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Development Economics • Data

LSMS Living Standards Measurement Study

FOODSYSTEMS 2030

50x2030 DATA-SMART AGRICULTURE

KOREA GREEN GROWTH TRUST FUND

GAFSP global agriculture & food security program

KWPF KOREA-WORLD BANK PARTNERSHIP FACILITY

50x2030
DATA-SMART AGRICULTURE

Scanning for Soil Health:

Assessing the Accuracy and Scalability of Innovations for In-Situ Soil Measurement

World Bank Better Data for Better Lives and Jobs Conference

Washington, DC | Dec 8–9, 2025

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SOIL HEALTH
Challenges in Data & Measurement

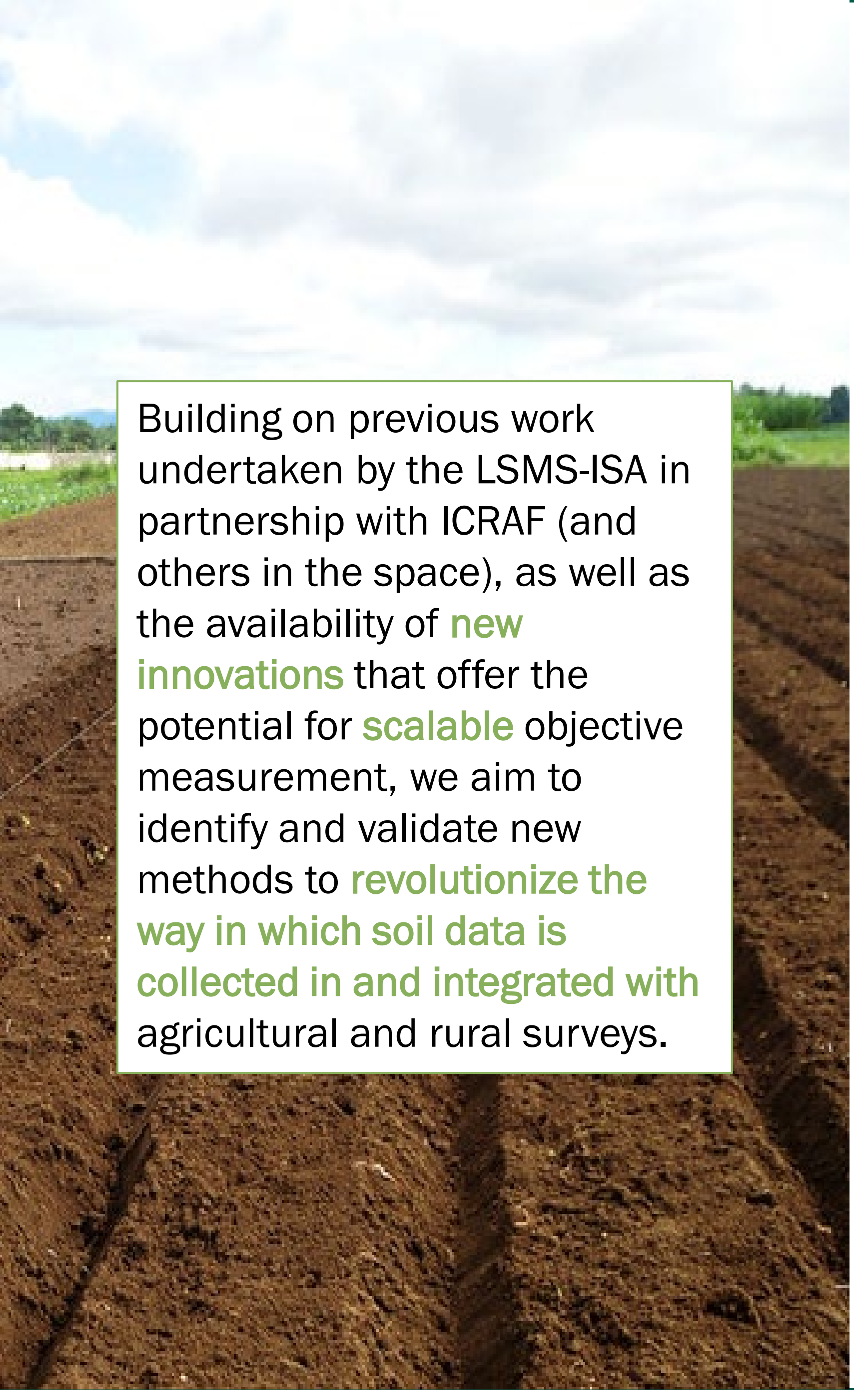
Soil health plays a critical role in rural livelihoods in sub-Saharan Africa.

→ Improved soil conditions correlate with lower malnutrition rates (Sanchez and Swaminathan 2005) and higher incomes (Bhargava, Vagen, and Gassner 2018; Heger, Zens, and Bangalore 2020), for example.

→ Heterogeneity in soil properties across plots is substantial, which can complicates policy implementation and the dissemination of agricultural technologies (Kihara et al. 2016; Hengl et al. 2021).

Despite its importance to global development outcomes, *data* on soil is largely unavailable at the **scale** or **quality** needed to inform effective policy change

→ Especially true of soil data that is integrated with household/farm level data on farming practices, outputs, and outcomes



Building on previous work undertaken by the LSMS-ISA in partnership with ICRAF (and others in the space), as well as the availability of new innovations that offer the potential for scalable objective measurement, we aim to identify and validate new methods to revolutionize the way in which soil data is collected in and integrated with agricultural and rural surveys.

SOIL HEALTH
Addressing Soil Data Gaps

Currently, household surveys often rely on (*if anything*):

- Subjective assessment of soil health, texture, etc., and/or,
- Integration of survey data with modelled, geospatial-based soil maps (contingent on georeferencing of plot locations)

→ We **evaluate new (and old) measurement tools and methods** that have the potential to be integrated into large-scale agricultural surveys.

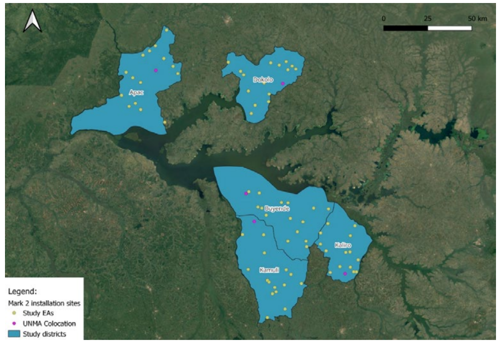
→ We assess the ***accuracy, scalability, and cost*** of each method.

