Cost Effective Tools for Soil Organic Carbon Monitoring

Ermias Betemariam & Erick Towett

CTCN exposure training meeting,
Nairobi

13 Dec 2018

World Agroforestry Centre
Soil-Plant Spectral Diagnostics Lab

Context

- Soils the largest carbon reservoir of the terrestrial carbon - small change could cause large effects on climate system
- Soil comes to the global agenda: Sustainable intensification; Global Environmental Benefits (UNFCCC, UNCCD, UNCBD)
- SOC as useful indicator of soil health. Taxonomic soil classification systems provide little information on soil functionality in particular the productivity function (Mueller et al 2010)
- But lack of coherent and rigorous sampling and assessment frameworks

Context (2)

- High spatial variability in soil properties - large data sets required
  - High spatial variability of SOC can rise sevenfold when scaling up from point sample to landscape scales, resulting in high uncertainties (Hobley and Willgoose, 2010)
- Soil monitoring is expensive to maintain
- Increasing demand for soil data at fine spatial resolution

Soil spectroscopy key for Land Health Surveillance

Define the purpose before measuring!

Soil carbon decisions – need for specificity

- Do we need to ameliorate soil organic carbon?
  - Do we know what is a good or bad level?
  - What is the value of accurately monitoring soil carbon levels if we don't know how to interpret?
  - Is critical limit the high-information-value variable?

- How much soil carbon credit to pay out?
  - Soil carbon has increased by x t/ha with 90% certainty

- Which variable has largest uncertainty and highest risk of being wrong: Bulk density? Sampling error due to spatial variation? Lab measurement?

Measuring Soil Carbon Stocks

Terrestrial Carbon pools

Biomass

- Aboveground woody biomass
- Non-tree vegetation
- Belowground biomass
- Dead wood
- Litter

Soil carbon

- Organic
- Inorganic

Terrestrial Carbon pools

What is CO_2 Sequestration?

Capturing CO_2 from the atmosphere and storing it

Soil nutrient balance

Inputs

- Litter, roots, branches

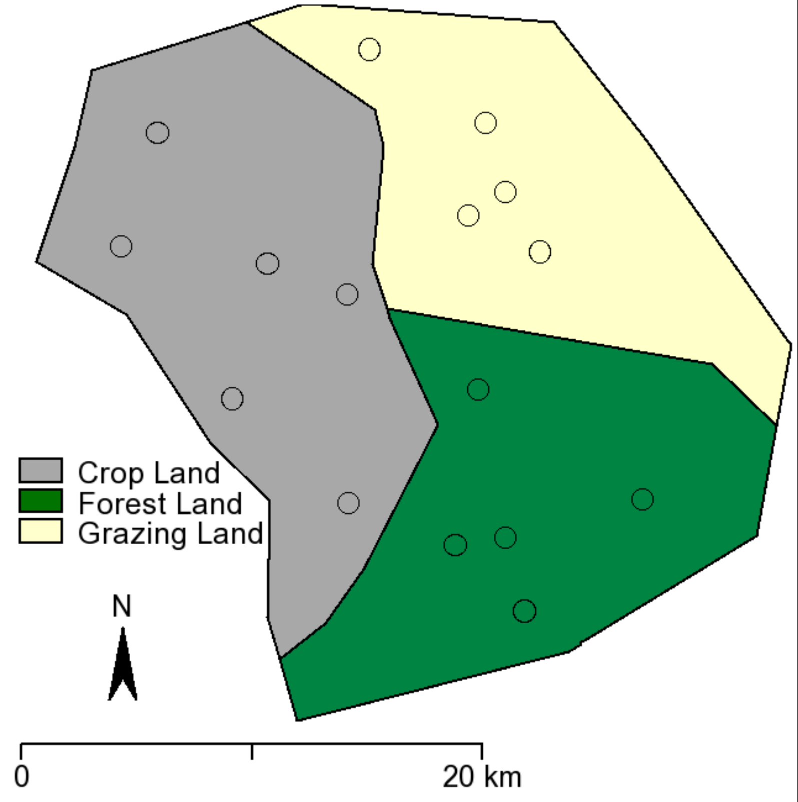
Outputs

- Autotrophic respiration: roots
- Heterotrophic respiration: CO_2 respiration of soil organisms that use dead plant matter as a food source

Sampling [1]

Main steps in quantifying soil carbon stocks

- Define boundary of project area (e.g. using existing maps of a project site, delineate using a GPS)
- Stratify the area based on carbon pools
  - Land use and management history and duration: crop land, forest land, grazing land
  - Existing soil classifications and mapping
  - Soil texture and parent material
  - Management: free grazing vs zero grazing
  - Geomorphic position and related soil processes
  - Ecology, plant community, and related soil processes
  - Other factors that influence the stratification for specific project areas.



Sampling [2]

Main steps in quantifying soil carbon stocks

- Determine sampling intensity- reconcile cost and error
  - Base on desired precision (IPCC: ±10% of mean at 95% CI)
  - Available resource (Financial, human, physical)

Sample size determination

$$n = \frac{(N \times S)^2}{\frac{N^2 \times E^2}{t^2} + (N \times S^2)}$$

- Decide how to allocate samples to different strata

Sample allocation

$$n_h = \frac{N_h \times S_h}{\sum_{h=n}^{L} N_h S_h} \times n$$

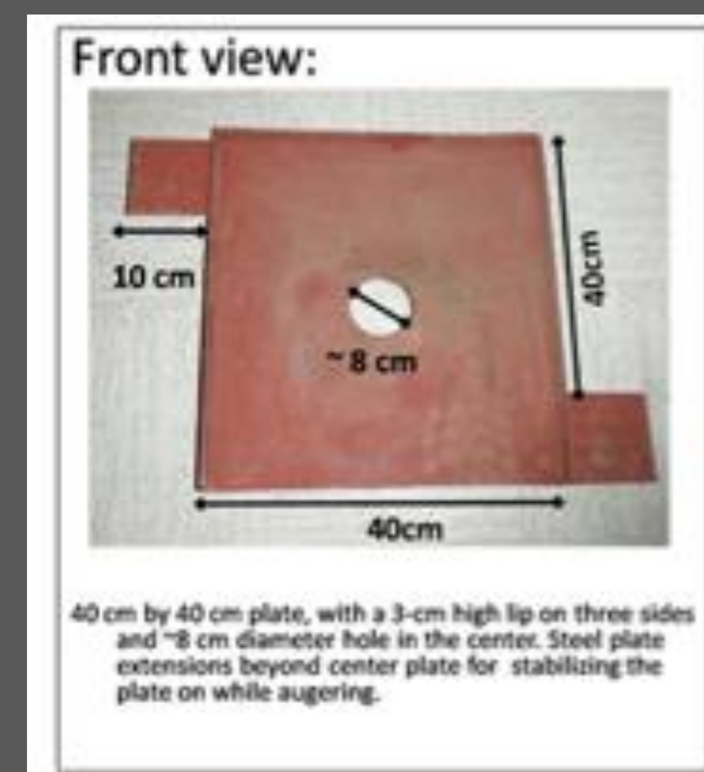
Field work [1]

Preparation for field work

- Proper preparation before going to the field
- Collate existing information (e.g. soil map)
- Train staff and pilot all procedures
- Prepare logistics in terms of transport, etc.

