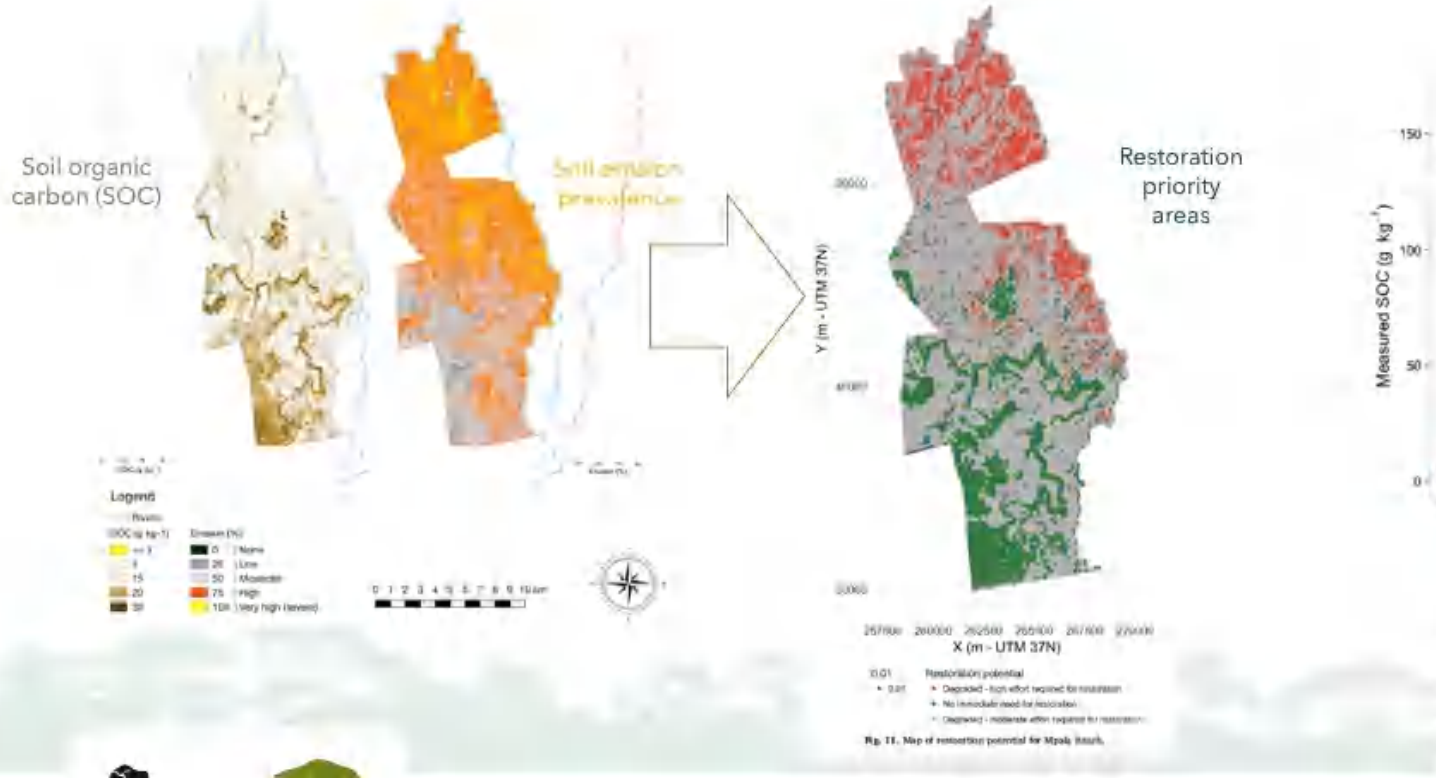
Ex 2: Assessing Restoration Potential in Kenya using spatially explicit maps of SOC and Erosion



