Landscape-scale Assessments of Soil Organic Carbon and Ecosystem Health

Bridging the gaps in data collection and use with the Land Degradation Surveillance Framework (LDSF) & Regreening App

World Agroforestry

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UNITED NATIONS DECADE ON ECOSYSTEM RESTORATION 2021-2030

Leigh Winowiecki &
Tor-Gunnar Vågen
29 April 2021

Land degradation threatens the livelihoods, food and nutrition security of the of over 3.2 billion people (IPBES 2018)

Photo: Kelvin Trautman

The challenge (and opportunity) is to scale locally appropriate option with large numbers of farmers to ensure sustainable land restoration.

Photo: Kelvin Trautman

Generating and leveraging evidence needs to be seen as part of the project cycle, not an added activity

- Contributing to SDGs
- NDCs
- National restoration commitments
- Climate action targets
- Contributing to the project outcomes
- Providing valuable information for investments

Assessment of performance to improve interventions

In addition, the monitoring framework must address the barriers to data collection

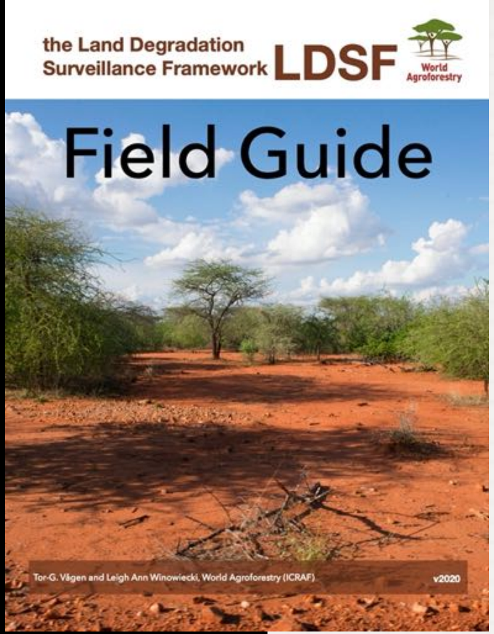
1) Assessing variability
2) Cost
3) Capacity
4) Data sharing/accessibility
5) Data reliability
6) Timeliness
7) Stakeholder engagement
8) …

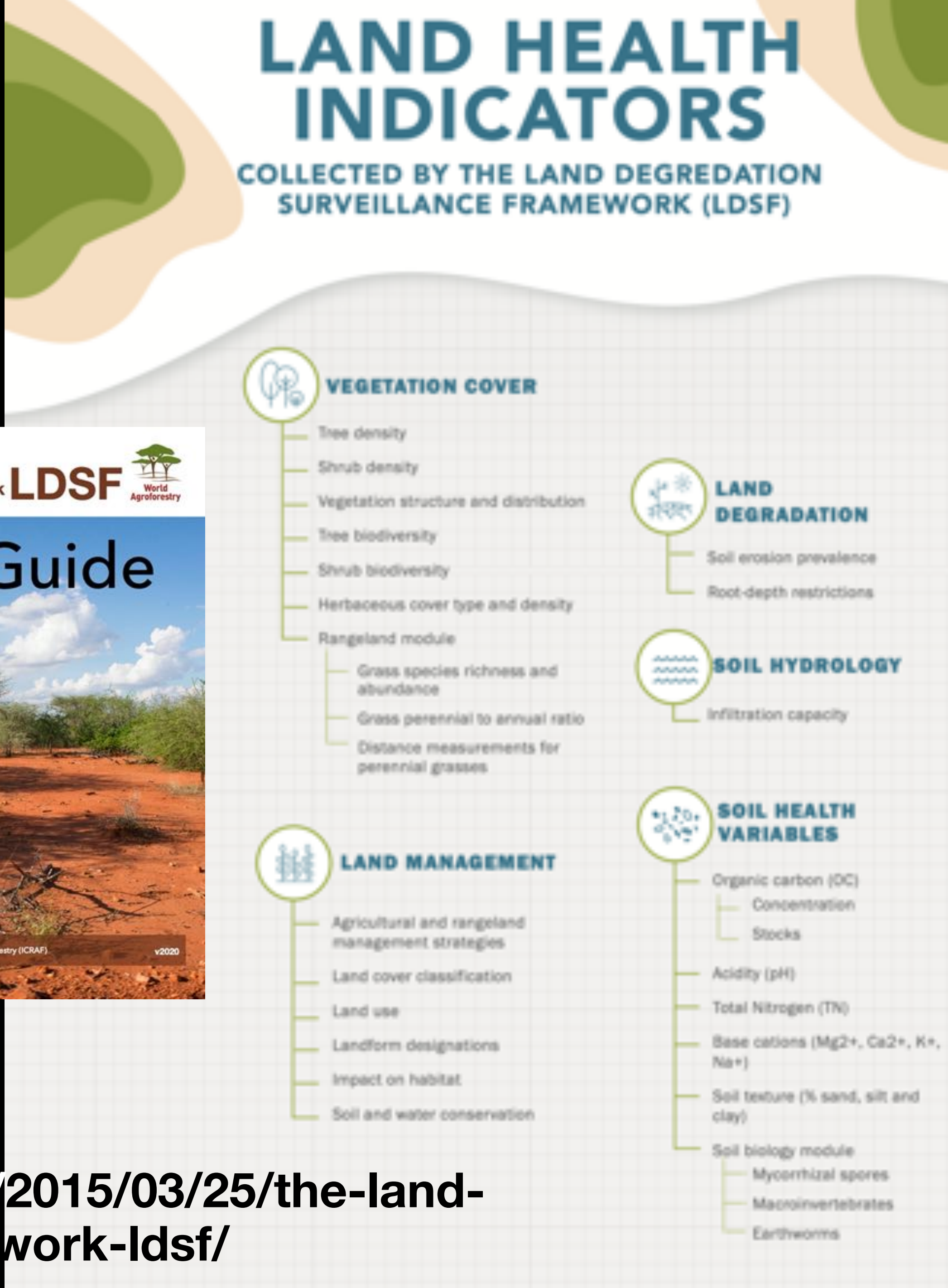
In response….

The LDSF was developed in response to the need for…

Systematic and science-based assessment and monitoring of soil and ecosystem health at scale, using a robust and consistent indicator framework that is…

- **Specific**: The indicator should accurately describe what is intended to be measured, and should not include multiple measurements in one indicator.
- **Measurable**: Regardless of who uses the indicator, consistent results should be obtained and tracked under the same conditions.
- **Attainable**: Collecting data for the indicator should be simple, straightforward, and cost-effective.
- **Relevant**: The indicator should be closely connected with each respective input, output or outcome.
- **Time-bound**: The indicator should include a specific time frame.





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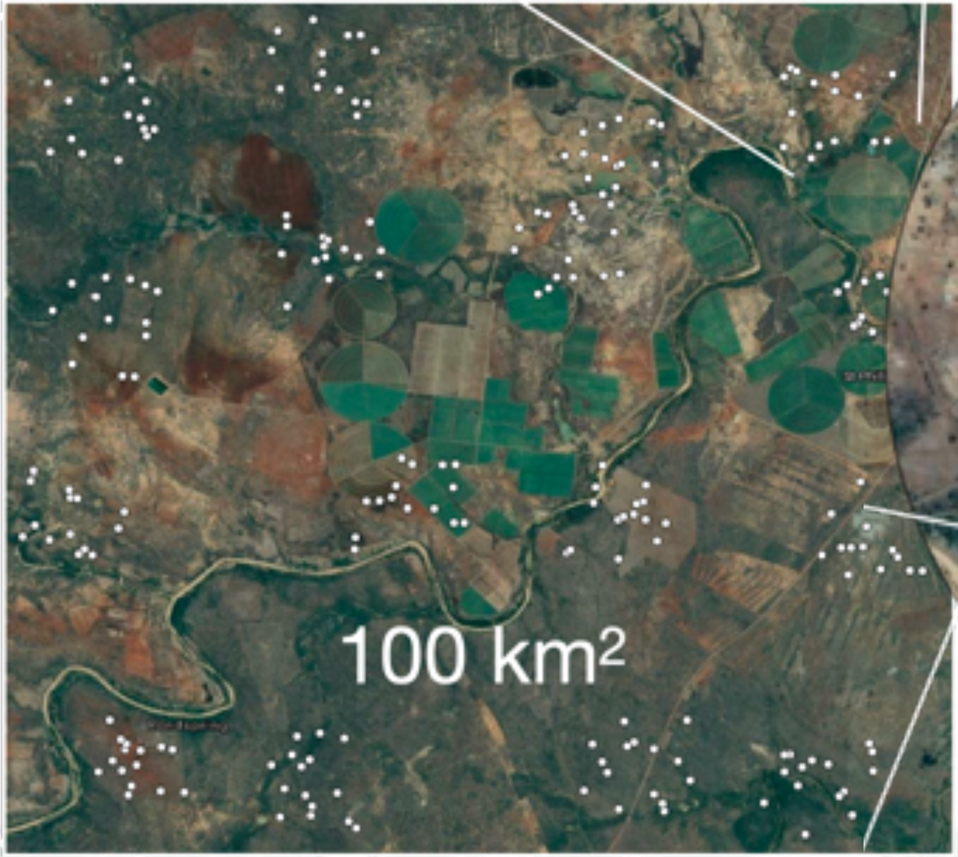
http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

Field-based Assessment of Land and Soil Health Using the LDSF

- The Land Degradation Surveillance Framework (LDSF)
  - A systematic field-based assessment of multiple variables at the same geo-referenced location
- Assessment of variability across landscapes, within and between land uses
- **Robust statistical analysis on drivers of degradation**
- Allows for rapid assessments of indicators of land and soil health
- Allows for the production of high quality maps of key indicators
- Setting a baseline and can be used to monitor changes over time
- Field guide available online here: http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