Collecting field samples

- Locate the predetermined sample location
- Take composite soil samples (e.g. using auger)
- Take sample for bulk density/mass - to calculate SOC stocks
- Collect any associated data required (e.g. land management)



Field work [2]

Properly locate your plots/sites



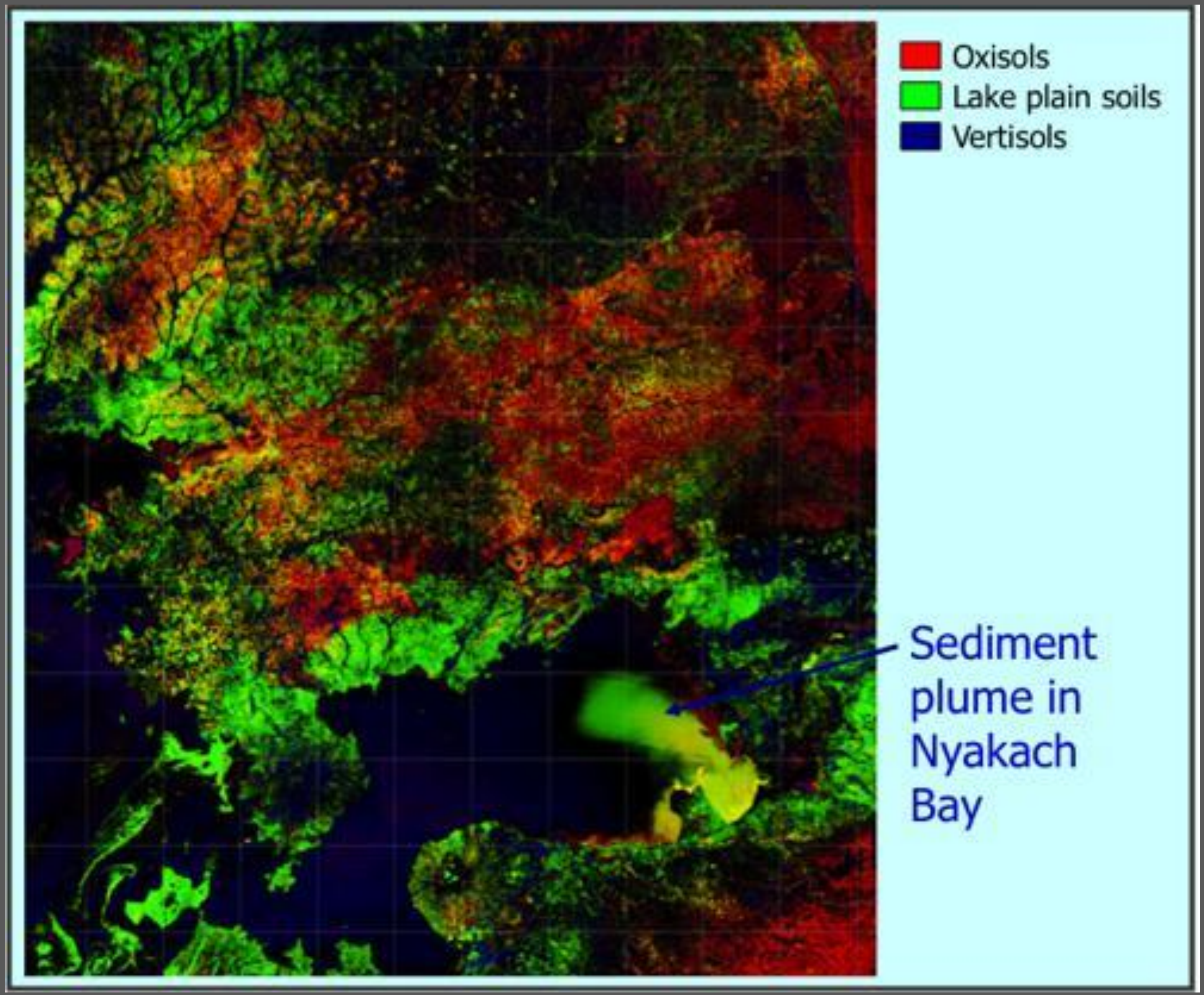
Proper labeling

Avoid contamination

Emerging technologies

Applications in Africa

Spectroscopy History



Shepherd KD and Walsh MG. (2002) Development of reflectance spectral libraries for characterization of soil properties. Soil Science Society of America Journal 66:988-998.

Instrument developments

Dispersive VNIR

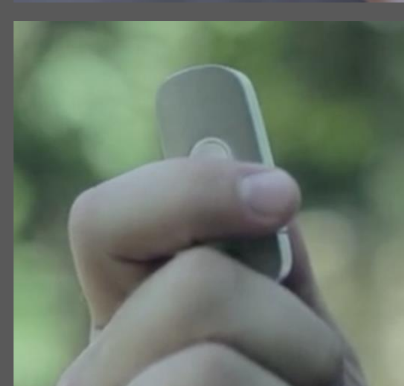
FT-NIR

FT-MIR Robotic

FT-MIR Portable

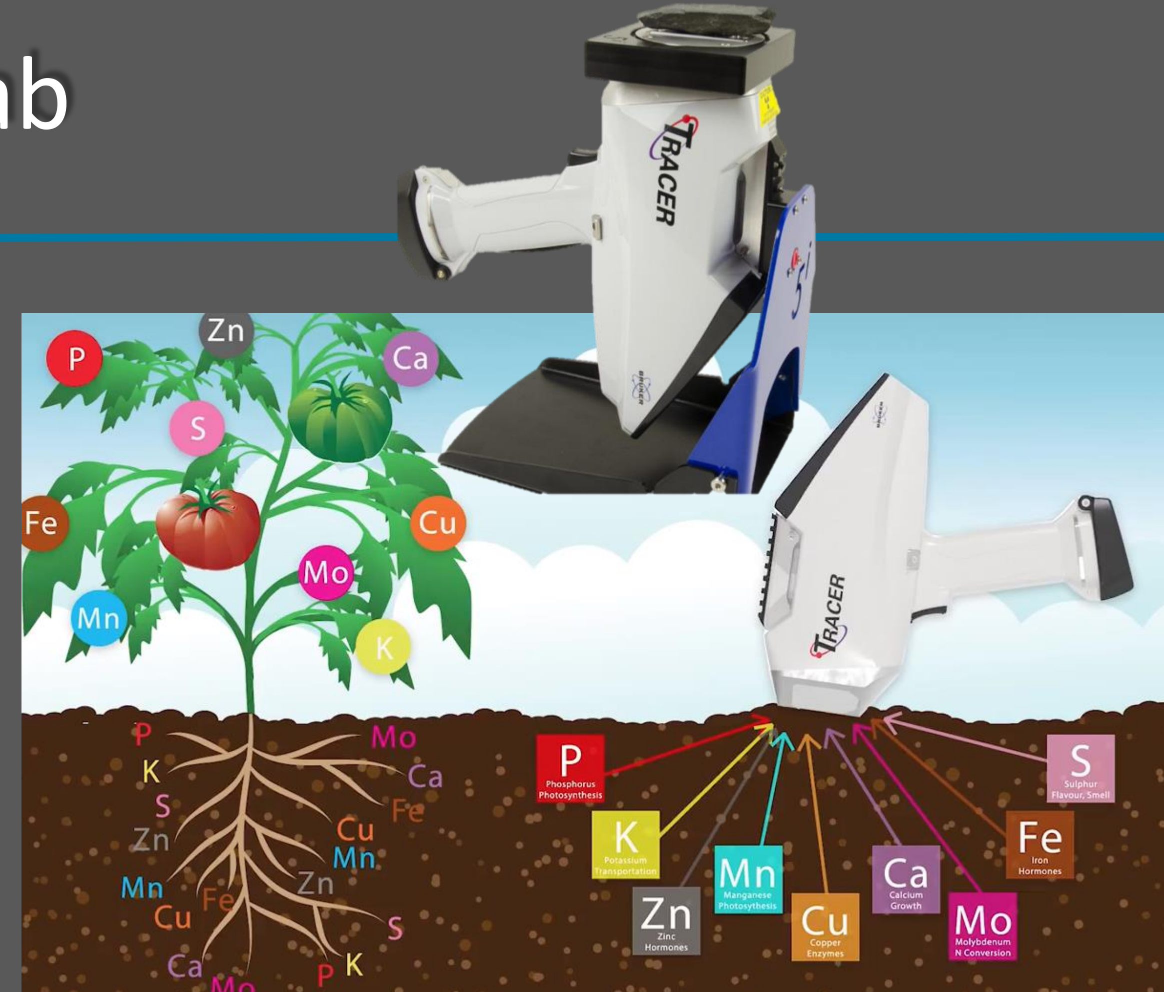
Handheld MIR

Mobile phone devices



Handheld Open Beam XRF

The Rural Soil-Plant Spectral Lab



Mid-infrared spectrometer (MIR)

- Soils properties
- Plant macro & micro nutrients
- Compost quality
- Fertilizer certification

Handheld x-ray fluorescence analyser (pXRF)

- Digital mapping of soil properties
- Plant nutrition monitoring; large n trials
- Soil carbon inventory
- Agro-input and output quality screening
- Mining reclamation

What soil MIR and XRF predicts

MIR

Consistently good:
Plant N
Soil total and organic C
Total N
pH
Texture
Extractable Al, Ca, Mg
ECEC
P sorption
Total P
Water holding capacity
Engineering properties

Consistently poor:
Extractable S, Na, P, K, micronutrients

pXRF

Consistently good:

All essential macro and micro nutrients in plants

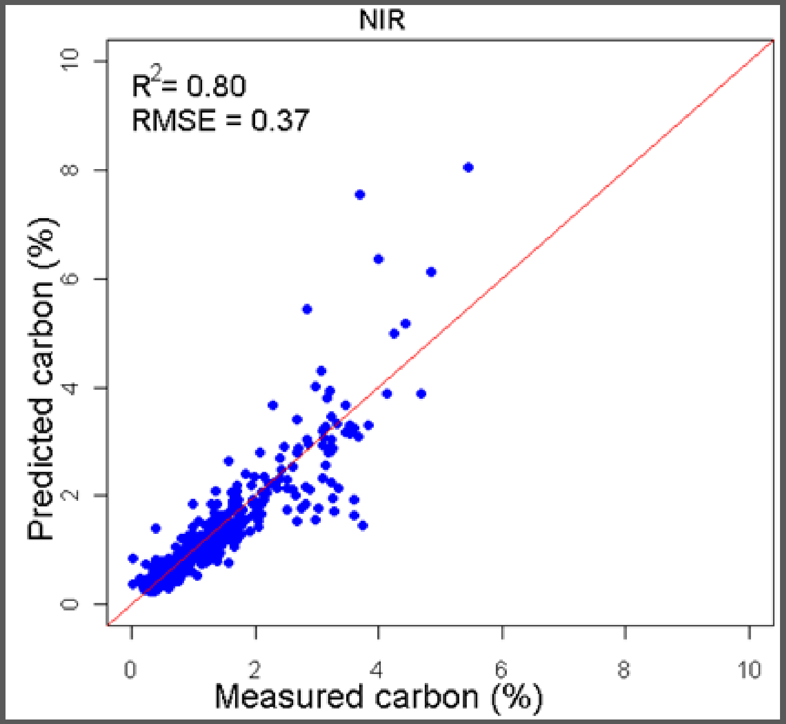
Total element analysis of soils

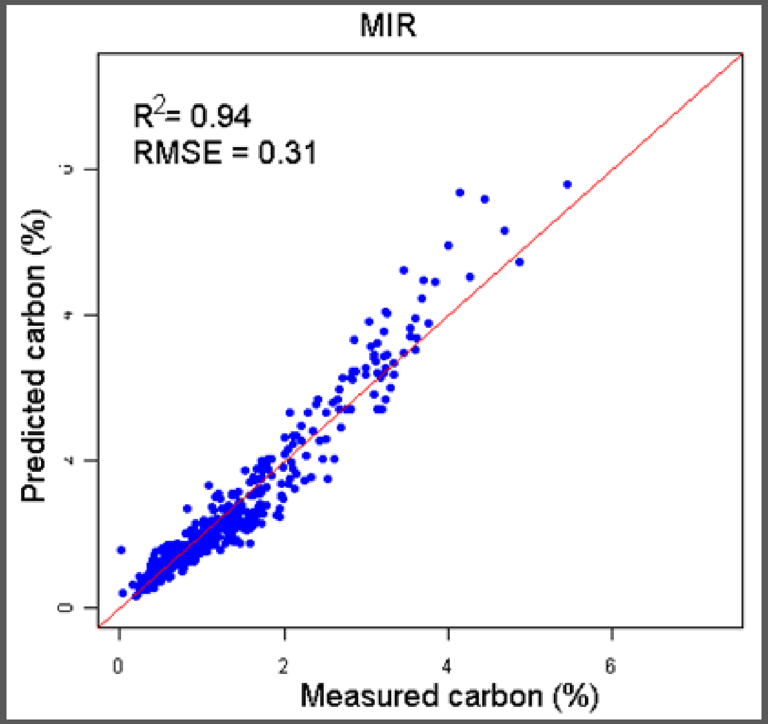
Heavy metals in soils and plants

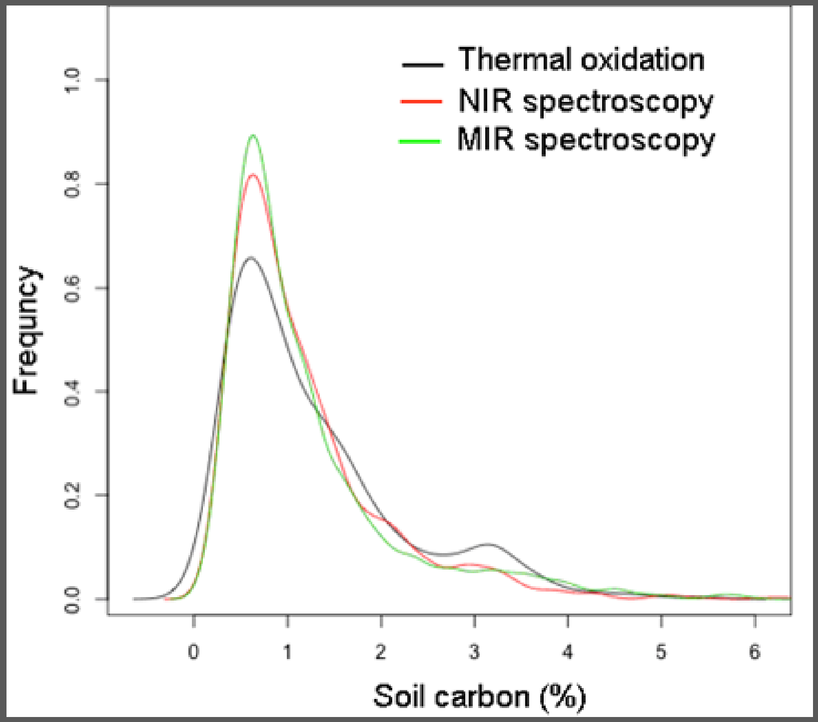
MIR – locally adjusted calibrations needed
pXRF – one time universal calibration

Predicting SOC stocks using soil infrared spectroscopy

A case study from Western Kenya







ICRAF Spectral Lab Network

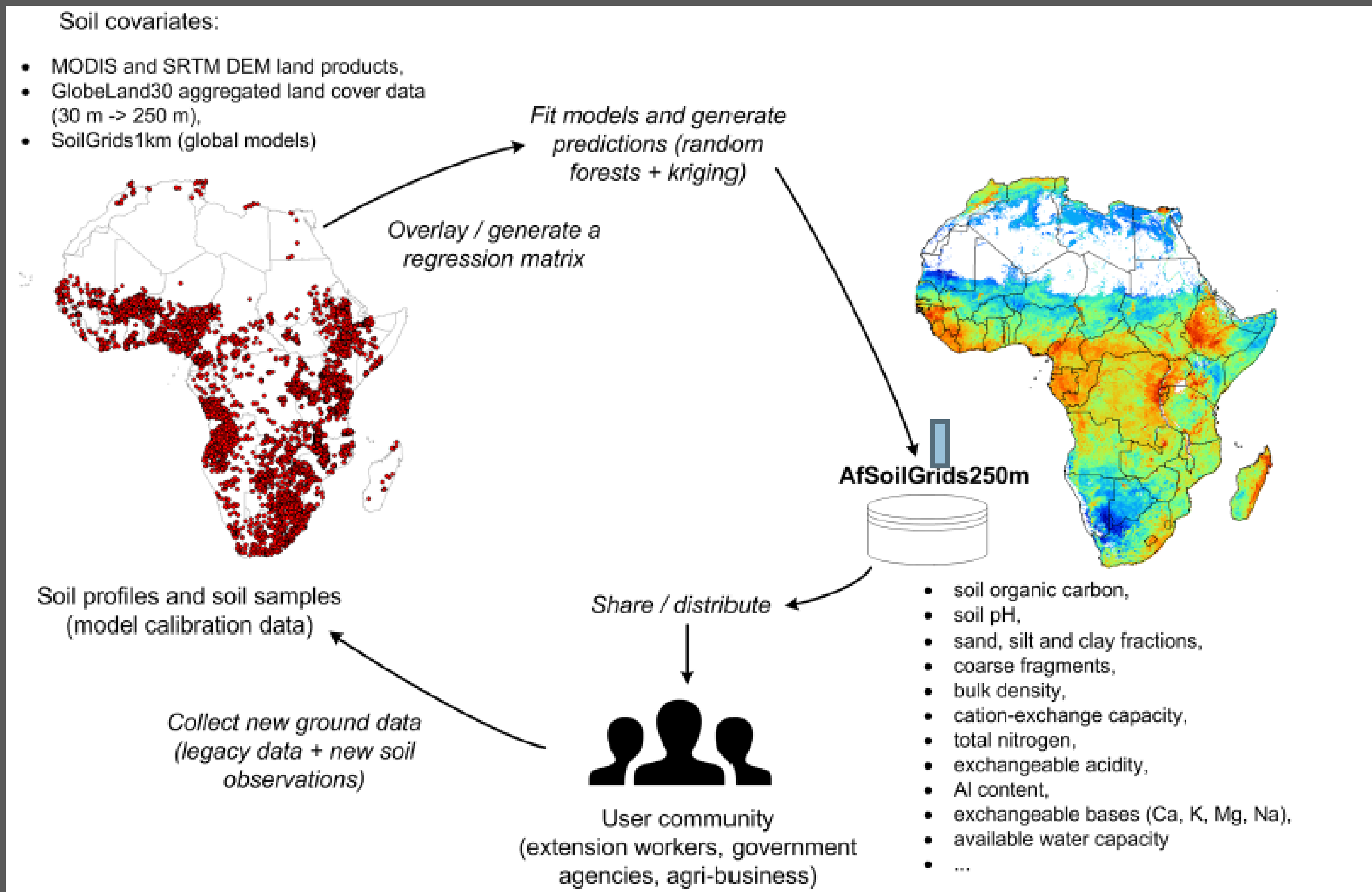
NARS: Ethiopia (7), Nigeria (3), Tanzania (>6), Ghana, Benin, Cameroon, Cote D’Ivoire (2), Kenya, Malawi, Mali, Mozambique, South Africa, Peru, India