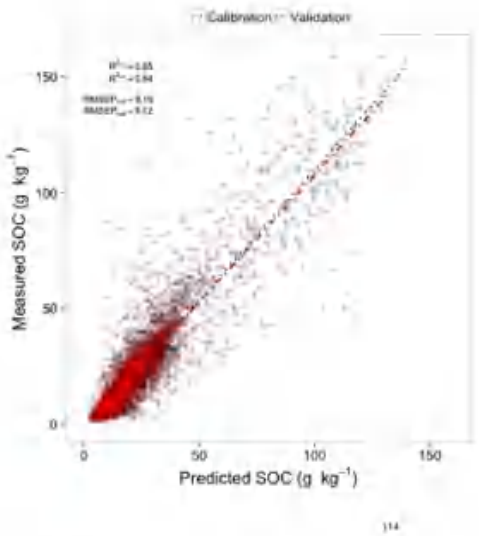


Fig. 7. Predicted vs measured SOC for calibration and validation model runs, respectively. The black dotted line shows the regression line for calibration model predictions, while the red dashed line shows the regression line for the validation model predictions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

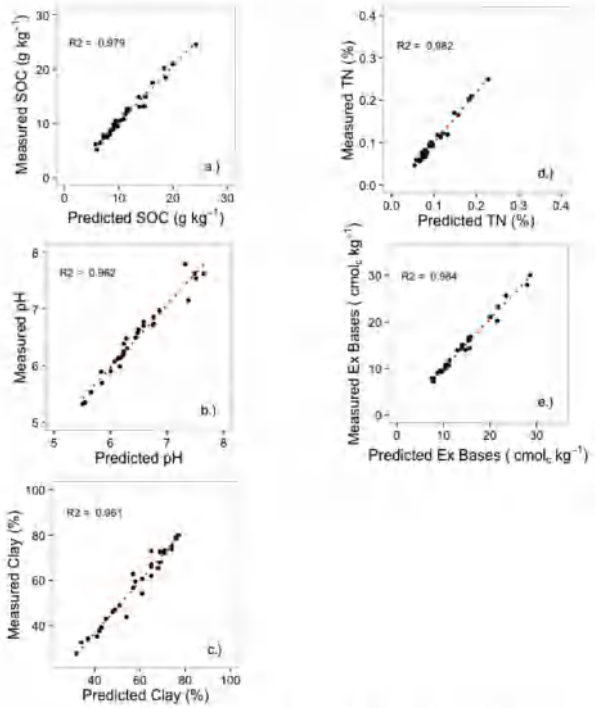


Fig. 3. Predicted versus measured soil properties based on MIR absorbance.

The ICRAF MIR database, which consisted of about 3939 soil MIR spectra with matching reference soil samples from 123 LDSF sites was used to develop the soil property prediction models.

Winowiecki, LA., Vågen, T-G., Kinnaird, MF, TG. O'Brien. 2018. Application of systematic monitoring and mapping techniques: Assessing land restoration potential in semi-arid lands of Kenya. Geoderma. https://www.sciencedirect.com/science/article/pii/S001670611830510X

Systematically sampled soil samples- in a physical archive- with QR code

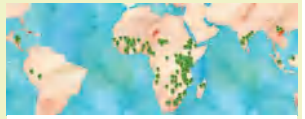
> 150,000 soil samples logged & physically archived from over 40 countries

ICRAF SOIL ARCHIVE

A Physical Archive of Systematically Collected Soil Samples

Largest Soil Collection

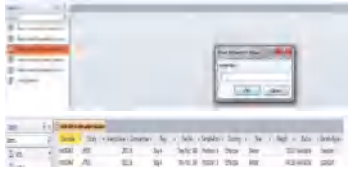
- The ICRAF Soil Archive contains samples from 46 countries across Africa, Asia and Latin America collected using a systematic field sampling method, the Land Degradation Surveillance Framework (LDSF).
- The LDSF provides a biophysical baseline at landscape level, and a monitoring and evaluation framework for assessing processes of land degradation and the effectiveness of rehabilitation measures over time.
- The figure on the right shows the location of the LDSF sites collected within various projects and programmes focused on assessing soil and ecosystem health globally.



Map Credit: ICRAF GeoScience Lab/ Tor-G. Vågen

Electronic Legacy Database

Each sample has a unique record that provides storage location, associated documentation, grant code and DOI. Also, each sample is accompanied by key data including the LDSF field data (which includes sampling date and GPS coordinates), mid-infrared spectra and reference analysis.