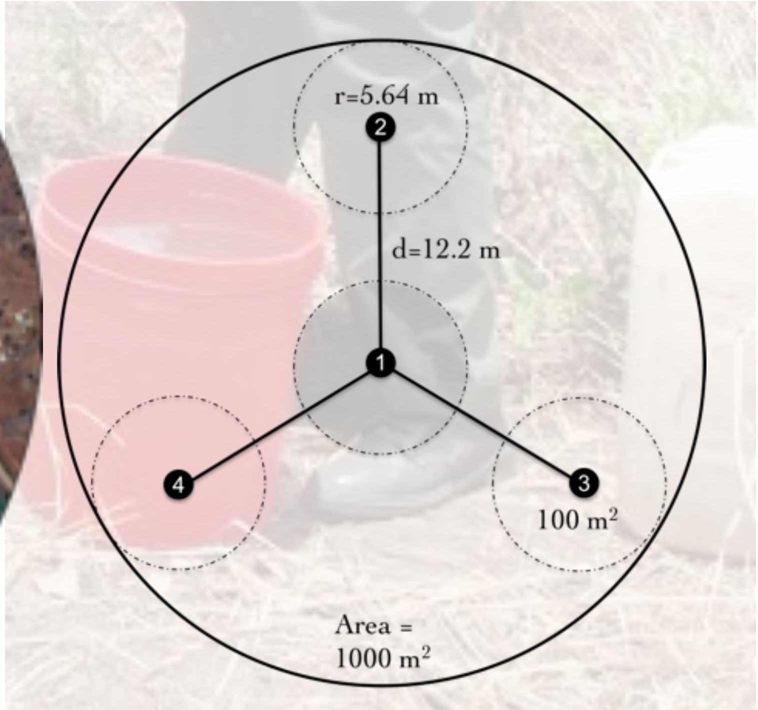
LDSF: Nested Sampling Scales

Unbiased sampling – capturing landscape variability



Site Level (10km * 10km)

Cluster Level
16-1km² per site



Plot Level
10-1000m² per cluster

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CGIAR Research Program on Water, Land and Ecosystems
CGIAR Research Program on Forests, Trees and Agroforestry
Global Landscapes Forum
Resilient Landscapes

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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Global Landscapes Forum
Resilient Landscapes

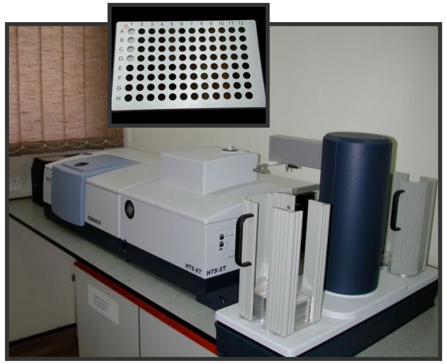
Collecting Soil Samples in the LDSF

- 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




Soil Spectroscopy enables landscape-scale assessments

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



Check out the ICRAF Soil-Plant Spectral Diagnostics Laboratory in Nairobi, Kenya: https://worldagroforestry.org/sd/landhealth/soil-plant-spectral-diagnostics-laboratory

- MIR 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 spectrometers
- Investment in spectral data analytics
- Read more and access ICRAF spectral data here:

http://worldagroforestry.org/blog/2020/08/13/data-streaming-spectrometer-new-dawn-soil-assessments

Examples of Accuracy of MIR Predictions – Validation model

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. 0. doi:10.2134/jeq2017.07.0300

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

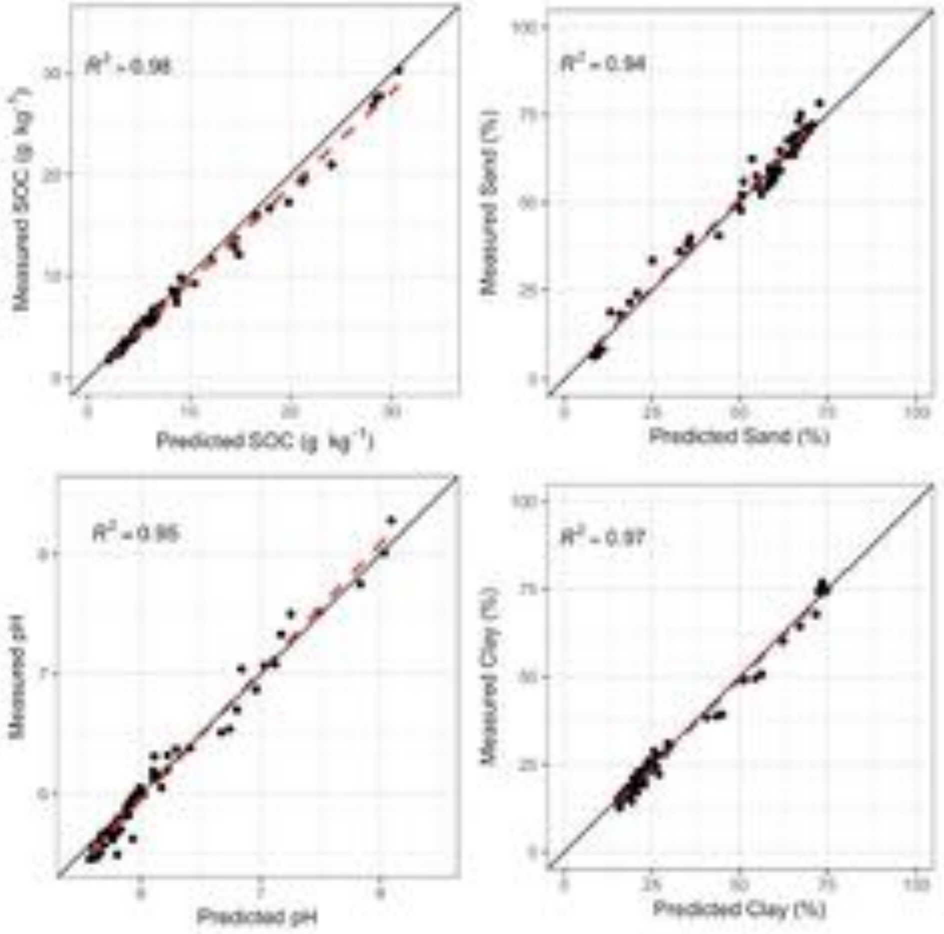


Fig. 3. Prediction results for soil organic carbon (SOC), pH, and texture according to mid-infrared spectral data from the two study sites combined. The red dashed lines represent the regression lines, and the 1:1 abline is the solid black line.

Global Soil Spectroscopy Community continues to Grow

GLOSOLAN
GLOBAL SOIL LABORATORY NETWORK

Food and Agriculture Organization of the United Nations

English Русский Español

Global Soil Partnership

Overview | Partners | Regional partnerships | ITPS | Technical networks | Areas of work | Pillars of action | Resources

Global Soil Laboratory Network

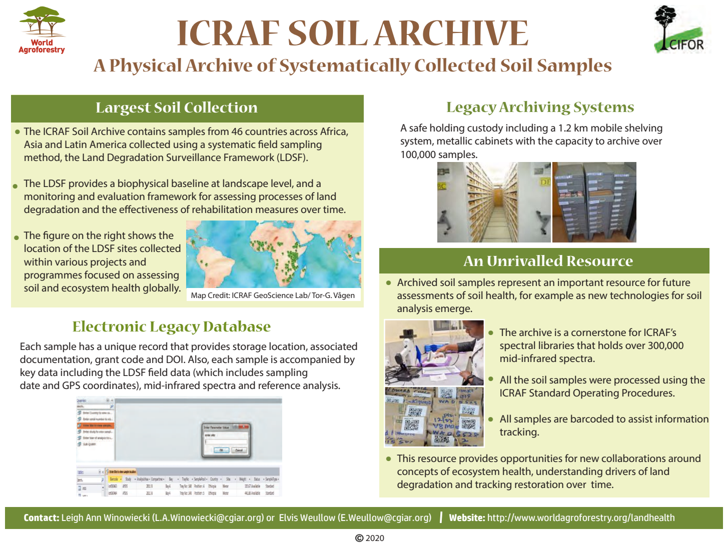
Soils: if you cannot measure it, you cannot manage it

The Global Soil Laboratory Network (GLOSOLAN) was established in 2017 **to build and strengthen the capacity of laboratories in soil analysis and to respond to the need for harmonizing soil analytical data.** Harmonization of methods, units, data and information is critical to (1) provide reliable and comparable information between countries and projects; (2) allow the generation of new harmonized soil data sets; and (3) support evidence-based decision making for sustainable soil management.