Private sector: CNLS, Mauritius Sugar, China phosphate mine, Soil Cares, OCP, Amplus Foods

CGIAR: Africa Rice, CIMMYT, IITA

International: NRCS, CSIRO, Rothamsted (reference lab for dry spectroscopy calibration), Global Soil Partnership

Applications



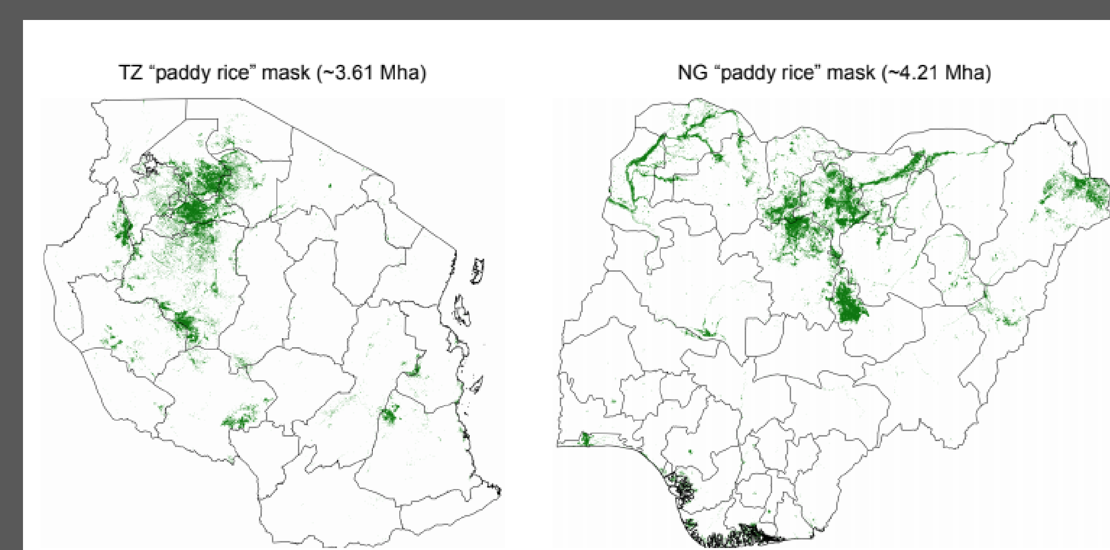
Spatial prediction scheme used to produce AfSoilGrids250m data.

EthioSIS

TanSIS

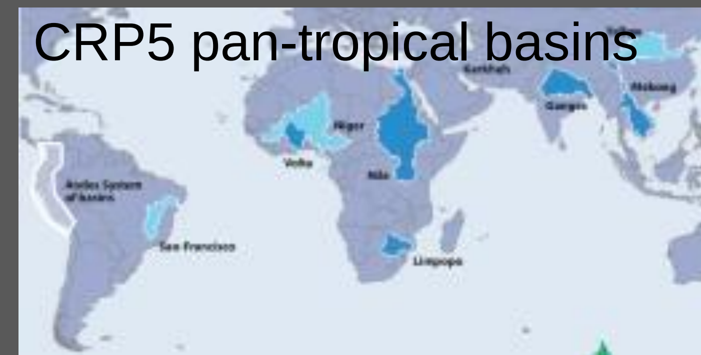
NiSIS

GhaSIS



Land Health out-scaling projects

Global-Continental Monitoring Systems

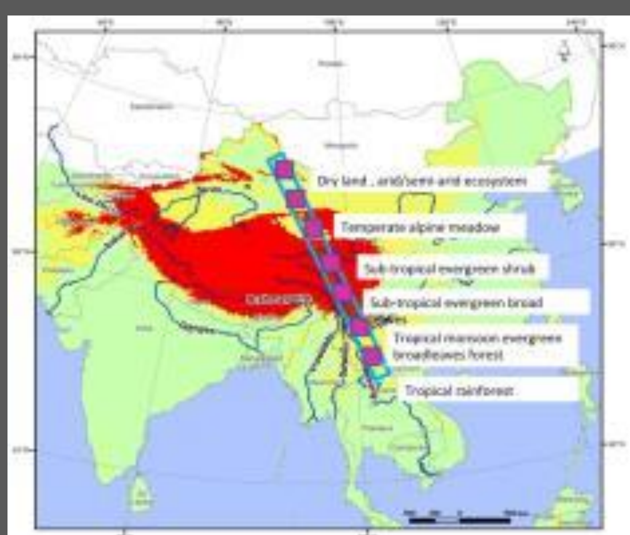


Vital signs

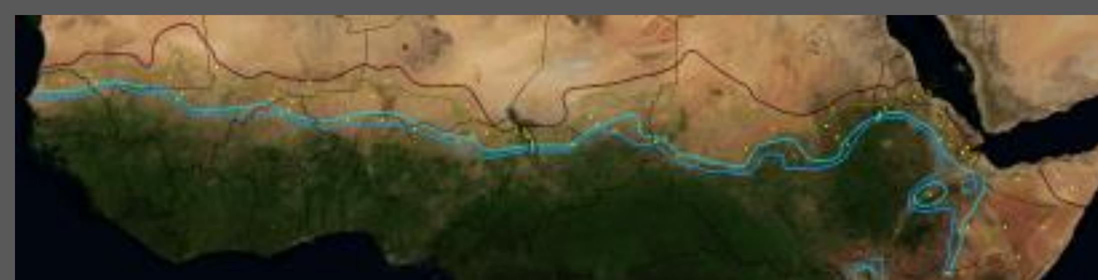
AfSIS

Regional Information Systems

Tibetan Plateau/ Mekong



Evergreen Ag / Horn of Africa



National surveillance systems

Ethiopia

Project baselines

SLM Cameroon

Parklands Malawi

Rangelands E/W Africa

Cocoa - CDI

MICCA EAfrica

Carbon sequestration in pastoral & agro-pastoral systems

Effects of range management on soil organic carbon stocks in savanna ecosystems of Burkina Faso & Ethiopia

Fire (controlled burning - 19 years) – Burkina Faso

Fire influence:

- Carbon allocation - SOC gain
- Decrease input - SOC loss

Grazing (Exclosures 12-36 years) – Ethiopia

ELSEVIER

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Long-term livestock exclosure did not affect soil carbon in southern Ethiopian rangelands

CrossMark

Ermias Aynekulu[a,*], Wolde Mekuria[b], Diress Tsegaye[c,d], Kenea Feyissa[e], Ayana Angassa[e,f], Jan de Leeuw[a], Keith Shepherd[a]