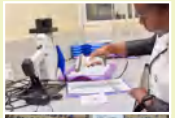


Legacy Archiving Systems

A safe holding custody including a 1.2 km mobile shelving system, metallic cabinets with the capacity to archive over 100,000 samples.

An Unrivalled Resource

- Archived soil samples represent an important resource for future assessments of soil health, for example as new technologies for soil analysis emerge.



- The archive is a cornerstone for ICRAF's spectral libraries that holds over 300,000 mid-infrared spectra.
- All the soil samples were processed using the ICRAF Standard Operating Procedures.
- All samples are barcoded to assist information tracking.
- This resource provides opportunities for new collaborations around concepts of ecosystem health, understanding drivers of land degradation and tracking restoration over time.

Contact: Leigh Ann Winowiecki (L.A.Winowiecki@cgiar.org) or Elvis Weullow (E.Weullow@cgiar.org) | **Website:** http://www.worldagroforestry.org/landhealth

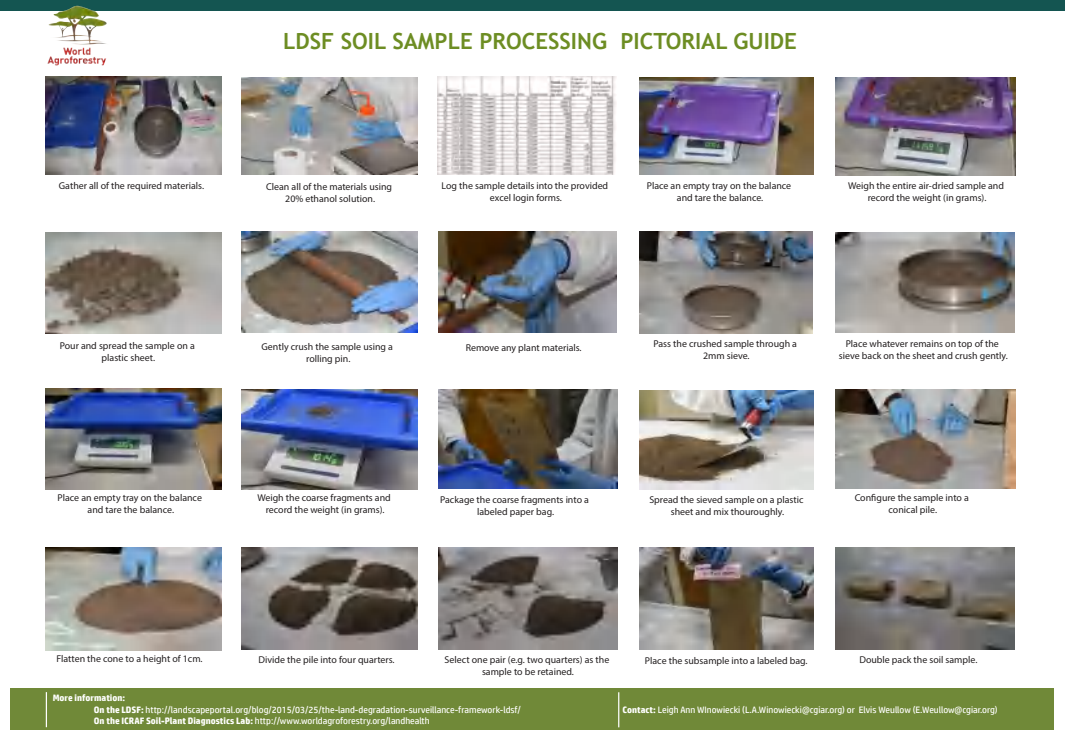
https://worldagroforestry.org/output/icraf-soil-archive-physical-archive-systematically-collected-soil-samples

Standard Operating Procedures (SOPs) to ensure quality control And tutorials for building capacity

Online SOPs

- http://worldagroforestry.org/sd/landhealth/soil-plant-spectral-diagnostics-laboratory/sops