Uganda Climate, Land Area, and Soil Study (CLASS)

Methodological study implemented in Uganda, in collaboration with ICRAF colleagues and other technical partners, aimed at testing & validating **innovative** methods for improved measurement of **soil health** (and climate variability and land area measurement) in small-scale agriculture.

Components:

- **Household survey** conducted in multiple visits
- Community-level weather data collection via weather sensors installed at survey locations



5 districts, 75 rural enumeration areas, 900 maize-growing households, with methods components implemented at following level:

- EA level + co-location sites (1 per district) for climate component
- **Plot level for soil & land area measurement – maize plots to facilitate integration with objective crop production measurement**

Uganda CLASS
Soil Methods & Tools Tested

Subjective Soil Assessment

- Inexpensive, easily implemented (but…)
- Evidence suggests limited relationship with objective measures of soil health

MIR analysis @ ICRAF lab

- MIR spectral analysis conducted at ICRAF lab in Nairobi (wet chemistry on % of sample)
- Longer turnaround time, logistically complex

Palintest SKW500 Kits with Jabba Engineering

- Use of test kits in regional laboratories
- Relatively quick turnaround as samples delivered continuously

Low-cost pH Meter

- Very low cost (<$20/unit)
- Limited scope of data (soil pH and moisture indicator)
- Rapid results

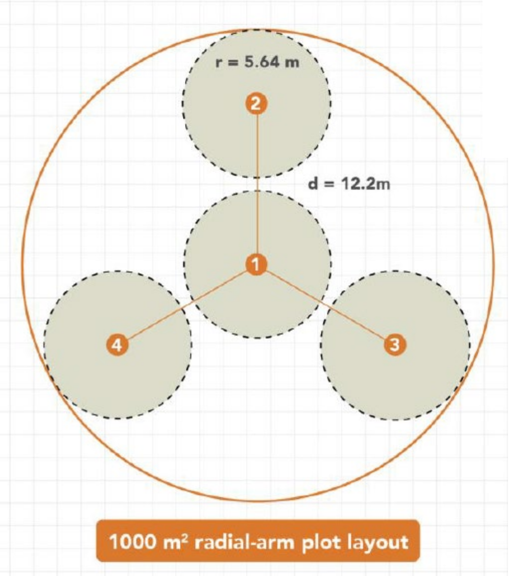
AgroCares In-Field Scanner (NIR)

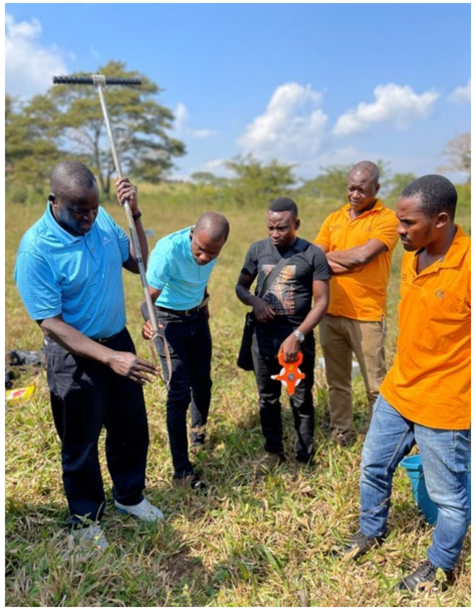
- Portable near-infrared (NIR) scanner for in-situ analysis
- Low/no soil processing
- Results available in real time (with network connection)

+ comparison with digital soil map products (SoilGrids 2.0 and iSDASoil), based on plot-level GPS coordinates

Uganda CLASS
Soil Component Design & Implementation

- **All methods** implemented on one randomly selected maize plot per household, allowing for direct comparison
- Collection of soil samples followed protocols based on ICRAF's LDSF Framework
    - Composite topsoil (0-20cm depth) analyzed with Agrocares and at Jabba and ICRAF labs
    - Composite sub-soil samples (20-50cm depth) analyzed at ICRAF labs

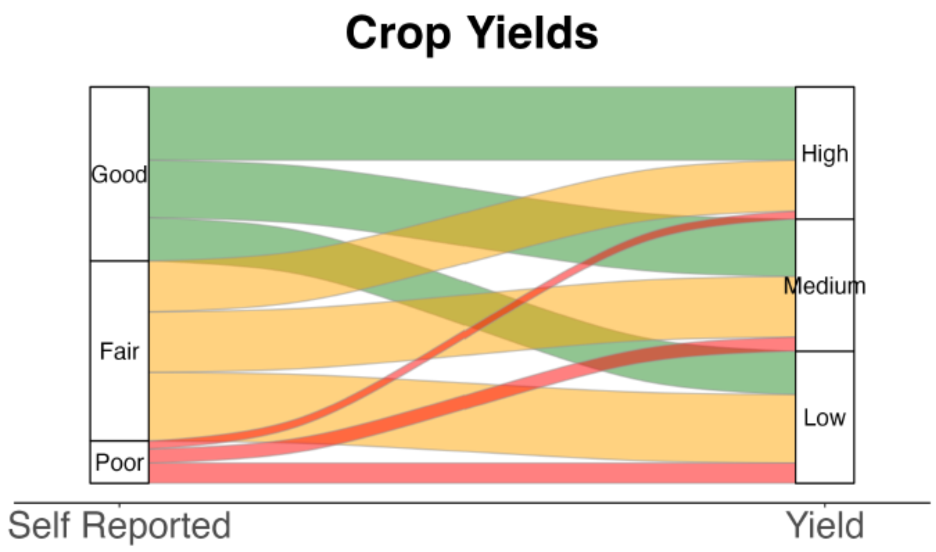


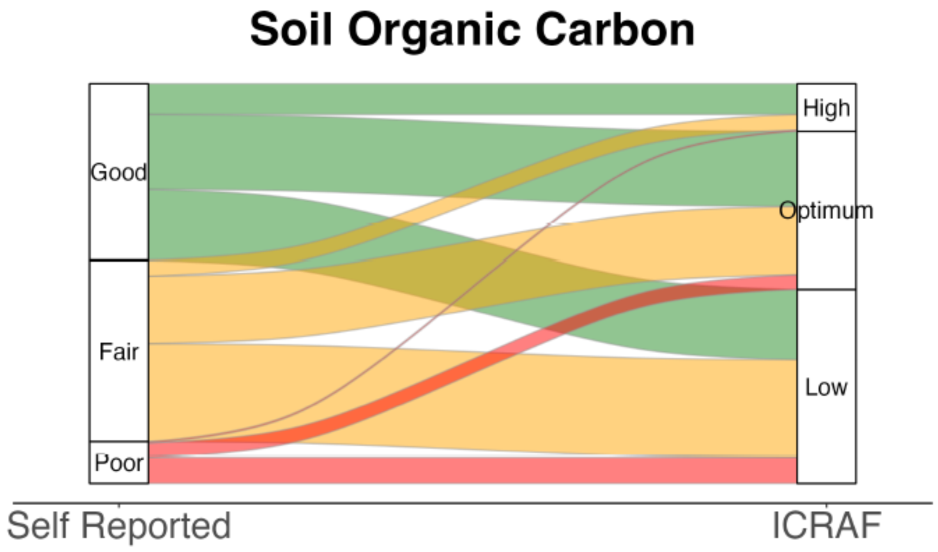


Key Findings
Farmer-reported soil quality

Respondent criteria for self-reported soil quality		
	N	%
Soil color	1104	22.9%
Soil texture	365	7.6%
Soil type	626	13.0%
Soil moisture	253	5.2%
Presence of weeds	719	14.9%
Crop yield	1730	35.9%
Other	23	0.5%