Uncertainties in SOC stock monitoring

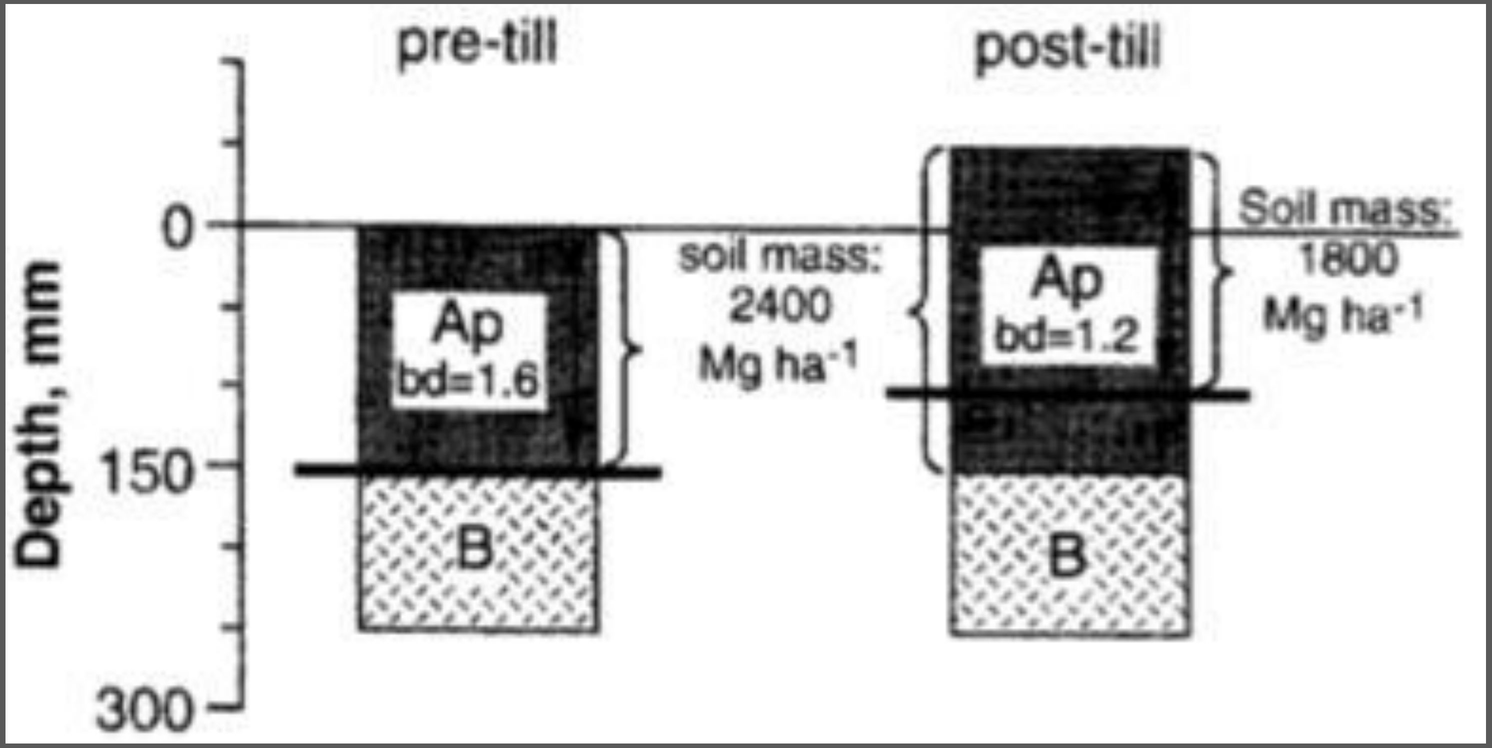
Measurement uncertainties

- Measuring soil carbon stock changes for carbon trading purposes requires high levels of measurement precision
- But there is still large uncertainty on whether the costs of measurement exceed the benefits
  - Sample size
  - Bulk density and measuring based on equal-depth

High spatial variability of SOC can rise sevenfold when scaling up from point sample to landscape scales (Hobley and Willgoose, 2010)

- High uncertainties in calculations of SOC stocks.
- This hinders the ability to accurately measure changes in stocks at scales relevant to emissions trading schemes

Monitoring SOC stock change



Think mass not depth

Bulk density as confounding variable in comparing SOC stocks

- Tillage increases the thickness per unit area
- A management that leads to a DECREASE in bulk density will UNDER ESTIMATES SOC stocks & vice versa (*Ellert and Bettany, 1995)*

C conc.(%)	Depth (cm)	Bulk density (g/cm)	SOC stock (Mg/ha)	Error
1.5	150	1.2	270	
1.5	150	1	225	-16.67%

Monitoring SOC change

Cumulative soil mass sampling

- Comparing SOC stocks between treatments or monitoring over time on <u>equivalent soil mass</u> basis
- No need to dig pits for deep bulk density

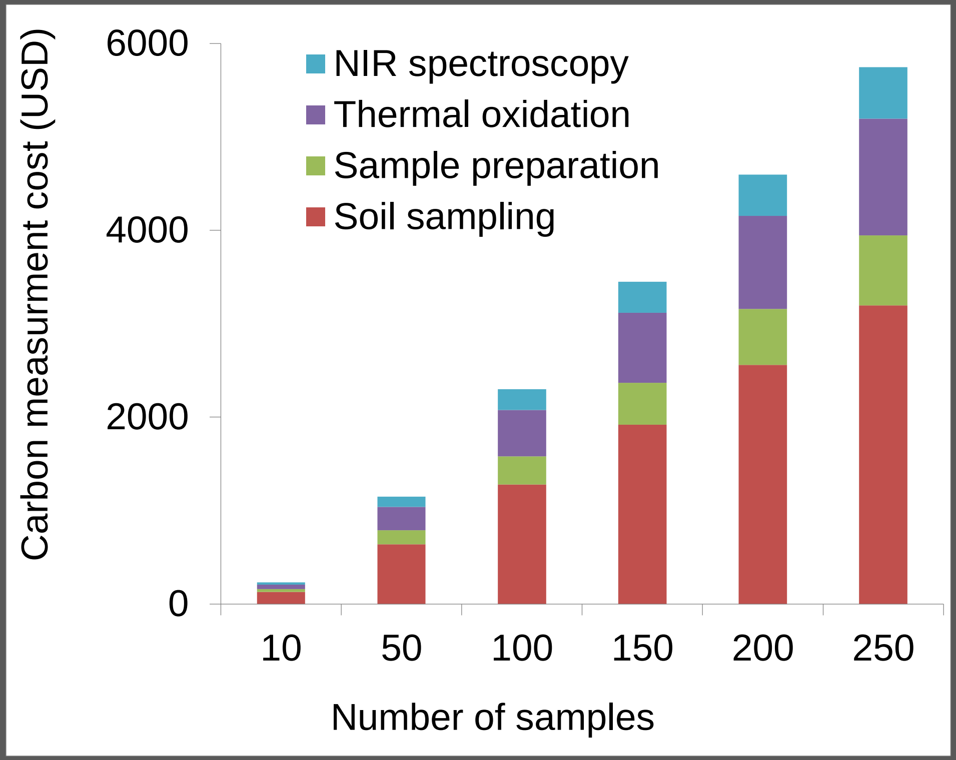
Determining auger-hole volume using sand filling method

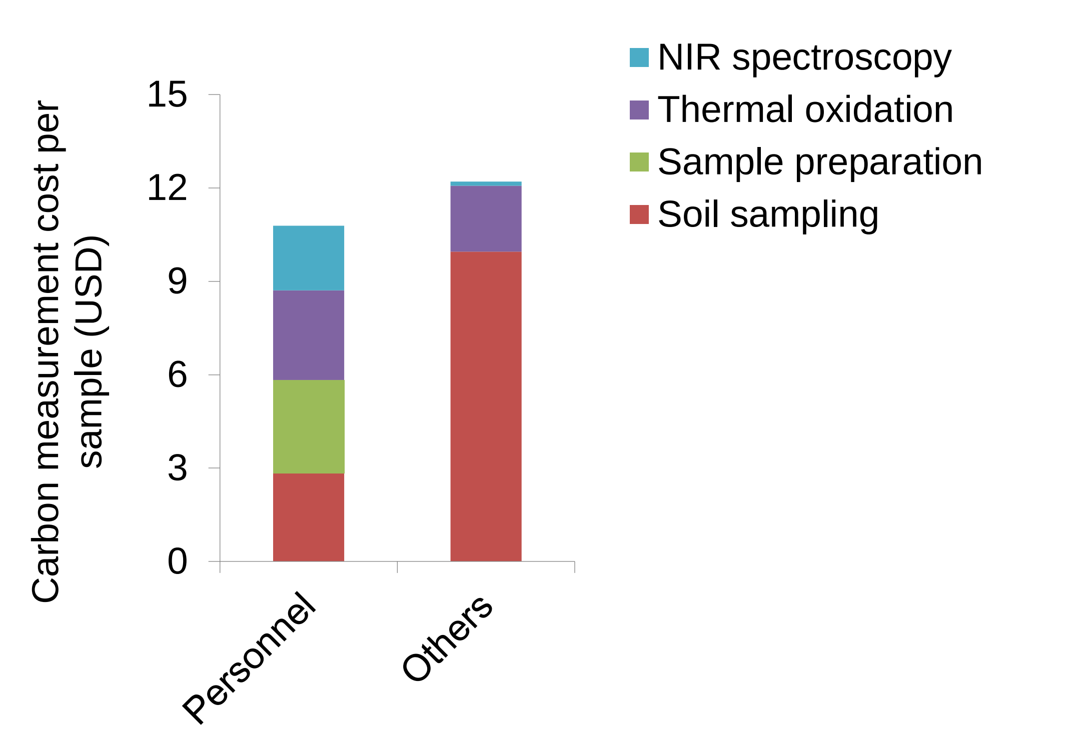
Cumulative soil mass sampling plate: to recover soil samples for measuring soil mass