- Having SOPs and tutorials are key for capacity building for scaling soil health assessments and soil spectroscopy
- From sample preparation to instrument set up to spectral processing



Online videos for soil processing

- https://worldagroforestry.org/output/video-ldsf-soil-sample-processing-protocol

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Data streaming from spectrometers: a new dawn for soil health spectrometers: https://worldagroforestry.org/blog/2020/08/13/data-streaming-spectrometer-new-dawn-soil-assessments

World Agroforestry

ICRAF Soils Theme Transforming lives and landscapes with trees

World Agroforestry - Research Data Repository > ICRAF Soils Theme >
Mid-Infrared Spectra (MIRS) from ICRAF Soil and Plant Spectroscopy Laboratory: Africa Soil Information Service (AfSIS) Phase I 2009-2013

Metrics 202 Downloads Contact Share

Mid-Infrared Spectra (MIRS) from ICRAF Soil and Plant Spectroscopy Laboratory: Africa Soil Information Service (AfSIS) Phase I 2009-2013 Version 1.0

Vågen, Tor-Gunnar;Winowiecki, Leigh Ann;Desta, Luseged;Tondoh, Ebagnerin Jérôme;Weullow, Elvis;Shepherd, Keith;Sila, Andrew, 2020, "Mid-Infrared Spectra (MIRS) from ICRAF Soil and Plant Spectroscopy Laboratory: Africa Soil Information Service (AfSIS) Phase I 2009-2013", https://doi.org/10.34725/DVN/QXCWP1, World Agroforestry - Research Data Repository, V1, UNF:6:bMN2MBGqFewDKHPgleRjog== [fileUNF]

Cite Dataset

Learn about Data Citation Standards.

Description

AfSIS Phase I was a collaborative projective funded by the Bill and Melinda Gates Foundation (BMGF), which aimed to provide a consistent baseline of soil information for monitoring soil ecosystem services in sub-Saharan Africa (SSA). Partners included, CIAT-TSBF, ISRIC, CIESIN, The Earth Institute at Columbia University and World Agroforestry (ICRAF). The Land Degradation Surveillance Framework (LDSF), developed at ICRAF, was employed to systematically sample key biopshyical indicators of land and soil health, across landscapes. LDSF sites were randomized using spatial stratification based on Koeppen-Geiger Climate zones across 19 countries in SSA. Soil samples were collected using the LDSF at two depths, 0-20 cm and 20-50 cm. Mid-infrared diffuse refectance spectroscopy (MIR) was a key soil characterization and screening tool in AfSIS. MIR measurements of the ~18,500 samples were centralized at ICRAF's Soil-Plant Spectral Diagnostics Laboratory based in Nairobi Kenya using the Bruker Tensor 27/HTs -XT_FT-IR. The MIR dataset is provided here, organized by country.

Subject

Earth and Environmental Sciences

Keyword

Spectrosocpy, Chemometrics, Mid-infrared spectra, Soil, Soil profile, Sub-Saharan Africa (SSA)

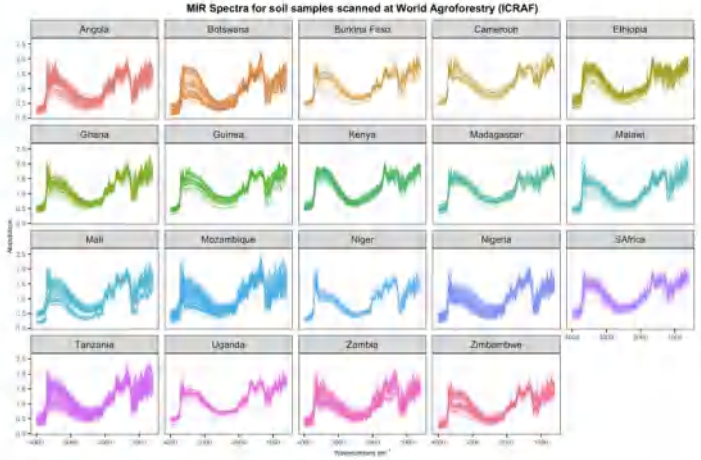
Related Publication

Vågen, Tor-G., Winowiecki, L., Tondoh, J.E., Desta, L.T. and Gumbricht, T. 2016. Mapping of soil properties and land degradation risk in Africa using MODIS reflectance. Geoderma. http://dx.doi.org/10.1016/j.geoderma.2015.06.023. http://www.sciencedirect.com/science/article/pii/S0016706115300082 doi: 10.1016/j.geoderma.2015.06.023