(multiple responses possible)





Key Findings

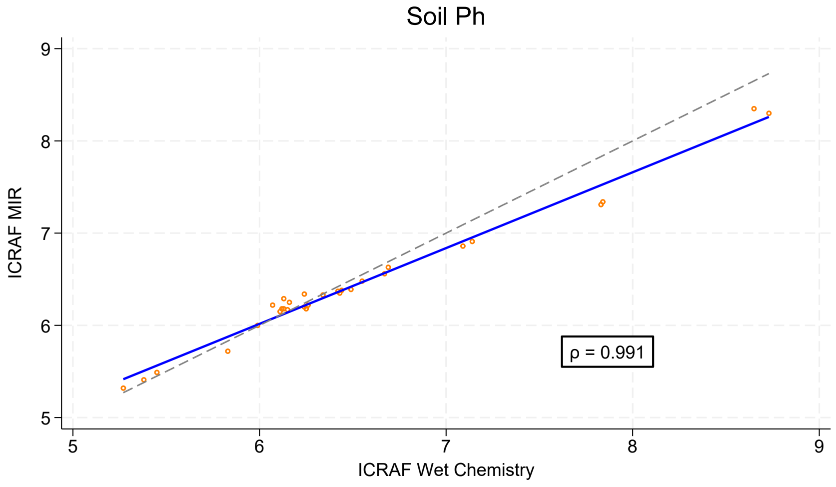
Comparison of Methods – Defining the benchmark

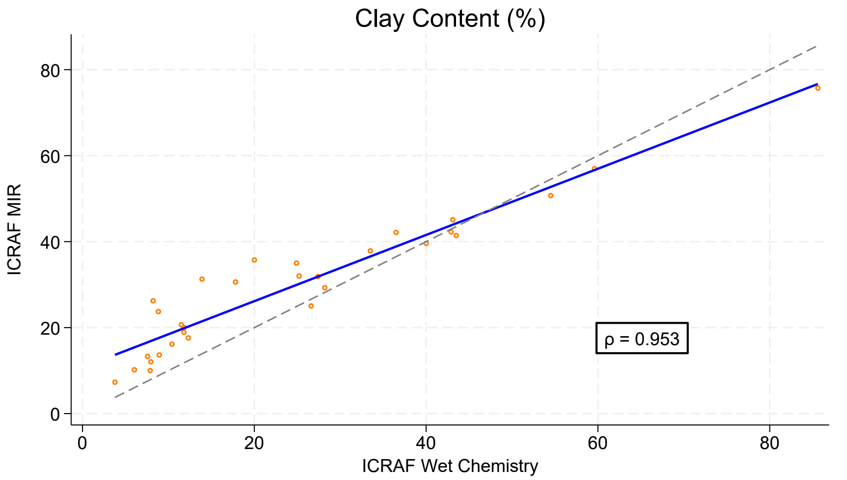
Wet Chemistry = Gold Standard

- Direct chemical measurement of soil properties
- Basis for calibration for soil spectral libraries
- Expensive (and relatively slow)

ICRAF MIR = Scalable Benchmark

- ICRAF MIR models trained on a large regional library linked to wet chemistry
- Rapid, lower-cost soil property estimates from standardized dried and ground samples
- In Uganda CLASS, MIR and wet chemistry show **very strong agreement**
  - Wet chemistry implemented on 10% of CLASS sample for select properties
- Provides the most reliable reference for evaluating AgroCares, Palintest, Sonkir, and soil maps