The work of GLOSOLAN supports the implementation of the Sustainable Development Goals, the Agenda 2030 for Sustainable Development and the mandate of FAO on food security and nutrition. For more information contact Lucrezia.Caon@fao.org

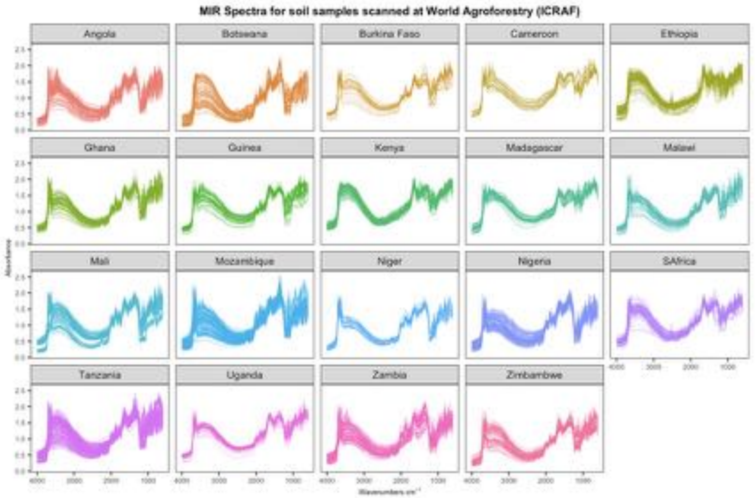
- Growing global community investing and scaling soil spectroscopy
- Growing publications on soil spectroscopy
- Increasing number of private sector investments
- ICRAF is the Regional Champion Lab for SSA in the FAO-led GLOSOLAN: http://www.fao.org/global-soil-partnership/glosolan/soil-analysis/dry-chemistry-spectroscopy/regional-champions-on-soil-spectroscopy/cifor-icraf-kenya/en/

Systematic Spectral Library and Soil Archive of Barcoded Soil Samples



Exiting Opportunities for collaboration:

- ICRAF hosts over 150,000 systematically collected, barcoded soil samples with MIR spectra, and growing
- The ICRAF Soil Archive contains samples from 46 countries across Africa, Asia, and Latin America for:
    - Expanding analytical techniques
    - Testing new methodologies
    - Data analytics
- This large database enables assessments of ecosystem health, including building robust models for **Soil mapping**



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

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

Indicators measured with the LDSF at plot and subplot levels

Soil health variables

- Organic carbon (OC)
  - Concentrations
  - Stocks
- Acidity (pH)
- Total Nitrogen (TN)
- Base cations (Mg^{2+}, Ca^{2+}, K^{+}, Na^{+})
- Soil texture (% sand, silt and clay)
- Soil biology module
  - Earthworm presence
  - Mycorrhizal spores
  - Macroinvertebrates

Land Management

- Agricultural and rangeland management strategies
- Land cover classification
- Land use
- Landform designations
- Impact on habitat
- Soil and water conservation practices
- Fire mangament

Land degradation

- Soil erosion prevalence
- Root-depth restrictions

Hydrologic function

- Infiltration capacity for modeling saturated hydraulic conductivity

Vegetation cover

- Tree density
- Shrub density
- Vegetation structure and distribution
- Tree biodiversity
- Shrub biodiversity
- Herbaceous cover type and density
- Prescence of invasive species
- Rangeland module
  - Grass species richness and abundance
  - Grass perennial to annual ratio
  - Distance measurements for perennial grasses

Applications of the LDSF

Photo: Kelvin Trautman

Soil Organic Carbon Assessments

Spatial assessment of Soil Organic Carbon (SOC) at 30 meter resolution for Rwanda

Winowiecki et al. SOIL

Land Degradation Dynamics (LDD)

Regreening Africa

The objective of component two of the Regreening Africa project is equipping partners in the 8 project countries with surveillance and analytical tools on land degradation dynamics to support strategic decision-making and monitoring in the scaling-up of evergreen agriculture.

Data on indicators of land and soil health are collected in the field and analysed to understand drivers of degradation, prioritise areas for implementation of interventions and monitor changes over time.

Land degradation dynamics are spatially assessed across landscapes for the project action areas.

Partners are trained in systematic field data collection using the LDSF and data interpretation.

Funded by the European Union

World Agroforestry · World Vision · care · CRS Catholic Relief Services · Oxfam · Sahel Eco · ELD The Economics of Land Degradation

Mapping Soil Organic Carbon (SOC) Stocks

Winowiecki, L., Vågen, T.-G., Huising, J., 2016. Effects of land cover on ecosystem services in Tanzania: A spatial assessment of soil organic carbon. Geoderma 263, 274–283. https://doi.org/10.1016/j.geoderma.2015.03.010

Linking soil organic carbon and land degradation

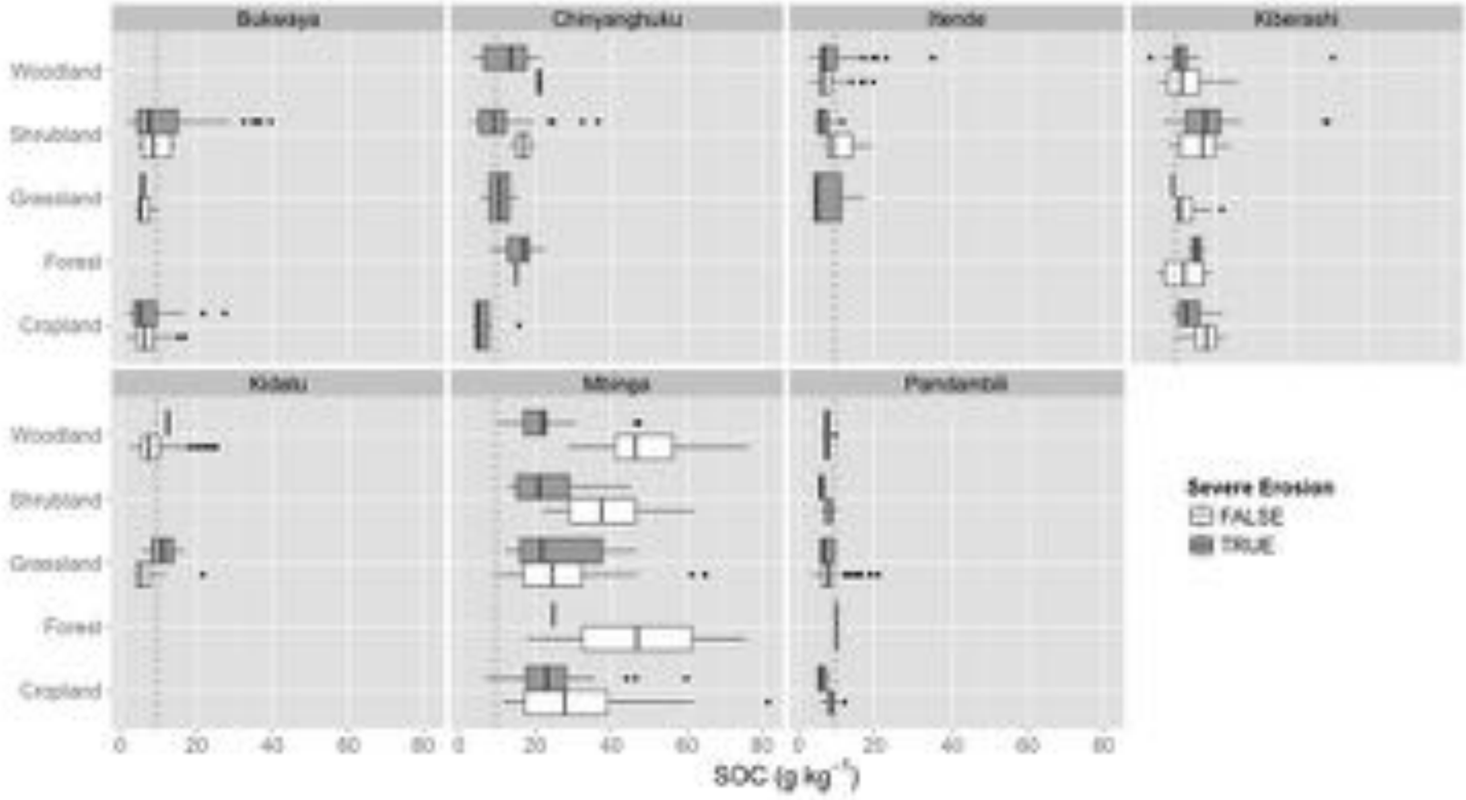
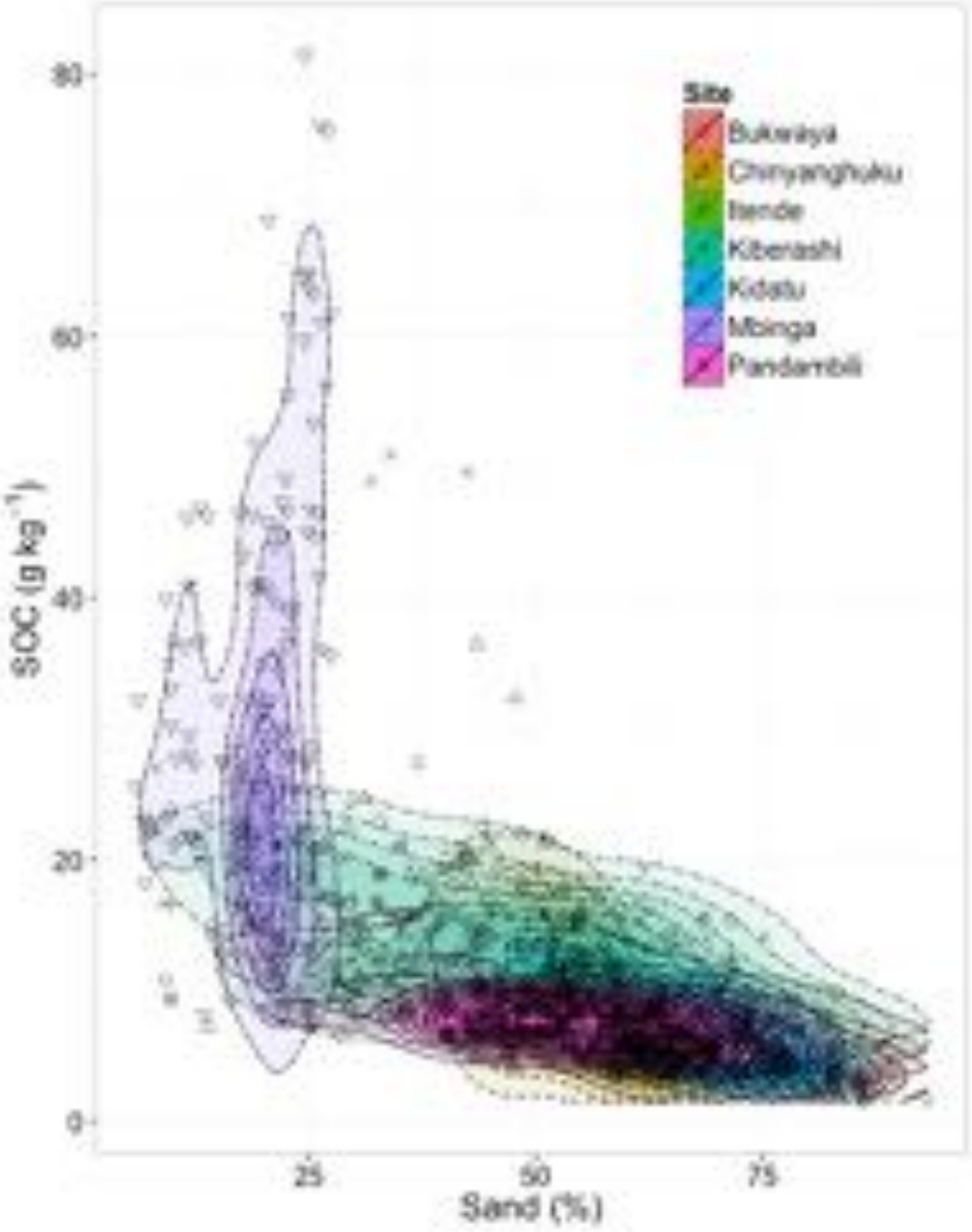