Soil Spectra Library

For over two decades, the Soils Theme of World Agroforestry (ICRAF) in collaboration with partners has been at the cutting edge globally of innovations in soil spectroscopy, creating a large planetary database of soil data, which plays an important role in agricultural research and ecosystem restoration.

MIR Spectra for soil samples scanned at World Agroforestry (ICRAF)



In line with the CGIAR's Open Access Open Data policy, ICRAF is committed to sharing data using credible data repositories such as World Agroforestry Research Data Repository where data and associated meta data are stored and shared in a trackable and citable way, making data accessible to both researchers and the public.

http://www.worldagroforestry.org/sd/landhealth/soil-plant-spectral-diagnostics-laboratory/soil-spectra-library

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Supporting a network of regional labs: new soil Lab at Sinematialli, Ivory Coast

- ICRAF is supporting a network of spectral labs, globally

Kandia Camara, centre, and officials. Photo: World Agroforestry/Gilberte Koffi

The recently opened lab represents a giant step towards improving soil productivity and health.

- https://worldagroforestry.org/blog/2021/05/25/new-laboratory-spectral-analysis-soils-and-plants-cote-divoire

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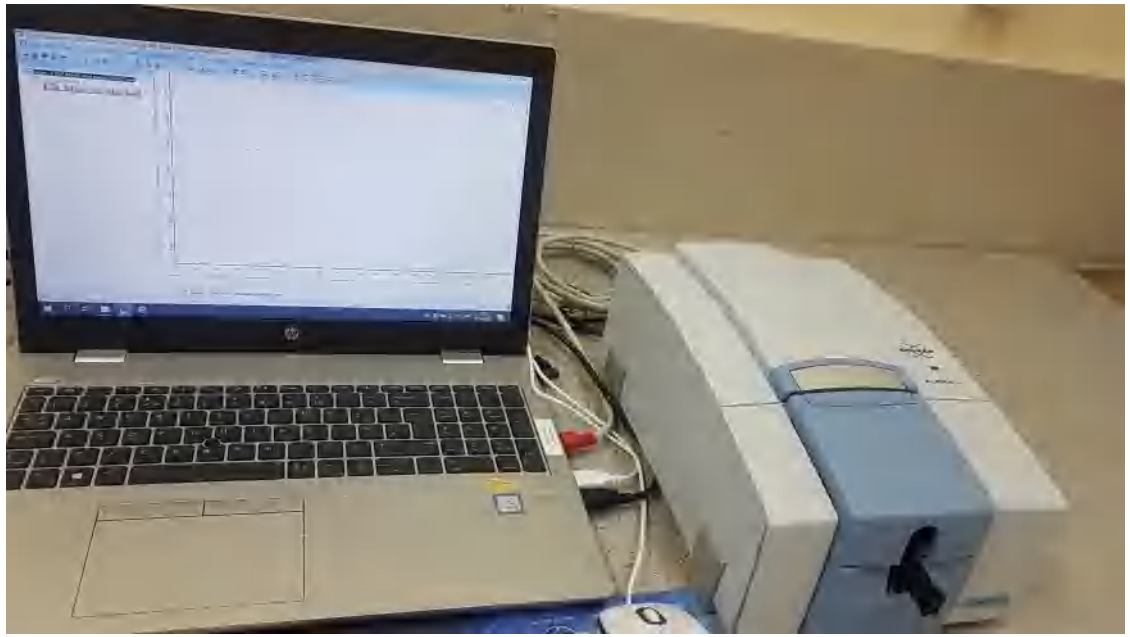
ICRAF now has several MIR and NIR spectrometers