Key Findings

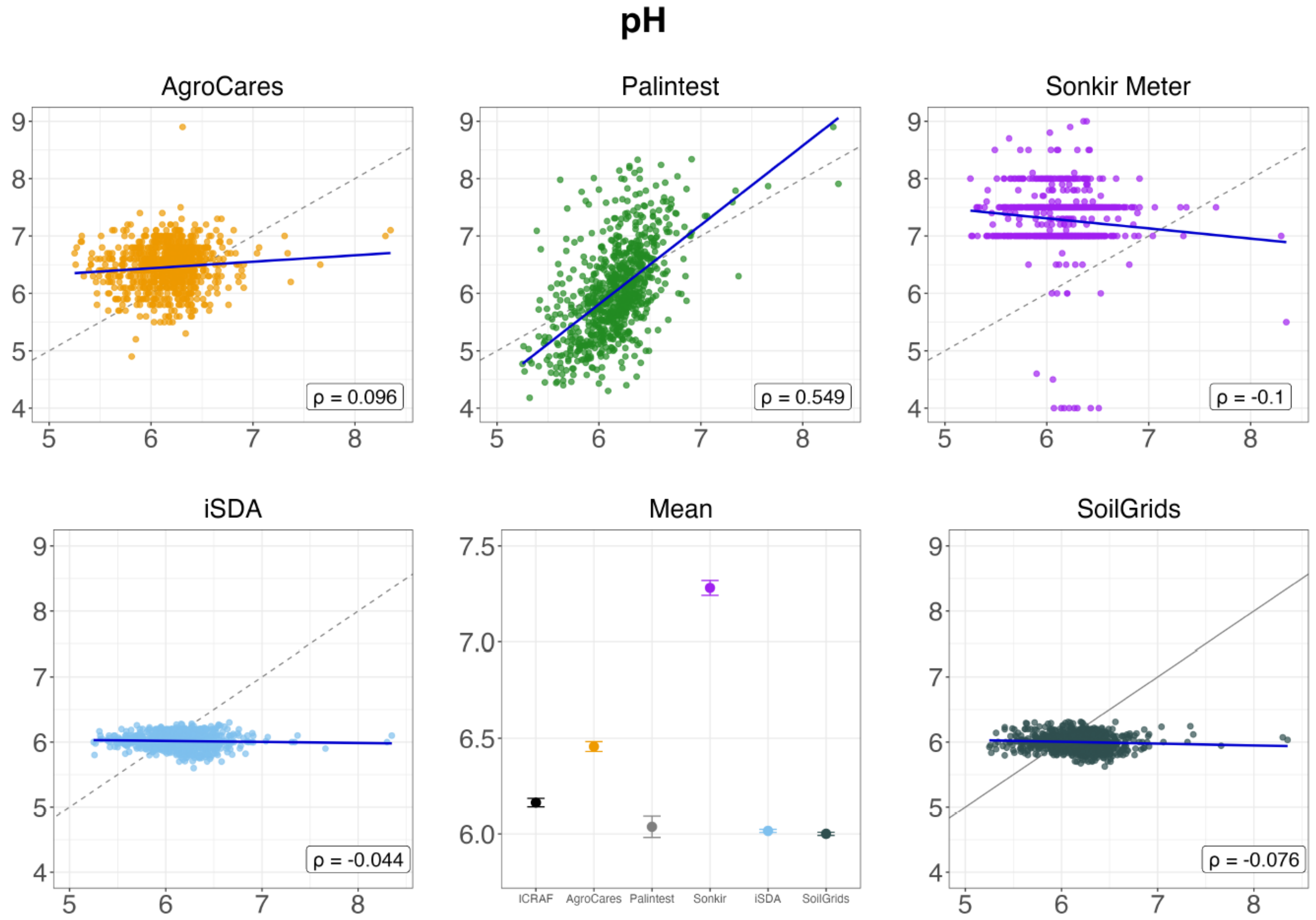
Comparison of Methods – Correlations

Correlation of key soil properties with ICRAF MIR estimates

	AgroCares	Jabba / Palintest	Sonkir Meter	ISDA	SoilGrids
pH	0.096	0.549	-0.1	-0.044	-0.076
Clay	0.683	-0.009		0.159	-0.022
Soil Organic Carbon	0.441			0.372	-0.062
Total Nitrogen	0.425			0.348	-0.005
Extractable Potassium	0.008 *	0.324		-0.101	

Key Findings

Comparison of Methods – Means & Bias (pH)



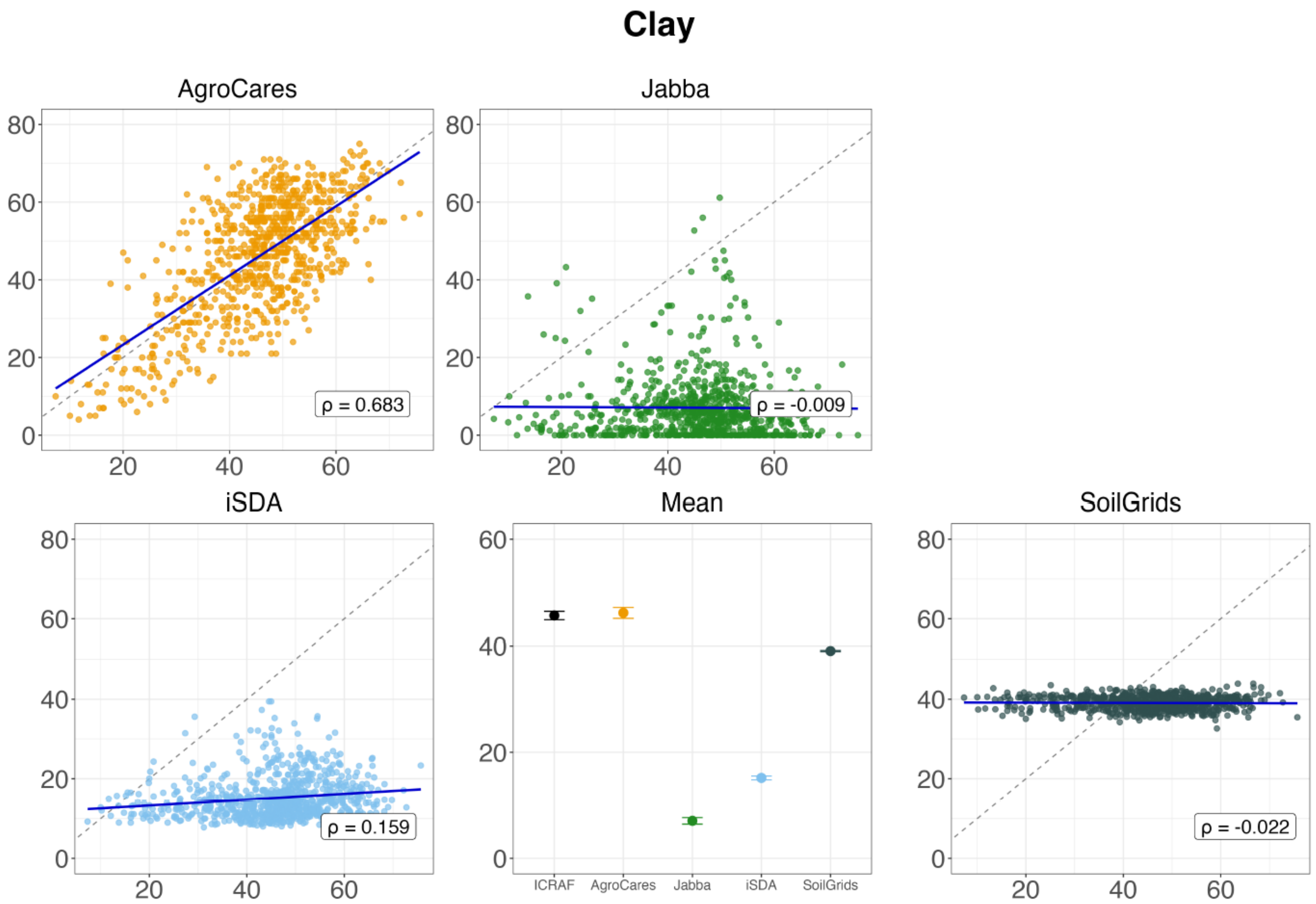
- Palintest most similar to ICRAF MIR – same extraction method and similar soil:water ratio used in Palintest kit and in ICRAF calibration data
- AgroCares uses same extraction method but different soil:water ratio in their calibration data, could result in higher estimates; limited variation
- Sonkir severely overestimates and shows heaping on whole/half numbers (potentially due to UI)
- Soil maps provide almost no variation
- Means: all means statistically different from ICRAF MIR

Note: In each scatter plot, the x-axis represents the ICRAF values, while the y-axis corresponds to the values from the respective tool.
The errorbars in the Mean plot represents the 95% confidence interval.