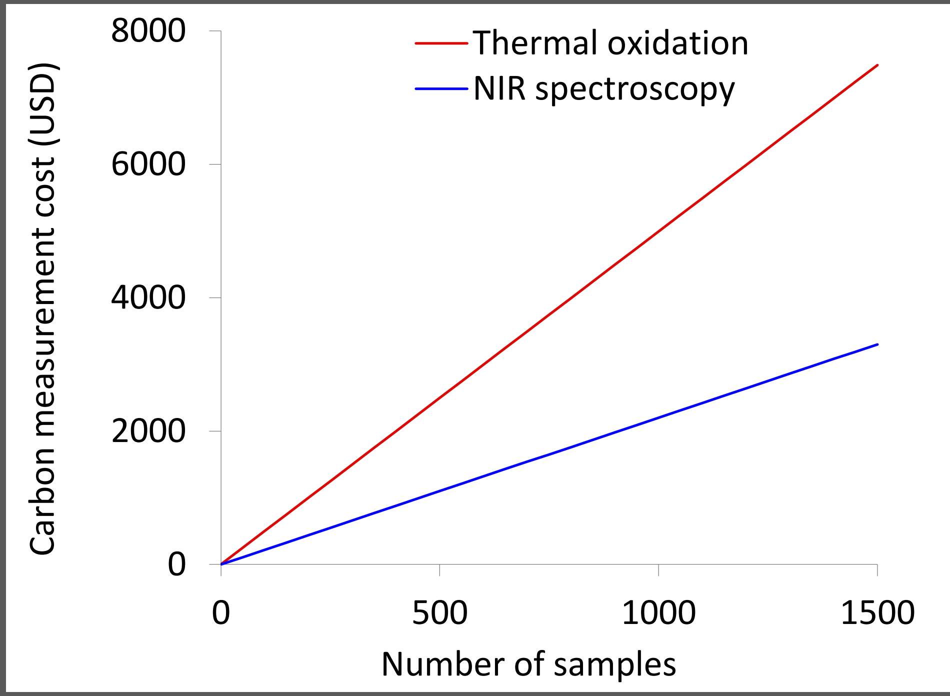
What is the minimum detectable change?
What time interval for monitoring?