Fig. 5. SOC content in eroded and non-eroded plots for each land cover typology within each site.

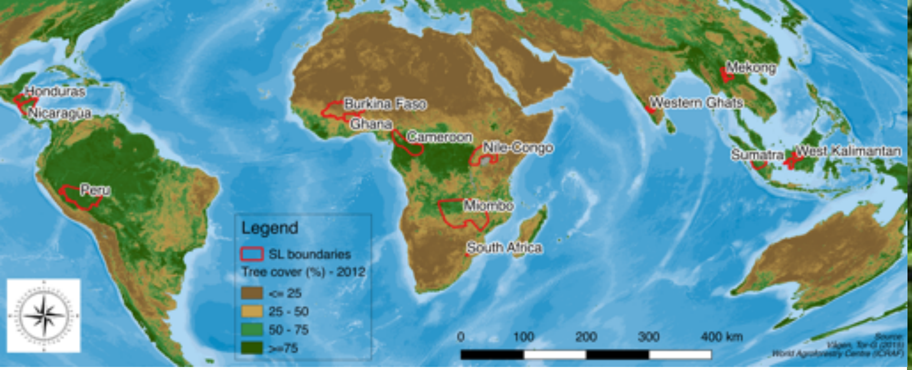
We assessed the effects of erosion on SOC for the study sites and different land cover typologies using the LME model. Non-eroded plots (n = 619) had higher SOC (mean = 9.9 g kg^{-1}) than eroded plots (p b 0.05), with an overall decrease of 0.92 g kg^{-1} SOC in eroded areas relative to non-eroded.

Understanding and Identifying Constraint Envelopes

- There are inherent soil properties that can limit the extent to which the soil can provide ecosystem services....such as sequestration of soil organic carbon
- These constraint envelopes are important to understand in order to manage for agricultural productivity
- This graphic shows that soil with HIGH sand limit the amount of carbon that can be stored



Winowiecki, L., Vågen, T.-G., Huising, J., 2016. Effects of land cover on ecosystem services in Tanzania: A spatial assessment of soil organic carbon. Geoderma 263, 274–283. https://doi.org/10.1016/j.geoderma.2015.03.010



Sentinel Landscapes Initiative

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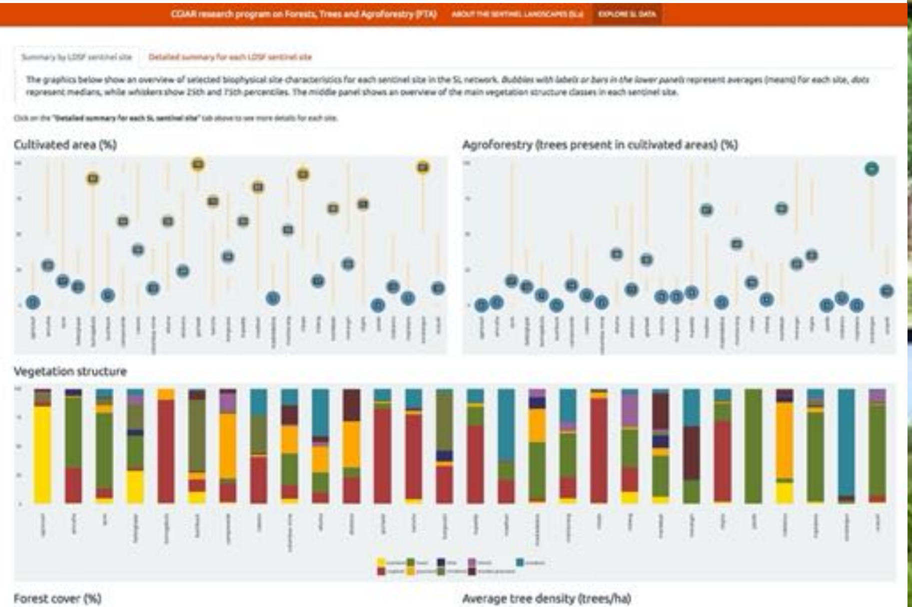
http://landscapeportal.org/slExplorer/



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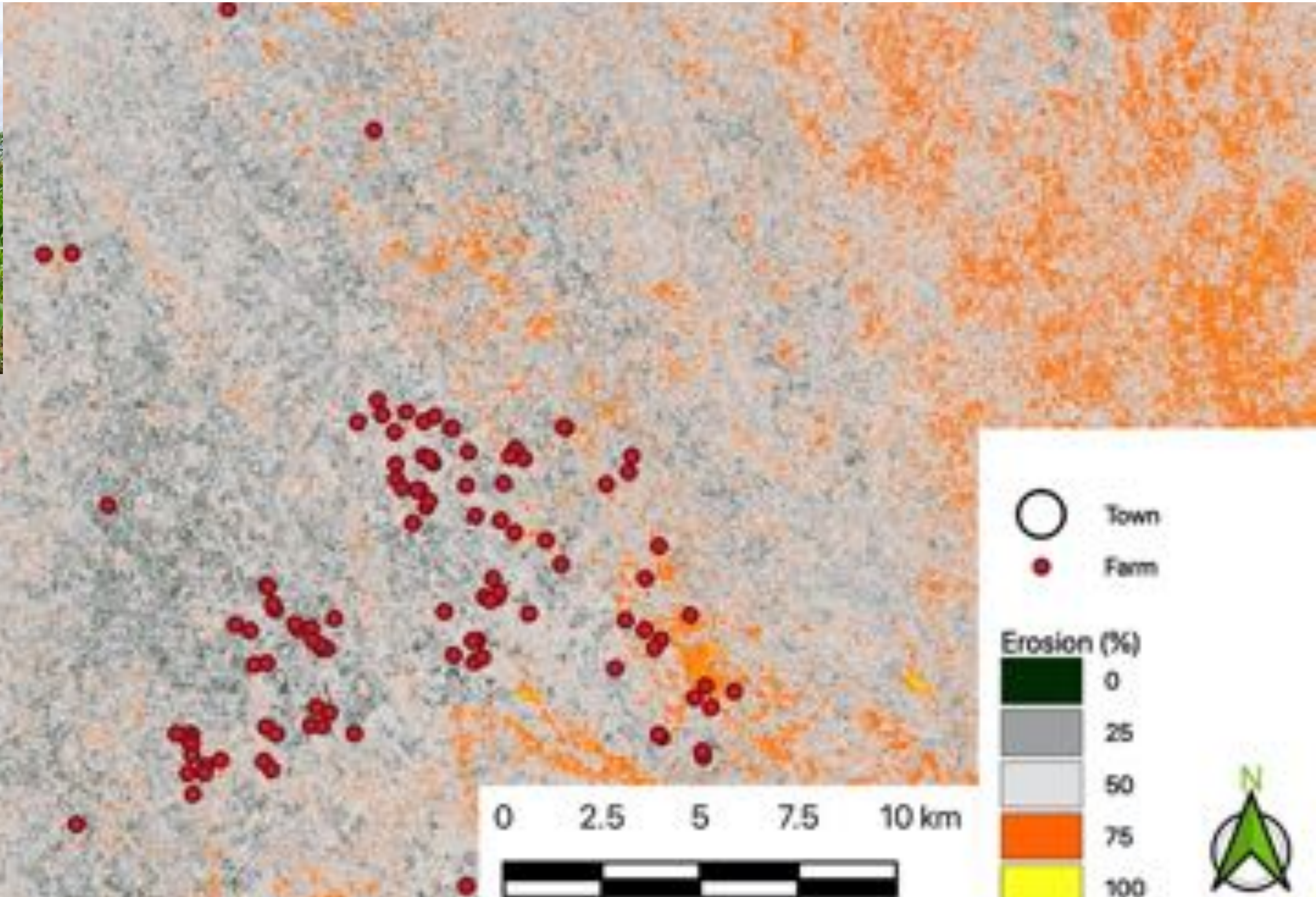
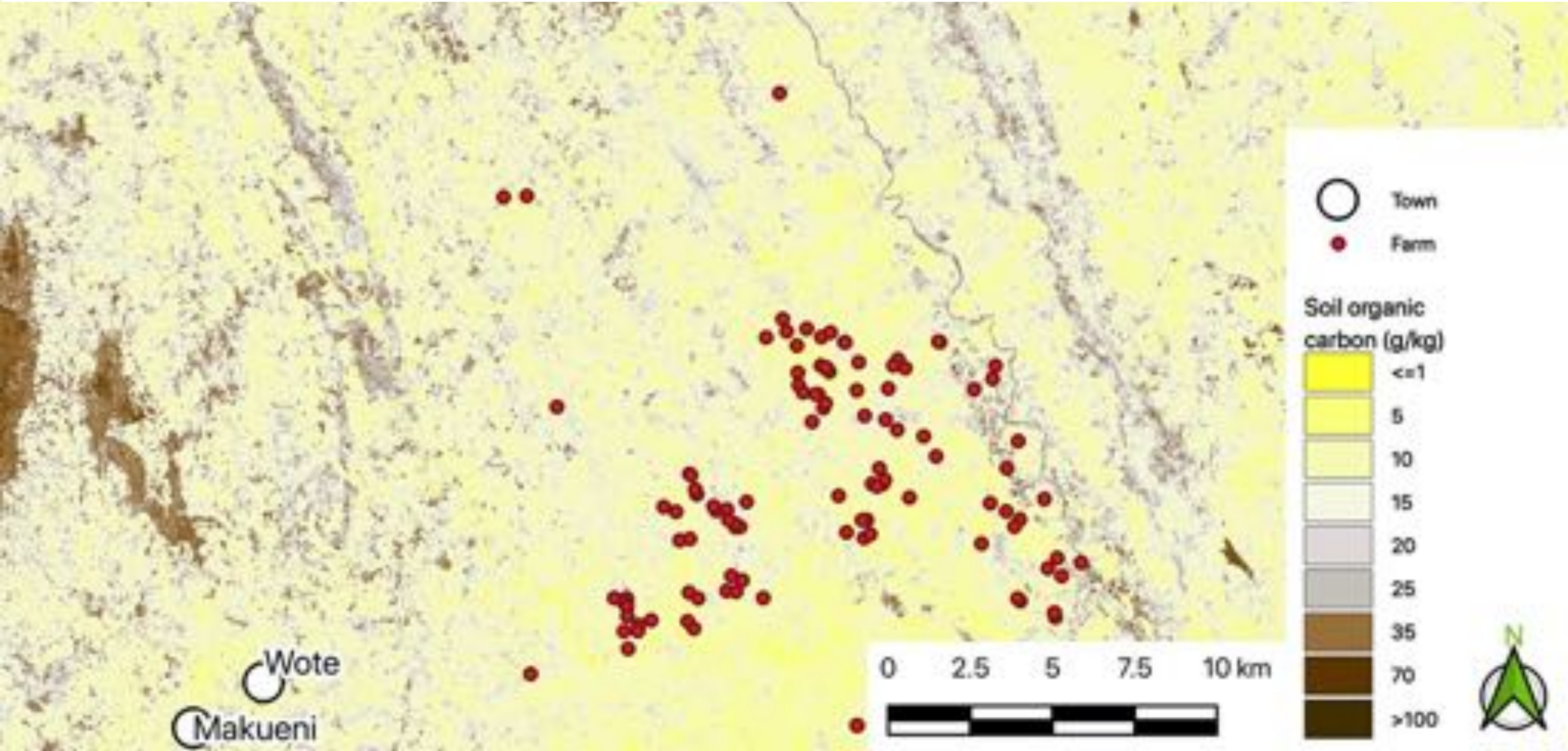
Farm-level assessments at 30 meter resolution to track what is happening at the farm/household level – impact of restoration/ management options on soil erosion