Key Findings

Comparison of Methods – Means & Bias (Clay Content)

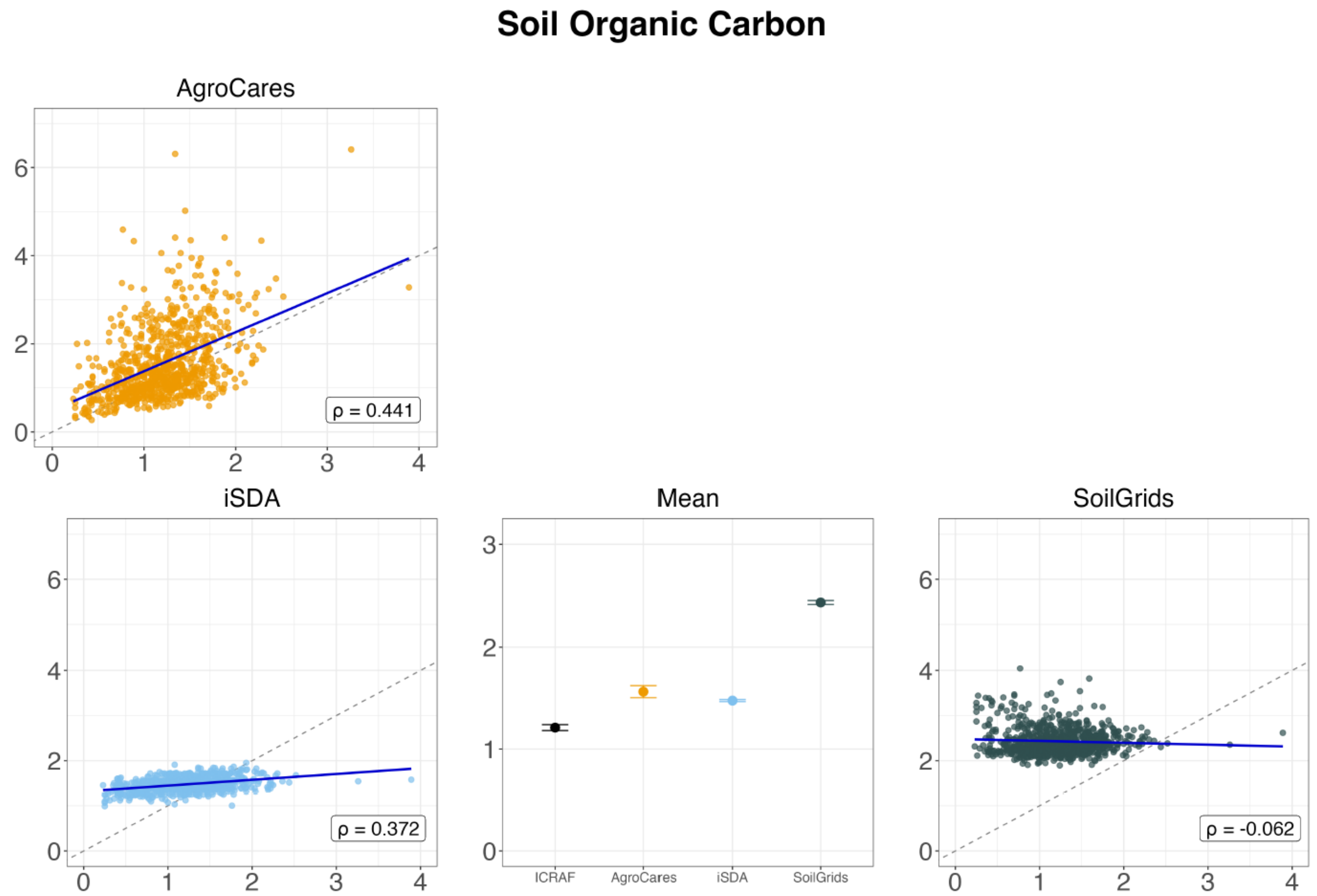
- AgroCares statistically similar to ICRAF MIR; strong correlation
- Jabba hydrometer approach severely underestimates clay content
- SoilGrids provides almost no variation; iSDA has slightly more variation but biased downward
- Means: all means statistically different from ICRAF MIR, **except AgroCares**



Note: In each scatter plot, the x-axis represents the ICRAF values, while the y-axis corresponds to the values from the respective tool. The errorbars in the Mean plot represents the 95% confidence interval.

Key Findings

Comparison of Methods – Means & Bias (SOC)



- AgroCares moderately correlated; upward bias
- SoilGrids grossly overestimates (mean double that of ICRAF)
- Means: all means statistically different from ICRAF MIR
- Similar pattern for nitrogen

Note: In each scatter plot, the x-axis represents the ICRAF values, while the y-axis corresponds to the values from the respective tool.
The errorbars in the Mean plot represents the 95% confidence interval.

SCALABILITY & ROUGH COST ESTIMATES

BASED ON STUDY EXPERIENCE

Method	Cost per Sample / Equipment	Scalability Notes
ICRAF MIR	~$18/sample for MIR (plus wet chemistry on 10% of samples) → excluding indirect costs, overhead, and staff time	Believed to have highest data quality of methods tested; slower turnaround; logistically complex due to sample shipment and processing.
Palintest/Jabba Eng.	~$27/sample → excluding costs related to overhead and staff time	Efficient regional labs; relatively quick turnaround; some logistical complications (sample bagging/delivery).
AgroCares	~$7,000 scanner + $1,800–$2,600/year license; ~$41/sample in CLASS → however, unlimited scans with a given license so per sample cost could be dramatically reduced	High fixed cost but unlimited scans within license period; user-friendly tool and application; near real-time results (with network).
Sonkir pH Meter	~$0.09/sample	Easy to use but accuracy renders it useless

Key Takeaways

Evidence that measurement method does matter…

→Ground based measures appear to capture much more variation than publicly-available digital soil map products

- Generally, digital soil maps inadequate for plot-level analysis

→Mean values were statistically different from the benchmark measure for all methods and all properties, with the exception of AgroCares measurement of clay

→Accuracy varies by soil property

→Important takeaways for the collection and/or use of soil data

- When implementing data collection as part of a survey or program at multiple points in time, consistency in method is key
- Differences in measures could have implications for decision-making (e.g., fertilizer recommendations → future work)

→Room for improvement of in-field technology for accurate and scalable soil testing

Thank you!