- The latest is the Bruker Invenio

- And the Alpha II ZnSe



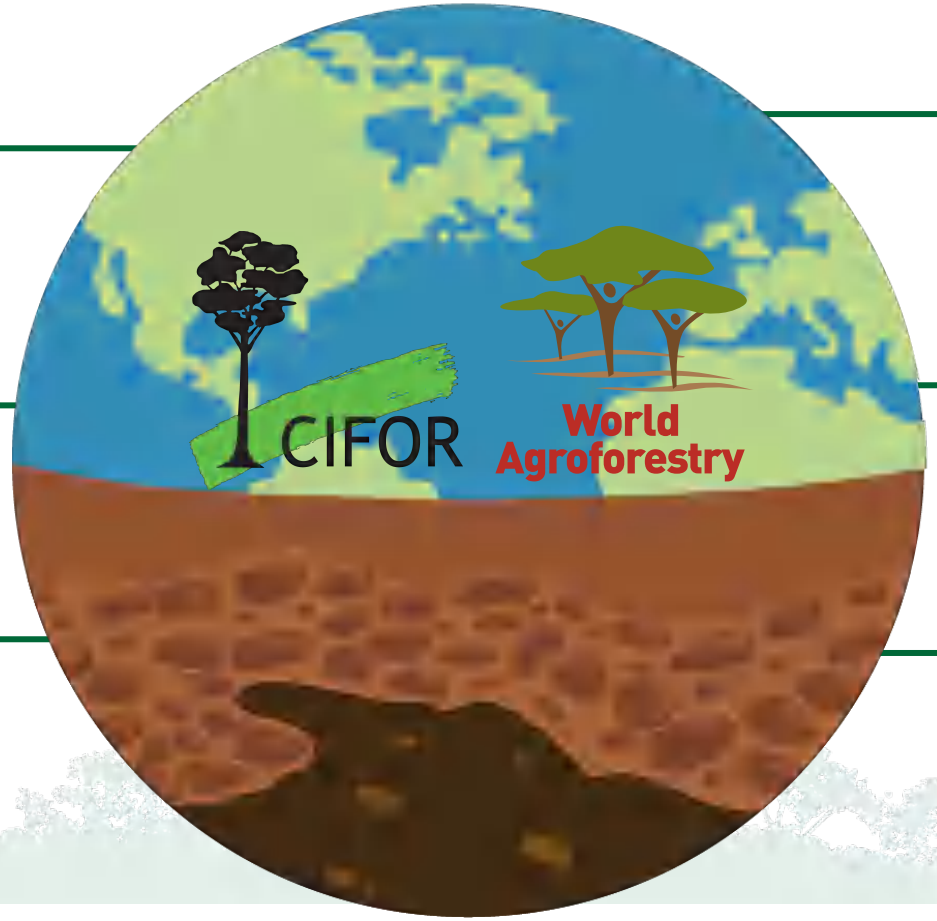
- Visit our webpage to learn more about what we are doing: https://worldagroforestry.org/landhealth

Soil and Land Health Theme:

Six sub-thematic research areas to address pressing global challenges, broken food systems, environmental degradation, accelerating climate change and biodiversity loss.

From Farm to Lab to Global Landscapes

- Soil organic carbon accounting for climate change mitigation and adaptation
- Linking soil health and human health
- Soil biodiversity and impacts on nutrient, pollutant, water and gas fluxes



- Ecosystem health monitoring over time
- Enhanced soil Information for improved targeting and decisions incl soil spectroscopy & data analytics
- Scaling, dissemination, and capacity development for soil health assessments and soil spectroscopy