Important to assess multiple biophysical indicators at the same time to capture complexity: Example of soil organic carbon a key indicator of soil health



Spatially explicit assessment of priority areas for restoration: SOC and Erosion in Laikipia County, Kenya

Soil organic carbon (SOC)

Soil erosion prevalence

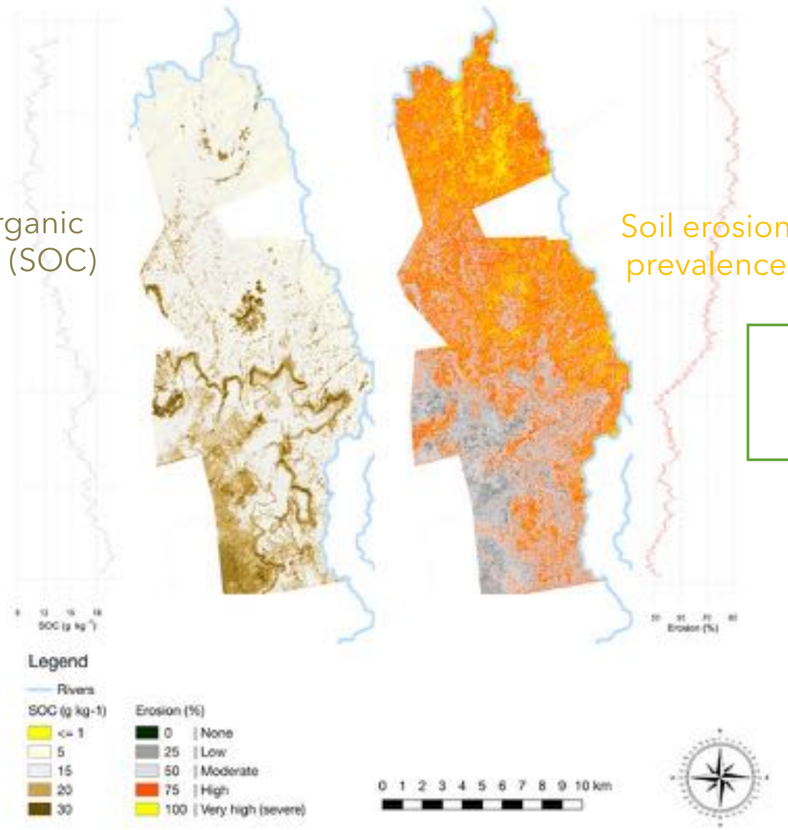


Fig. 11. Map of restoration potential for Mpala Ranch.

Restoration priority areas

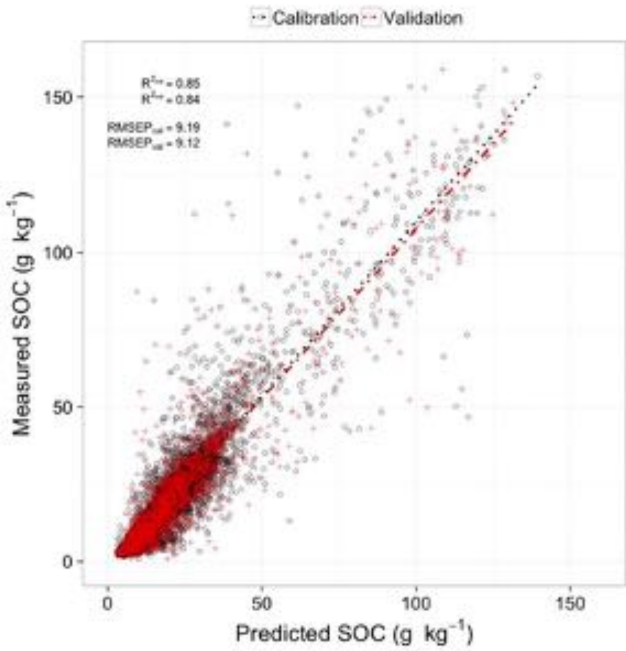


Fig. 7. Predicted vs measured SOC for calibration and validation model runs, respectively. The black dotted line shows the regression line for calibration model predictions, while the red dashed line shows the regression line for the validation model predictions. (For interpretation of the references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

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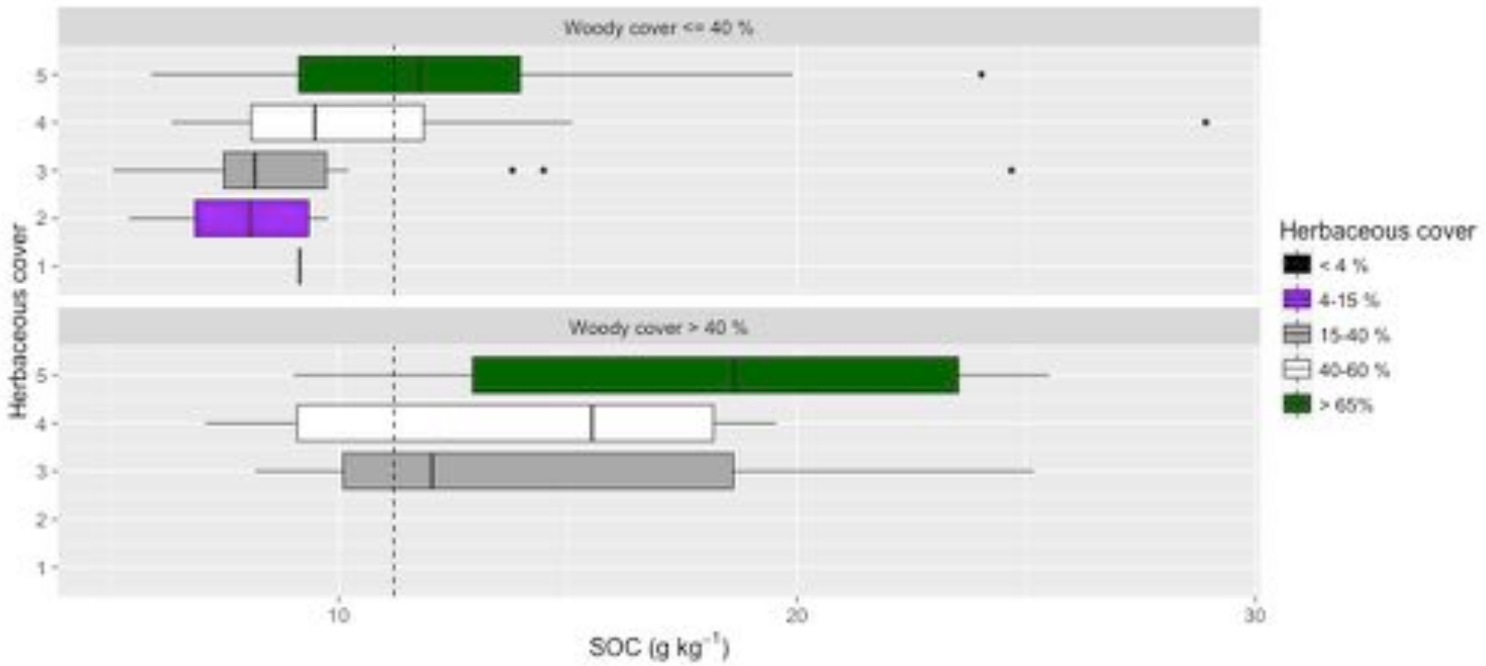
Winowiecki, LA., Vågen, T-G., Kinnaird, MF, TG. O'Brien. 2018. Application of systematic monitoring and mapping techniques: Assessing land restoration potential in semi-arid lands of Kenya. Geoderma. https://www.sciencedirect.com/science/article/pii/S001670611830510X