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Soil Properties Estimated

	ICRAF	AgroCares	Jabba
pH	○	Δ	□
Organic Carbon	○	Δ	
Organic Matter		Δ	
Total Nitrogen	○	Δ	
Nitrate Nitrogen			□
Ammonia Nitrogen			□*
Potentially Mineralizable Nitrogen		Δ*	
Clay	○	Δ	□
Silt	○		□
Sand	○		□
Soil Moisture		Δ*	
Cation Exchange Capacity (CEC)	○	Δ	
Calcium (exch.)	○	Δ*	□
Magnesium (exch.)	○	Δ*	□
Potassium (exch.)	○	Δ	□
Phosphorous	○	Δ	
Phosphate phosphorous			□
Phosphorous Sorption Index (PSI)	○		
Total Aluminum	○	Δ*	□*
Total Iron	○	Δ*	□*
Electrical Conductivity	○		□
Sulphur	○		□*
Manganese	○		□*
Copper	○		□*
Boron	○		
Zinc	○		
Fertilizer recommendations		Δ*	

*** indicates properties that are available with a certain license/test package**

Experience & Preliminary Findings

Observed variation in key soil properties *within* communities

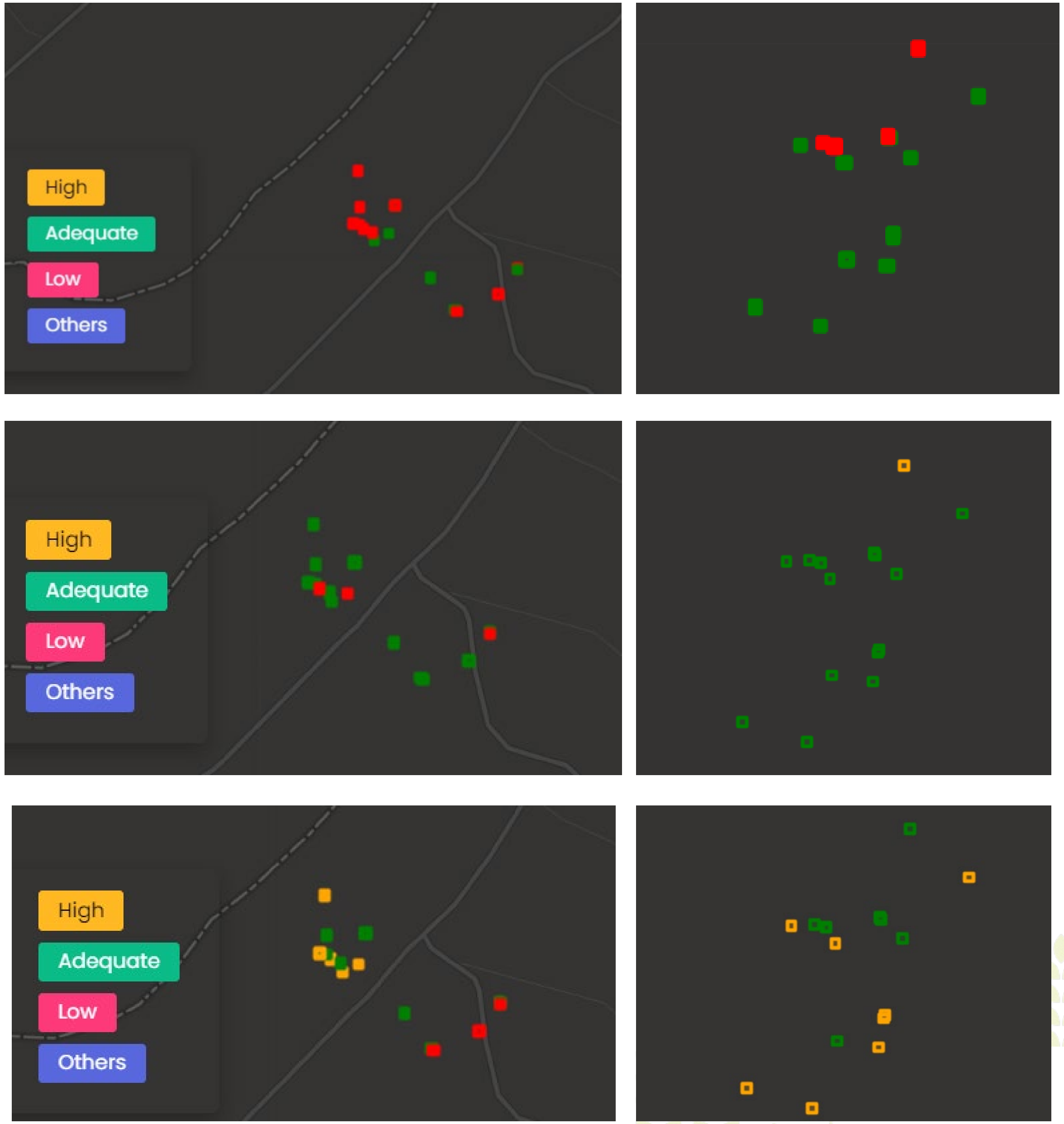
→ pointing towards benefits of analysis at the household/plot level