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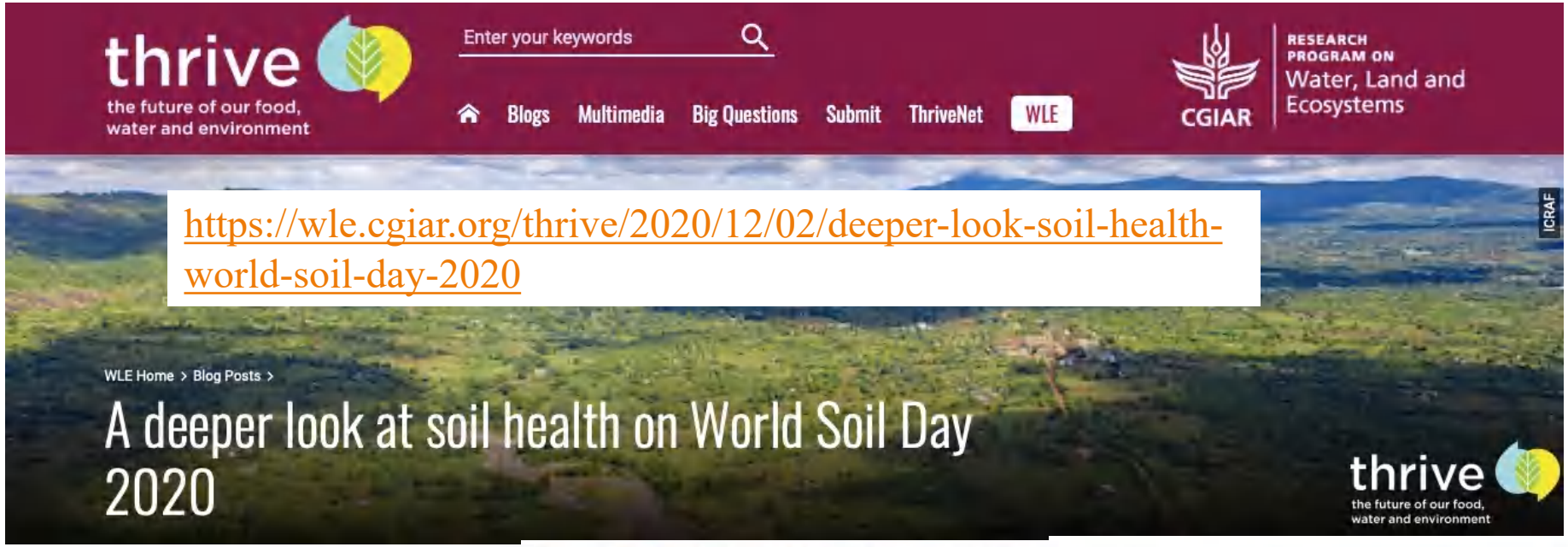
Read more about our work here: https://worldagroforestry.org/sd/landhealth/news including how soil spectroscopy was highlighted on AlJaZeera: http://youtu.be/vFMSEHV7Ap4



People, healthy soils and ecosystems in Africa

Learning how to apply the Land Degradation Surveillance Framework in Ethiopia

Earthrise in Kenya meets healthy soils, scientists and farmers

WSD Podcast: Unearthing the Importance of Soil http://youtu.be/vFMSEHV7Ap4 https://forestsnews.cifor.org/69959/dig-it-unearthing-the-importance-of-soil?fnl=

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Key messages

- Through stewardship, we can improve soil health.
- Scaling investments in soil health are urgently needed to meet the SDGs, and contribute to the goals of the three UN Conventions, the UN Food Systems Summit as well as climate actions and ecosystem restoration targets
- We have the tools and methods to measure and track changes in soil and land health at scales relevant to multiple stakeholders, including to capture the complex processes of degradation and restoration
- The use of soil spectroscopy will play a key role in enabling landscape scale assessments
- Investments in systematic field data collection, capacity development, databases, data analytics are key
- The global community will need to come together to strengthen the voice of soil health for food and nutrition security, ecosystem restoration and climate action

Check out our revised Soil and Land Health Theme Webpage for videos, brochures, and more!!
https://worldagroforestry.org/landhealth
CIFOR-ICRAF Restoration4Resilience:
https://www.cifor-icraf.org/restoration-for-resilience/

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foreststreesagroforestry.org | globallandscapesforum.org | resilientlandscapes.org

The Center for International Forestry Research (CIFOR) and World Agroforestry (ICRAF) envision a more equitable world where forestry and landscapes enhance the environment and well-being for all. CIFOR-ICRAF are CGIAR Research Centers.

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