Linking variables: assessing the thresholds for woody and herbaceous cover on Soil Organic Carbon (SOC)



Increasing herbaceous cover densities had a positive effect on SOC (F=4.114, df=4, 37.59, P=0.007) and SOC was significantly higher in plots with woody cover>40% (F=31.282, df=1, 116.09, P < 0.001) indicating interaction effects between woody and herbaceous cover.

Grant Agreement International Agricultural Research Centers

New collaboration with GIZ:
Soil protection and rehabilitation for food security: Spatial Assessments of Changes in Soil Health Indicators in Benin and Kenya
15-Nov-2020 to 30-Sept-2022

To generate evidence on the benefits of soil protection and rehabilitation for the mitigation of greenhouse gas emissions and carbon sequestration.

Location of the four LDSF sites: Benin (2) and Kenya (2)

- Kenya- fieldwork completed in April 2021
  - Ungunja, Siaya County
  - Sichel, Bungoma
- Benin
  - Djidja (fieldwork completed in April 2021)
  - Gogoinou (fieldwork started this week)

Key Benchmarks/ Outputs for the GIZ Assessments

- Provide a baseline of soil and land health
- Assess the impact of agricultural practices on key indicators of soil and land health
- Assess the soil and land health across time
- Identify ecological constraints affecting land (agricultural) productivity and soil organic carbon dynamics
- Produce moderate to high resolution spatial assessments (maps) of soil properties, and land degradation
- Compile and share data collected
- Engage local stakeholders in the field assessments

Capacity Development with Partners using the Land Degradation Surveillance Framework (LDSF)

1

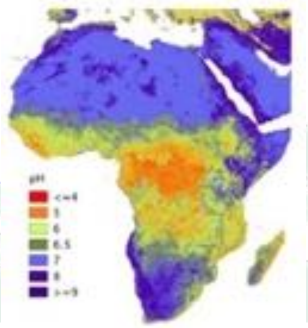
Field training includes all aspects of the LDSF such as: GPS navigation; electronic data entry and upload; LCCS vegetation classification; soil sampling; infiltration measurements; woody biodiversity measurements; and land degradation assessments. **Participants include** field technicians, members of the LDSF field team, partners interested in learning new techniques for land and soil health assessments.

2

Data analytics training to explore the LDSF data with R statistics. We will tidy and visualize data as well as apply mixed effect models to assess key indicators of land and soil health. We will also explore database development and data management. **Participants include** technical staff interested in data analysis and data management and those who will continue to work with the LDSF datasets.

3

Remote sensing (RS) training to explore key concepts, methods and applications of RS, including the use of open source GIS and remote sensing software. Conduct basic analysis using RS data (creation of image composites, image calculations, generation of vegetation indices and soil maps, etc). **Participants include** technical staff familiar with RS and GIS principles.



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Co-designed online decision dashboards for increased engagement with and interrogation of data: http://landscapeportal.org/tools/

SHARED the decision hub

http://www.worldagroforestry.org/output/decision-dashboards

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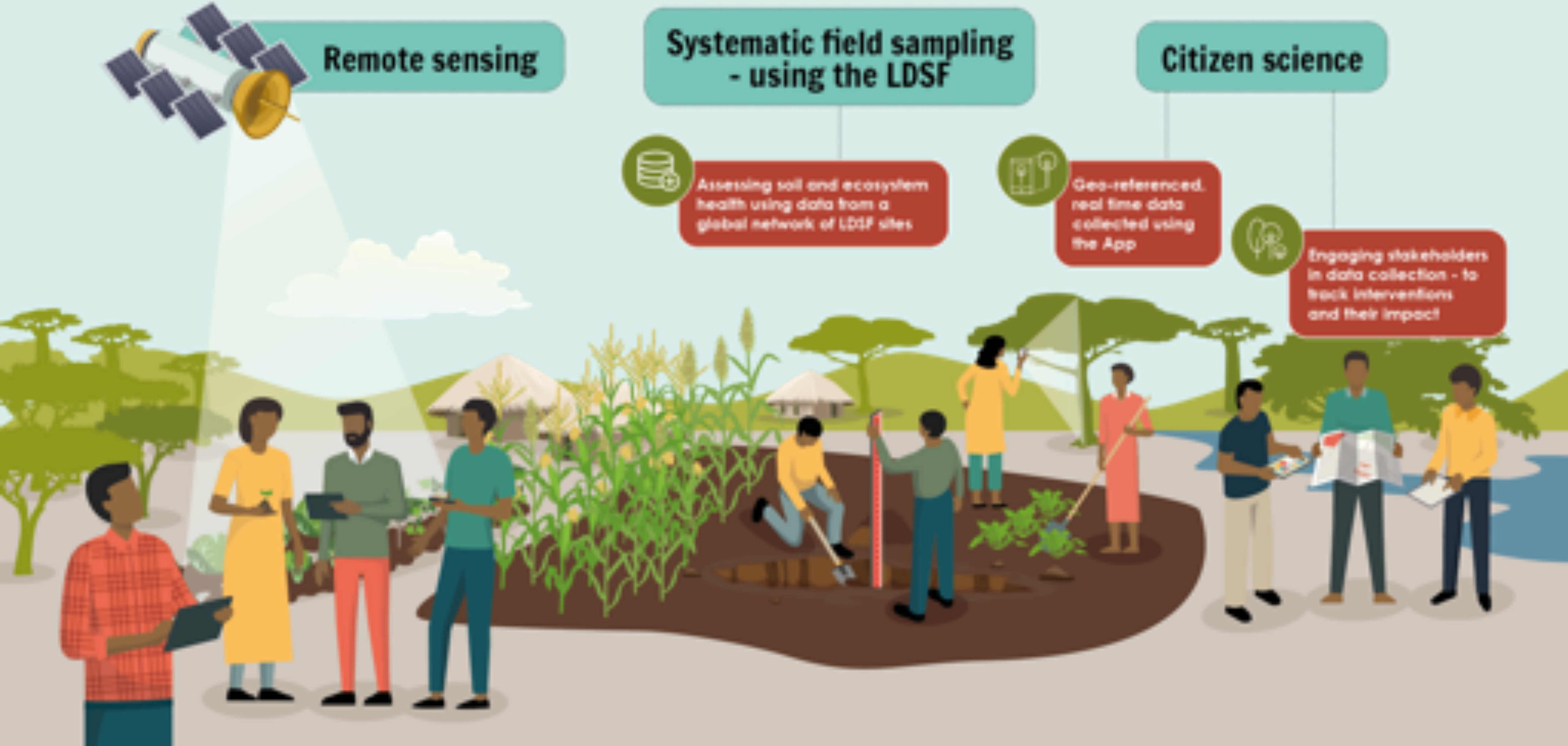
Linking on-the-ground monitoring with global models to track restoration and understand processes of degradation/restoration & monitor SOC