Community A | Community B

Organic Carbon

pH

Potassium



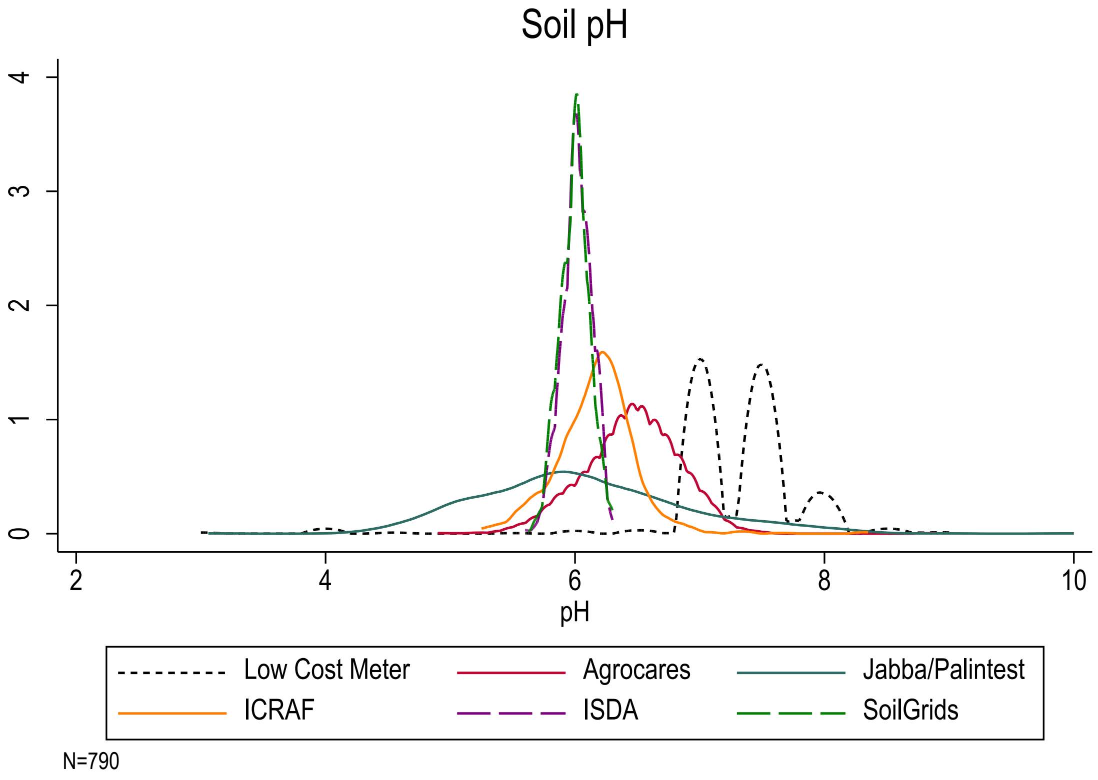
Snip from AgroCares Portal

Experience & Preliminary Findings

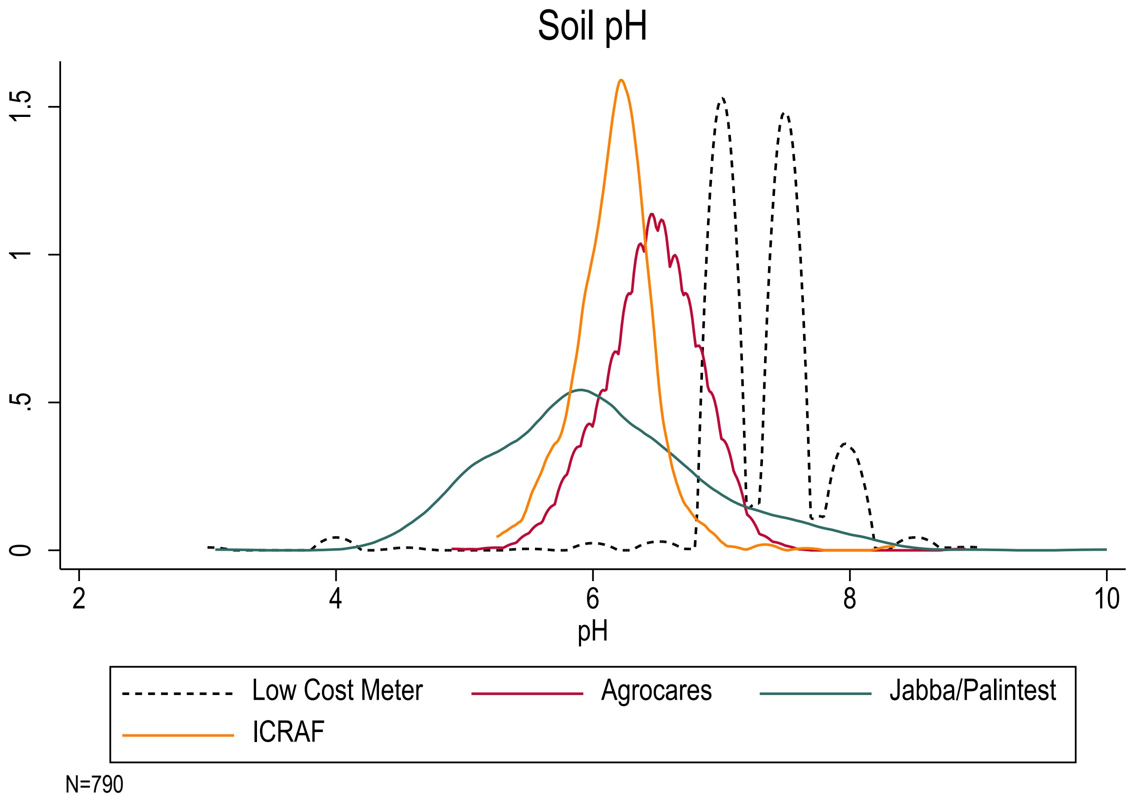
Comparison of Methods - Distributions

[preliminary – not for citation]