Cost –error analysis

Comparisons of costs of measuring SOC using a commercial lab and NIR







Cost

IR is cheaper (<~ 56%) than combustion method for large number of samples

Throughput

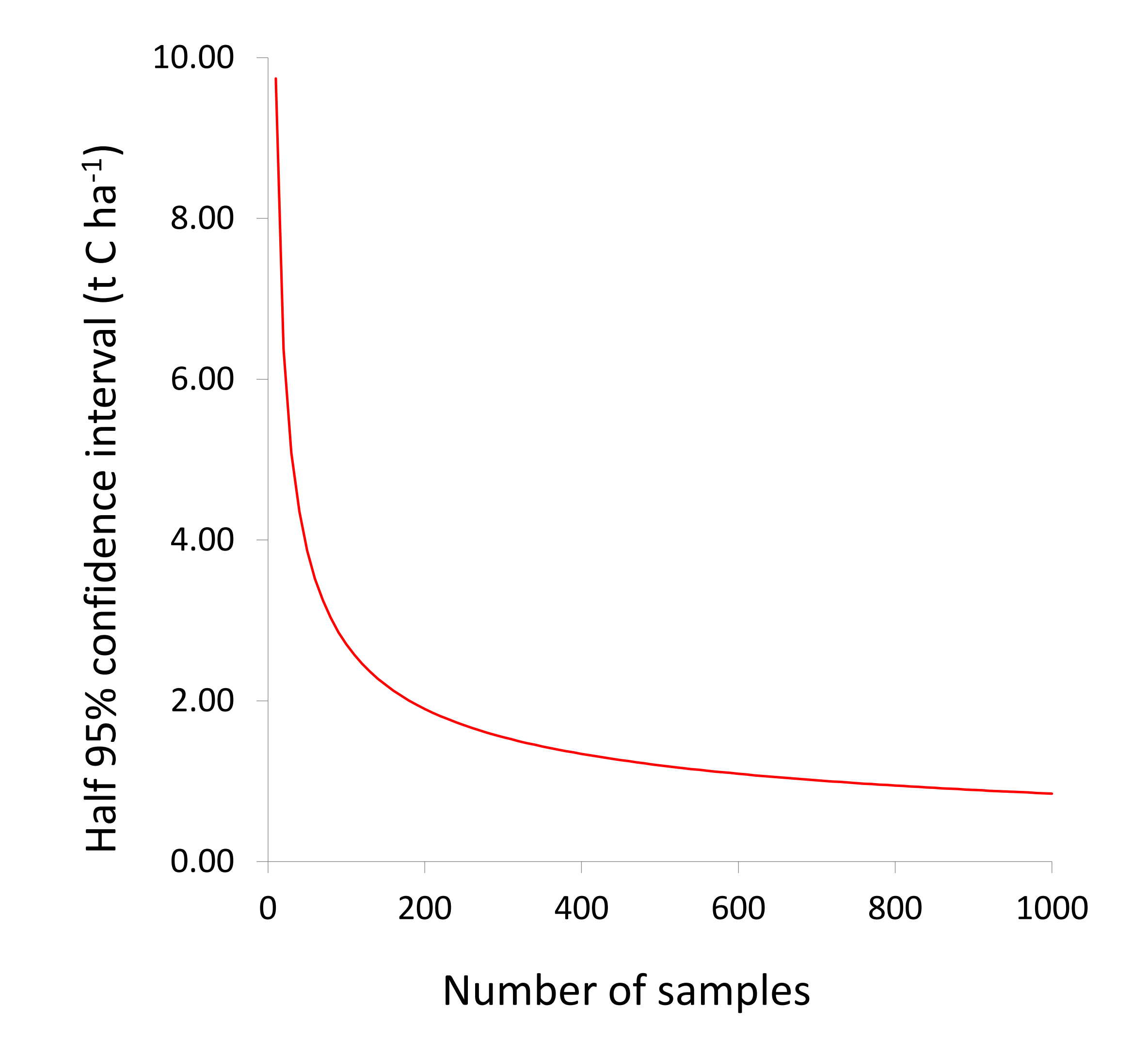
Combustion ~ 30-60 samples/day

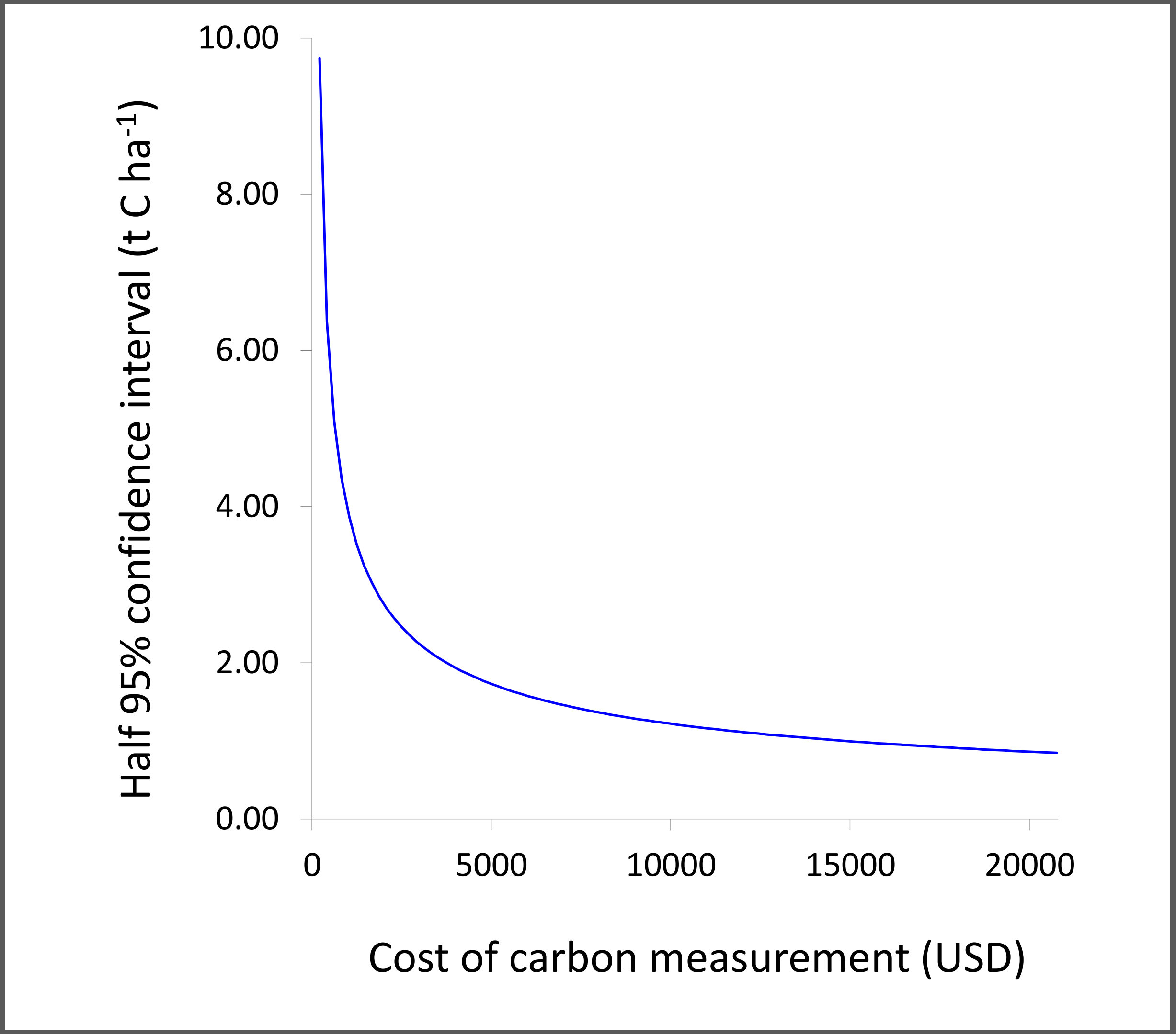
NIR ~ 350 samples/day

MIR ~ 1000/day

Cost –error analysis

Costs of measurement often exceed the benefits – soil spectroscopy address this challenge



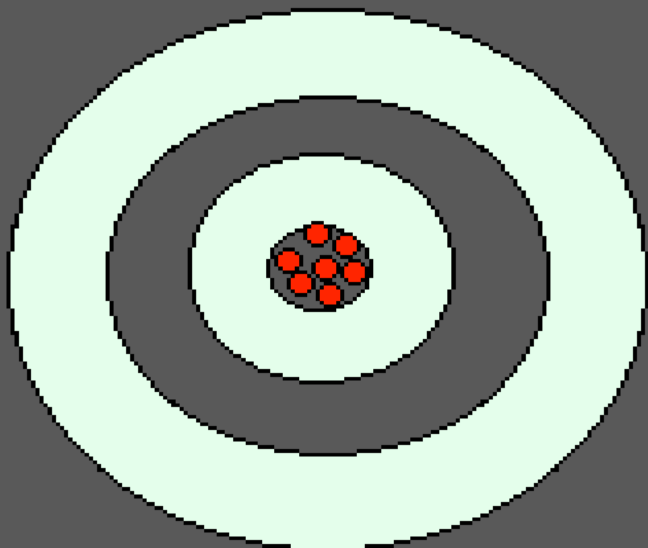


Sources of uncertainty

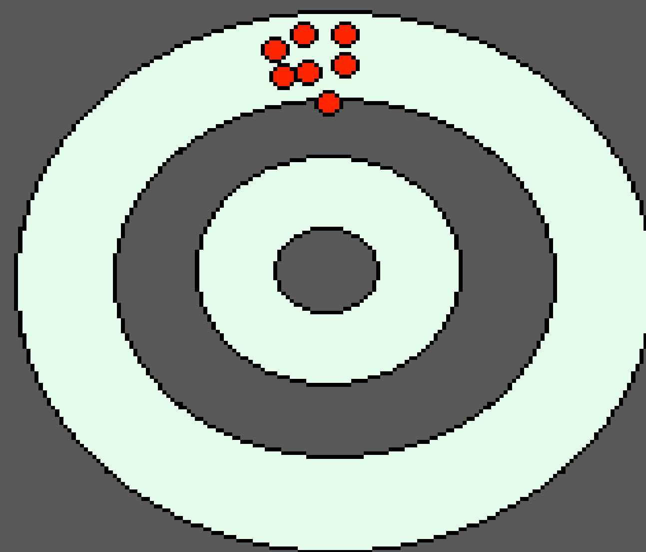
Activity	Sources of uncertainty
Sampling	Sampling design (random, stratified random)
	Sample size
SOC measurement	Natural variability (spatial)
	Sample preparation (e.g. contamination, subsampling)
	Lab method used (instrument resolution)
	Human error
	Field data collection (e.g. soil mass, volume)
SOC prediction using IR	Imported uncertainties (from reference data)
	Model (assumption)
	Instrument and human errors
Mapping SOC	Covariates used
	Image pre -processing (geometric and radiometric corrections)
	Scale/resolution (e.g. farm vs landscape)
	Model (assumption, strength)

Common causes of measurement uncertainty

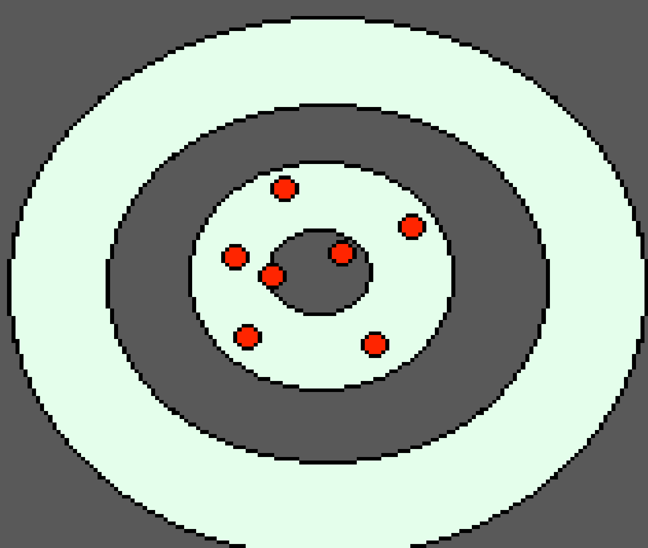
Accuracy versus precision



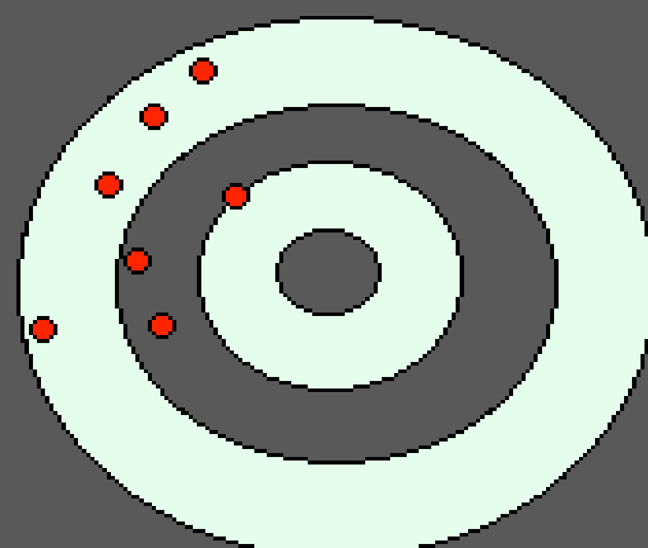
CASE 1
- High precision (repeatable)
- High accuracy
- Random error (less biased)



CASE 2
- High precision (repeatable)
- Low accuracy
- Systematic error (biased)



CASE 3
- Low precision (not repeatable)
- High accuracy
- Random error (less biased)