Systematic assessments enabling innovative data collection tools

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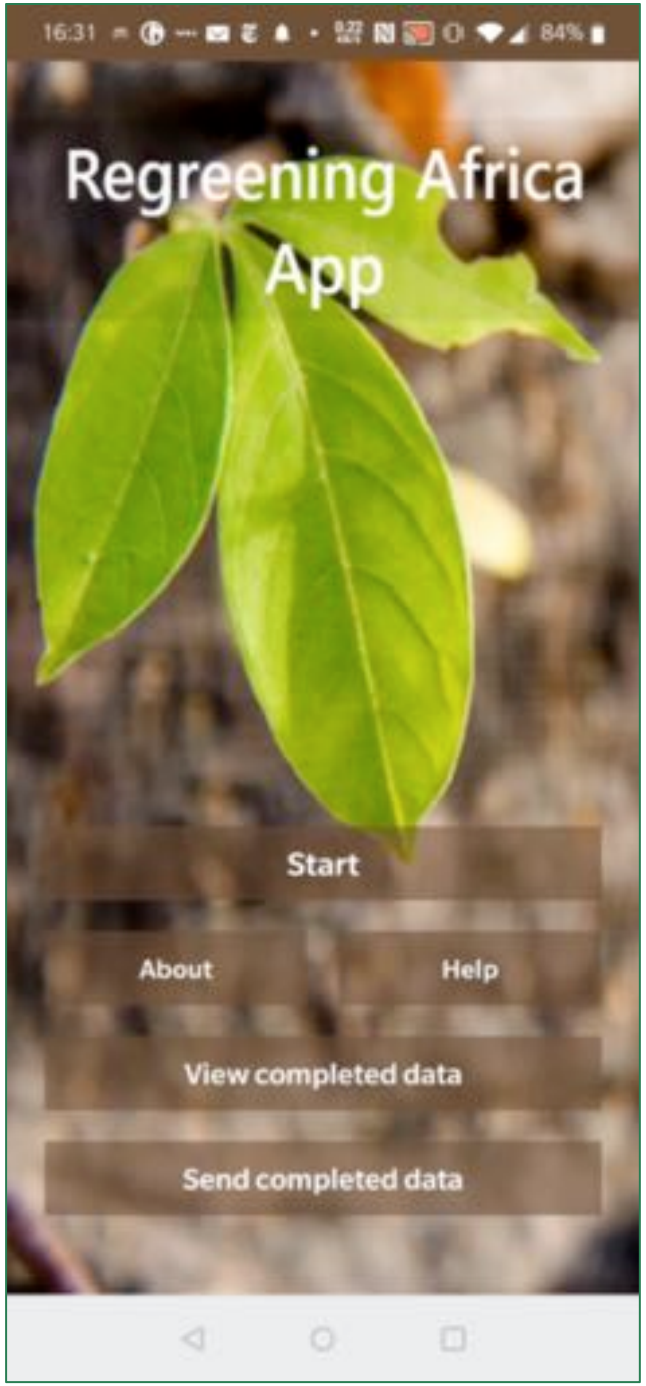
Global Landscapes Forum

Resilient Landscapes



Citizen science data collection using the Regreening App

https://play.google.com/store/apps/details?id=com.icraf.gsl.regreeningafrica&hl=en

Used by (among others):

- Implementing partners
- Scientists
- Extension agents
- Lead farmers
- Nursery managers

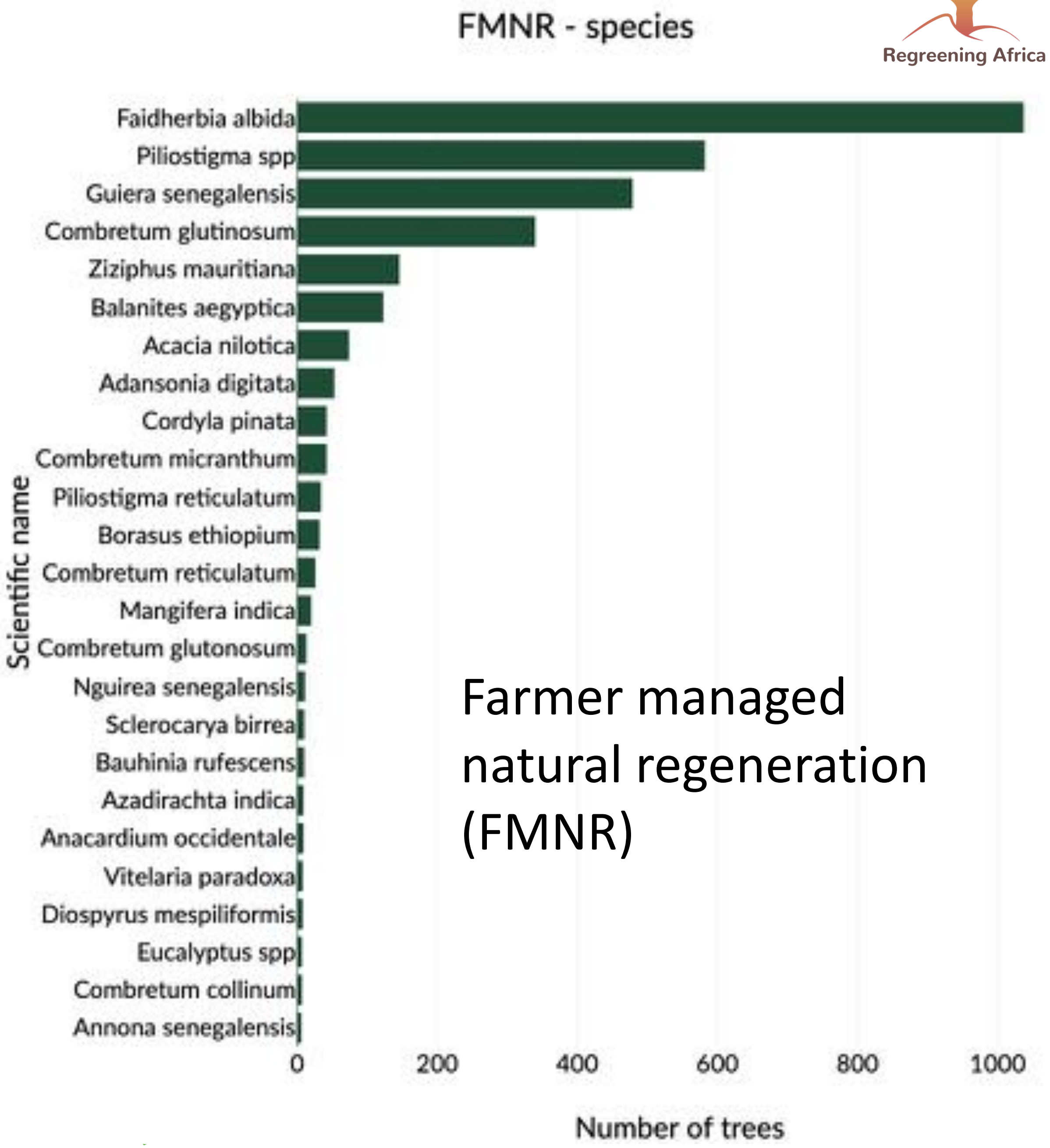
Modules:

- Tree planting
- FMNR
- Nurseries
- Training

Google Play

Results: Senegal > 4500 HHs

Regreening Africa

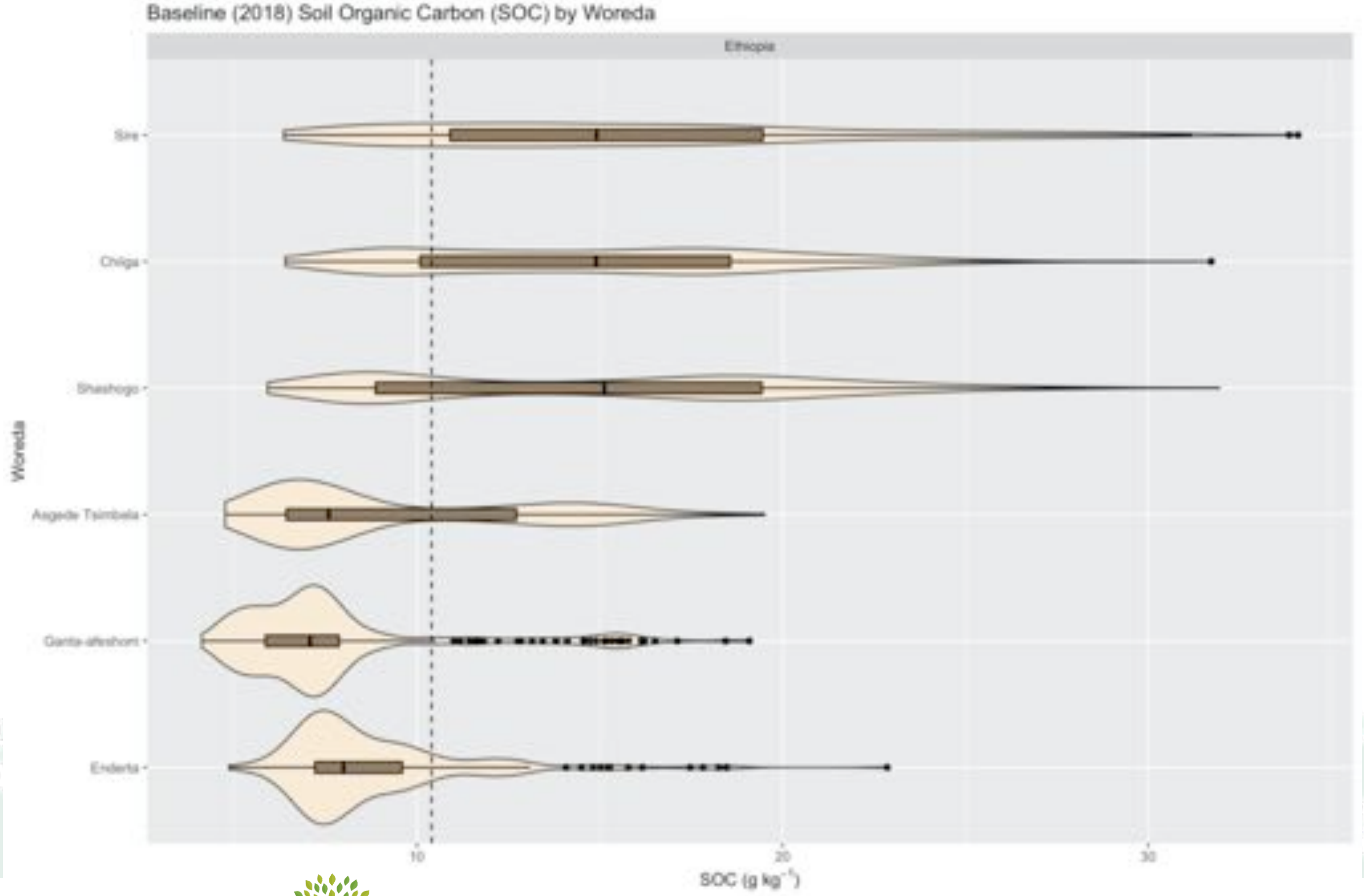


Farmer managed natural regeneration (FMNR)

- Users walk the boundary of fields with tree planting or FMNR interventions and submit the geo-tagged field polygons.
- These farm polygons can then **overlaid onto maps of land cover and soil health** allowing us to assess the effectiveness of these interventions on multiple aspects of ecosystem health.
- Potential applications of these assessments include soil carbon monitoring, relating directly to climate neutrality goals, etc.
- Also, biodiversity within farming systems can be assessed and tracked.

Soil Organic Carbon in Ethiopia- combing polygons with soil health maps

Boxplots show the variation in SOC by woreda. Median = 10.4 gC/kg – we will use these to track changes over time



Regreening Africa

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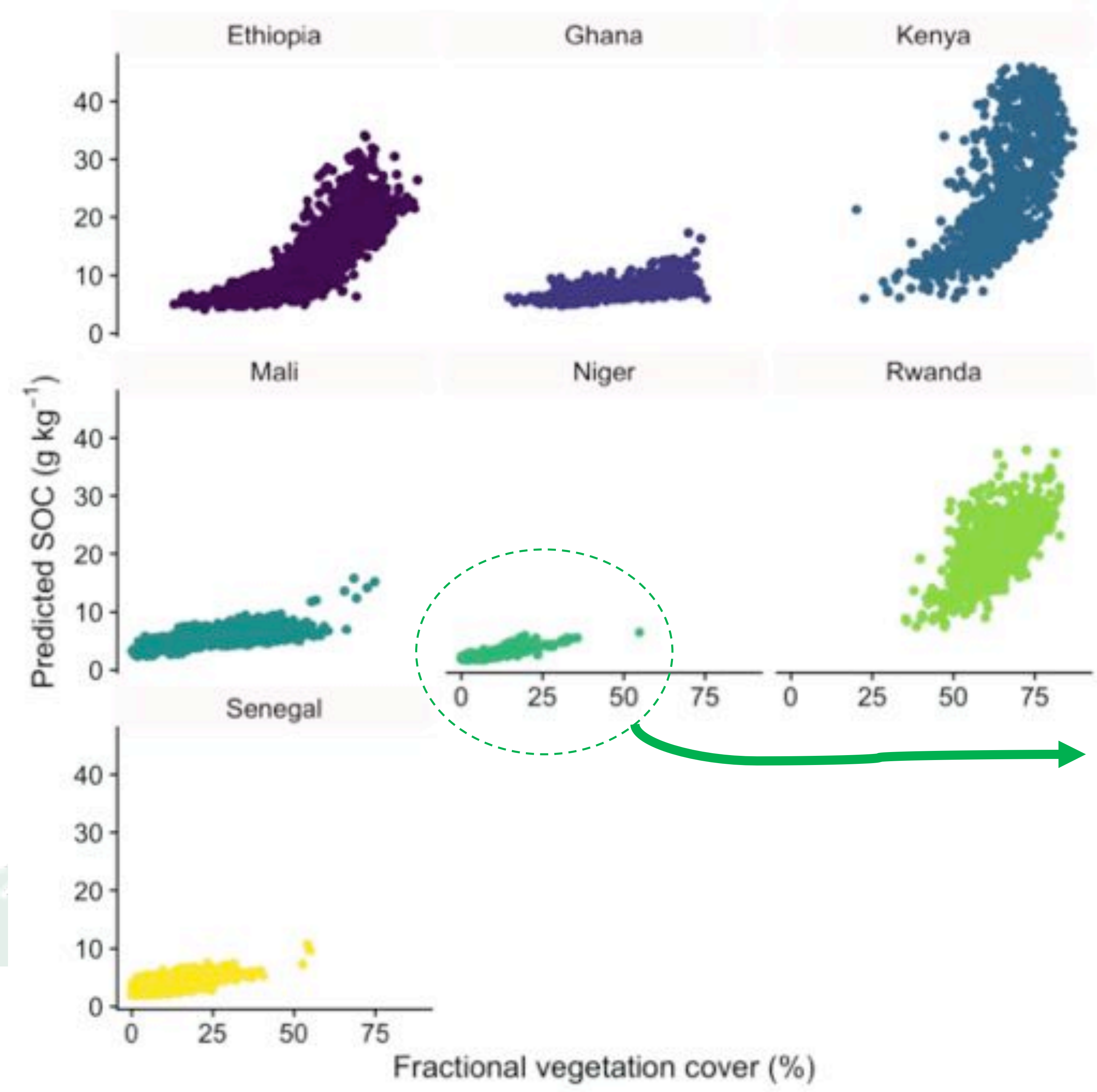
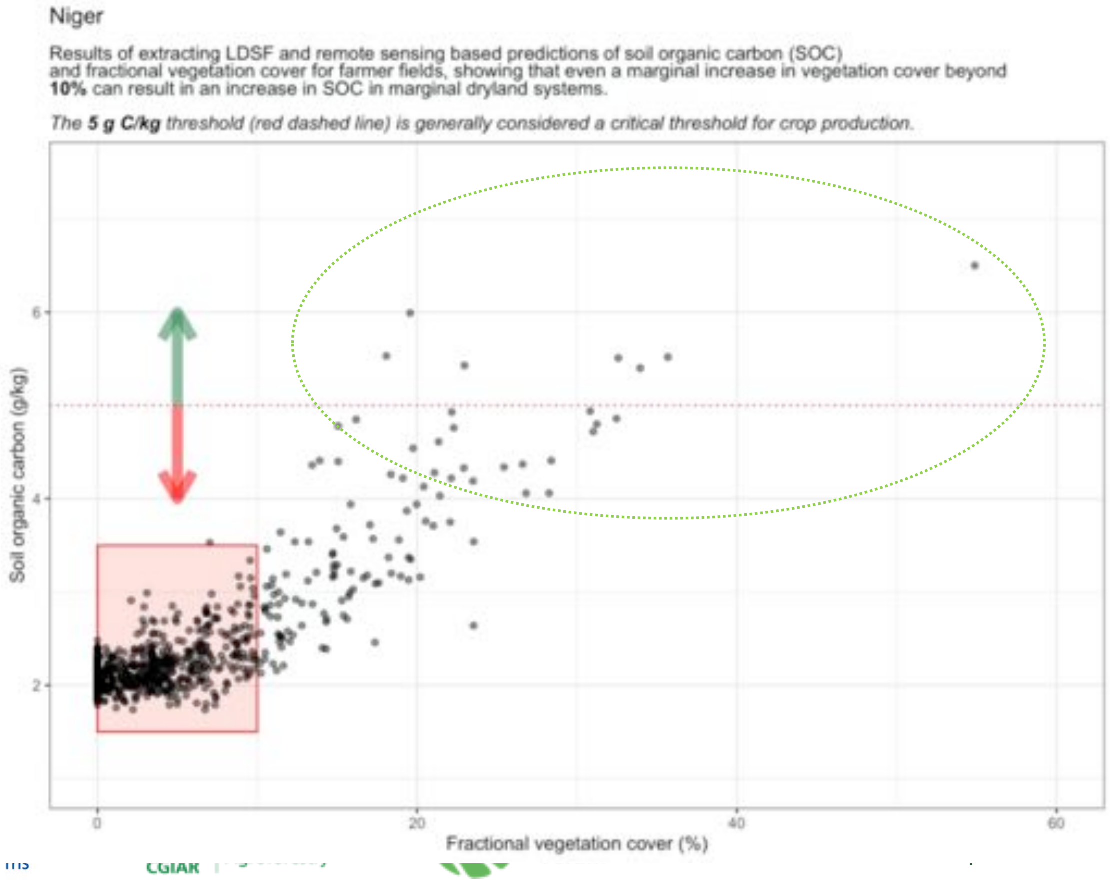
Linking SOC and Vegetation Cover: **Data from farmer intervention sites**



1) The relationship is not linear
2) Trajectories are context-specific
3) There is potential to increase soil organic carbon and improve soil health, even in marginal drylands



Key messages

1. There is a real opportunity to integrate systematic assessments of ecosystem health with citizen science to track the interventions on the ground and also the understand the processes (of degradation and restoration)
2. In order to contribute to the restoration and climate change agenda, we need to assess multiple indicators at relevant spatial scales
3. We have the tools and methods to measure and track not only regreening, but also the underlying processes of land degradation and the impacts of project interventions on soil health.
4. This means that we can measure the effectiveness of interventions on SOC sequestration and climate change mitigation, for example.
5. ICRAF has built a large spectral library using consistent field collection and wet chemistry methods to develop robust calibration models.
6. Soil Infrared Spectroscopy is an accurate and low-cost method that is more consistent than wet chemistry.
7. By building global databases, e.g., consistent reference analysis and robust field methodologies, we can conduct accurate landscape-scale assessments of soil and land health (including baselines and tracking changes overtime).
8. Developing capacity in target countries to conduct assessments (and see the value) and to interpret the results/data.
9. Through structured stakeholder engagement using the SHARED process, the data and evidence are fed back into the decision making cycle through co-learning and decision dashboards.

Thank You!

Leigh Ann Winowiecki L.A.Winowiecki@cgiar.org @lawinowiecki

LDSF Materials:

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

https://worldagroforestry.org/output/land-degradation-surveillance-framework

Regreening App:

https://play.google.com/store/apps/details?id=com.icraf.gsl.regreeningafrica&hl=en

https://regreeningafrica.org/wp-content/uploads/2020/01/Regreening_Africa_App_User_Guide_English-1.pdf

Check out our AlJaZeera Video on soil health: http://youtu.be/vFMSEHV7Ap4

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foreststreesagroforestry.org | globallandscapesforum.org | resilientlandscapes.org

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