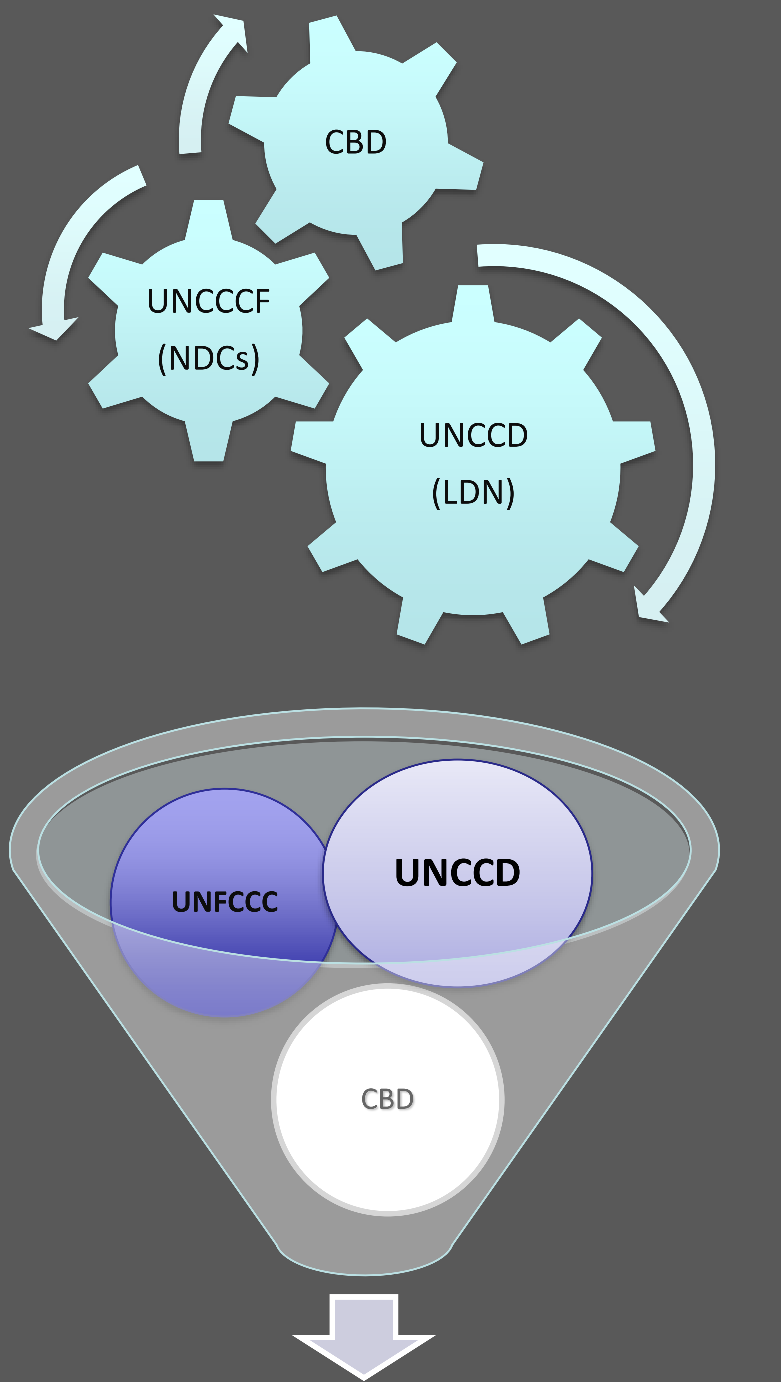
CASE 4
- Low precision (not repeatable)
- Low accuracy
- Systematic error (biased)

- the instruments used,
- the item being measured,
- the environment,
- the operator,
- other sources

Finally...

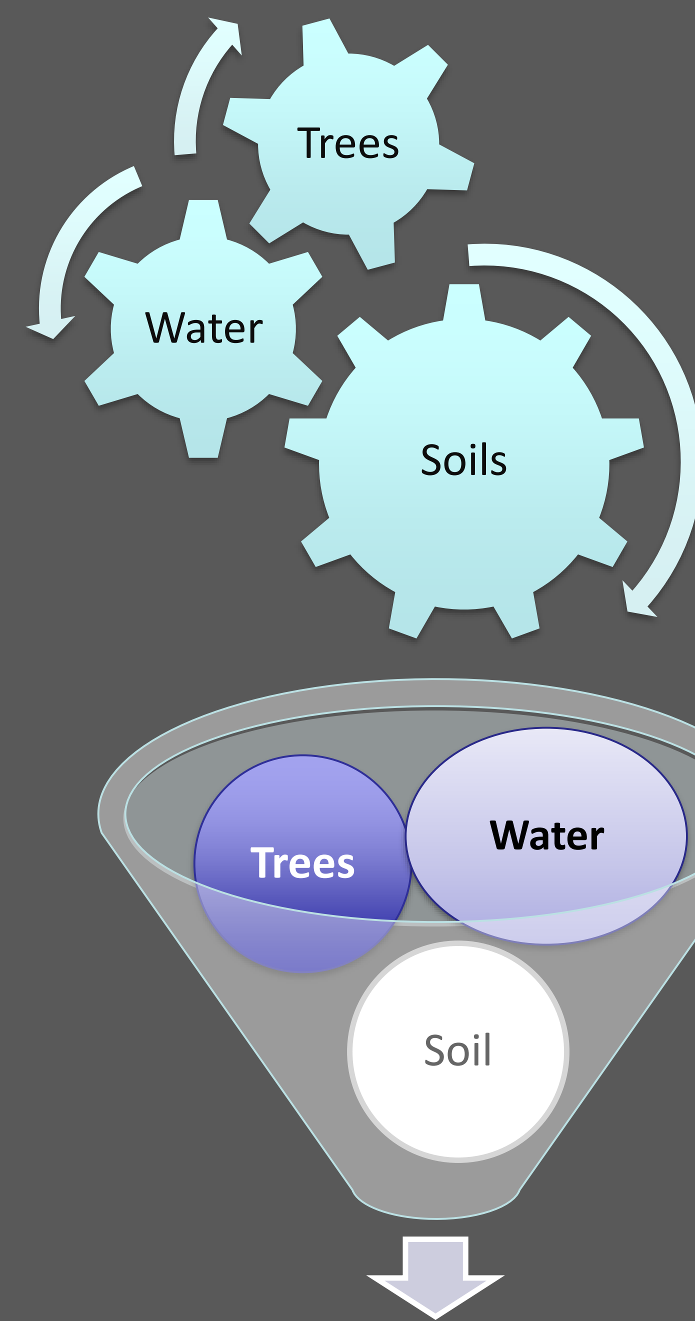
- More research on cost-effective measurement tools
  - Web services are needed that allow optimised soil information to be automatically exchanged via the internet
  - Proximal soil sensing
- Reduce uncertainties in measurements- error propagates
- Develop national capacities, networking and partnership
- Baselines are established for important soil properties across Africa
- Soil spectroscopy filling the data gaps- at National, Regional & Global levels
- Enable decision makers have clear understanding of soil status and trends
- Spectroscopy is proved good- adoption and application
  - Cross sentinel/regional sites analysis

A working synergy



Healthy multi-functional landscapes

Restore for multiple benefits



Healthy multi-functional landscapes

RESULTS (3)

Online- soil carbon measurement protocol

World Agroforestry Centre

Home | About us | Calculator | About CO_2 | Library | Contacts

Measurement and Monitoring Soil Carbon

- Guide
- Why measure soil carbon?
- What will the protocol deliver?
- How much will it cost?
- Sampling
- Field work
- Lab work
- Data analysis
- Present and use of the results
- Glossary

Google Search

☑ worldagroforestry.org only

A Protocol for Measurement and Monitoring Soil Carbon Stocks in Tropical Landscapes

This protocol has been developed over a number of years through various projects and is currently being refined in the context of the Africa Soils Information Service (AfSIS: www.africasoils.net), funded by the Bill & Melinda Gates Foundation and the Alliance for a Green Revolution in Africa (AGRA), and the Carbon Benefits Project: Modeling, Measurement and Monitoring, funded by the Global Environment Facility (GEF) of the United Nations Environment Program (UNEP).

This document was developed through a grant to the World Wildlife Fund from the Global Environment Facility and implemented by the United Nations Environment Program

Document Version 1.1

July 2014

Contributors: Ermias Aynekulu, Keith D. Shepherd, Richard Coe, Markus Walsh, Tor-G. Vagen, Leigh Winowiecki, Jiehua Chen and Andrew Sila.

Citation:
Africa Soil Information Service. 2014. A protocol for measurement and monitoring soil carbon stocks in tropical landscapes. Version 1.1. World Agroforestry Centre, Nairobi, Kenya

http://www.worldagroforestry.org/soc

Thank you

Contact us:

Email: e.betemariam@cgiar.org
Web: www.worldagroforestrycentre.org