Distribution of soil pH for geospatial soil products & benchmark measure



Zooming in to ground-based methods



Experience & Preliminary Findings

Comparison of Methods - Distributions

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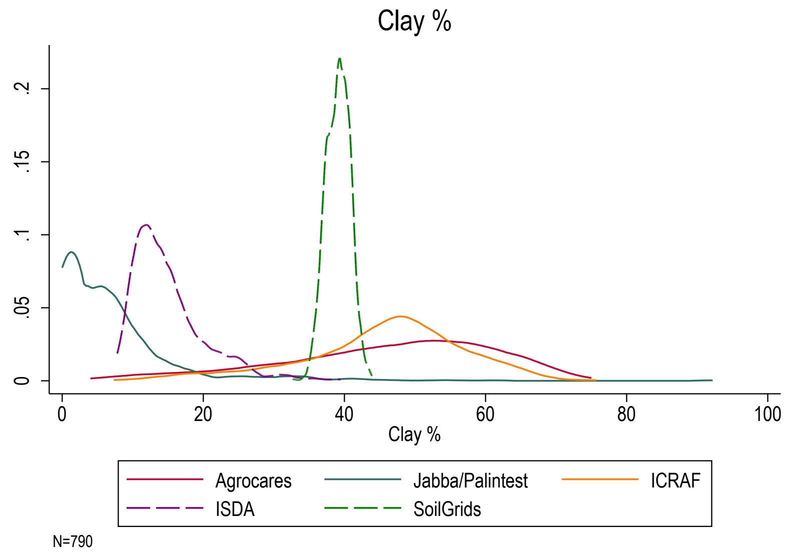
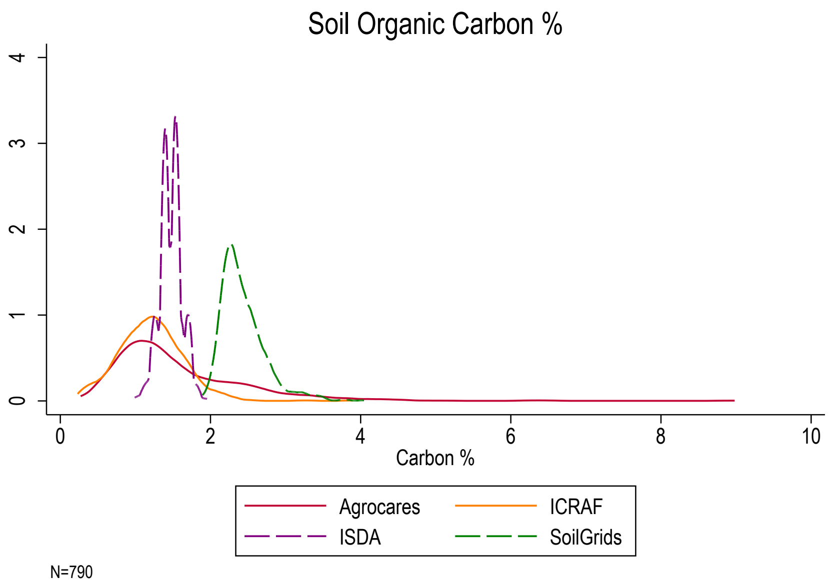
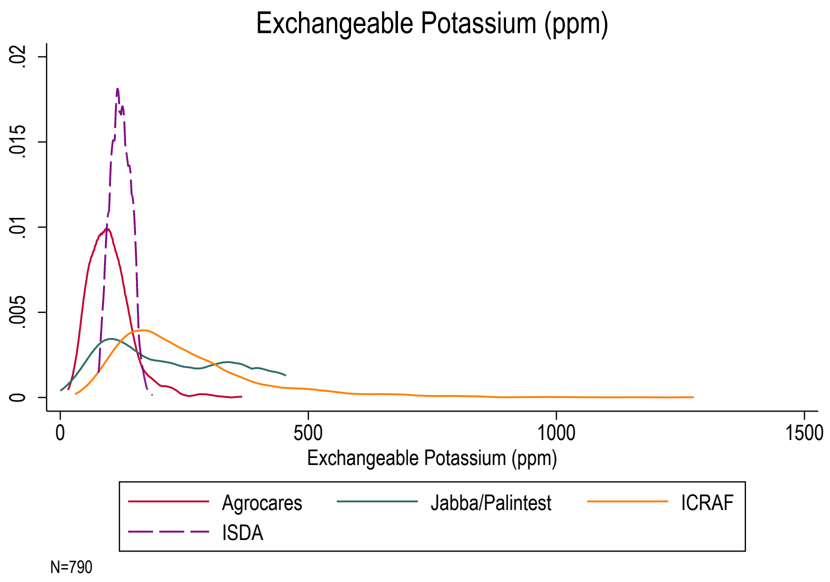




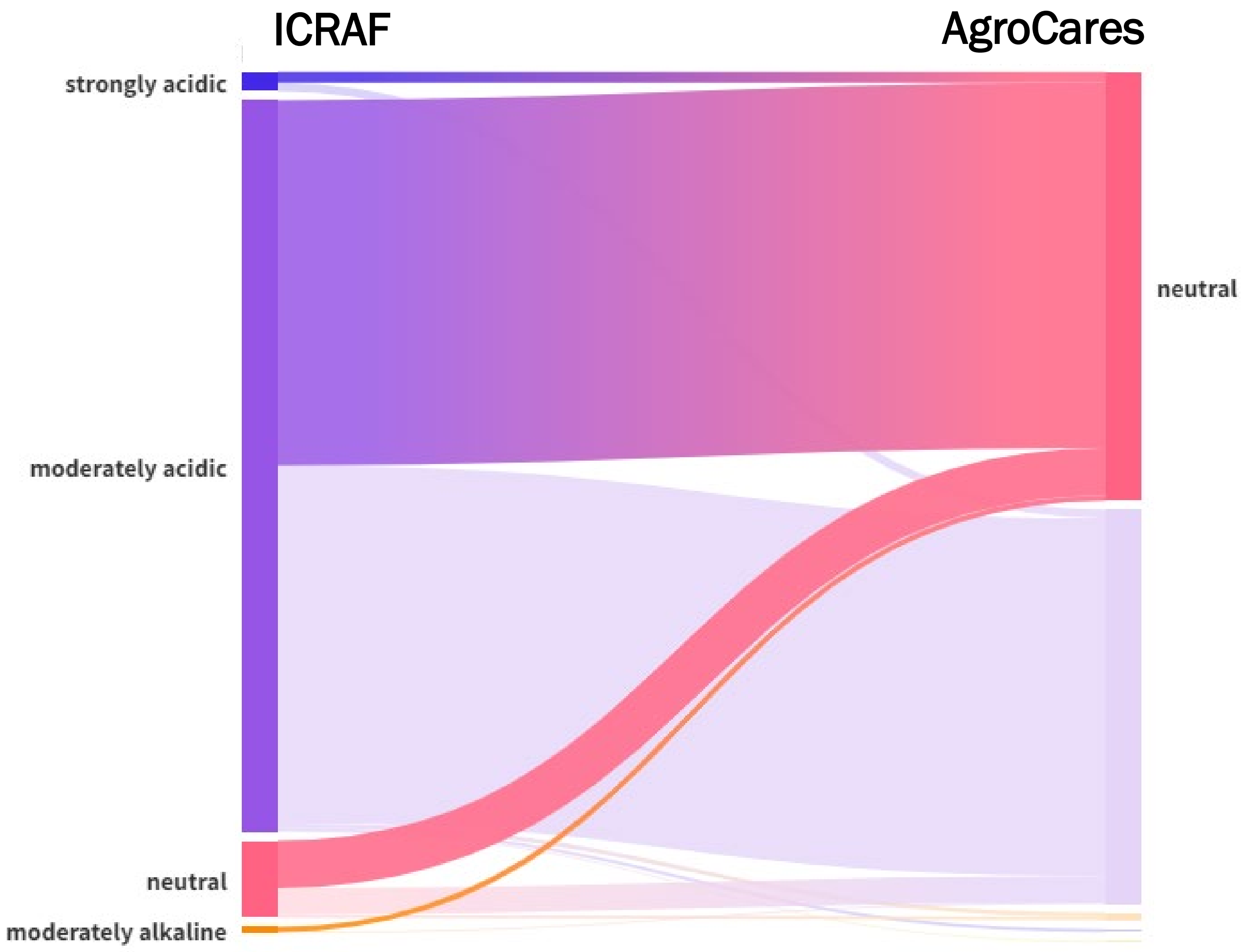


Experience & Preliminary Findings
Comparison of Methods – Classifications

[preliminary – not for citation]

Soil pH

Strongly acidic	<5.5
Moderately acidic	5.5 - 6.5
Neutral	6.5 - 7.3
Moderately alkaline	7.3 - 8.5
Strongly alkaline	>8.5



Classifications based on critical values provided by ICRAF; not specific to maize

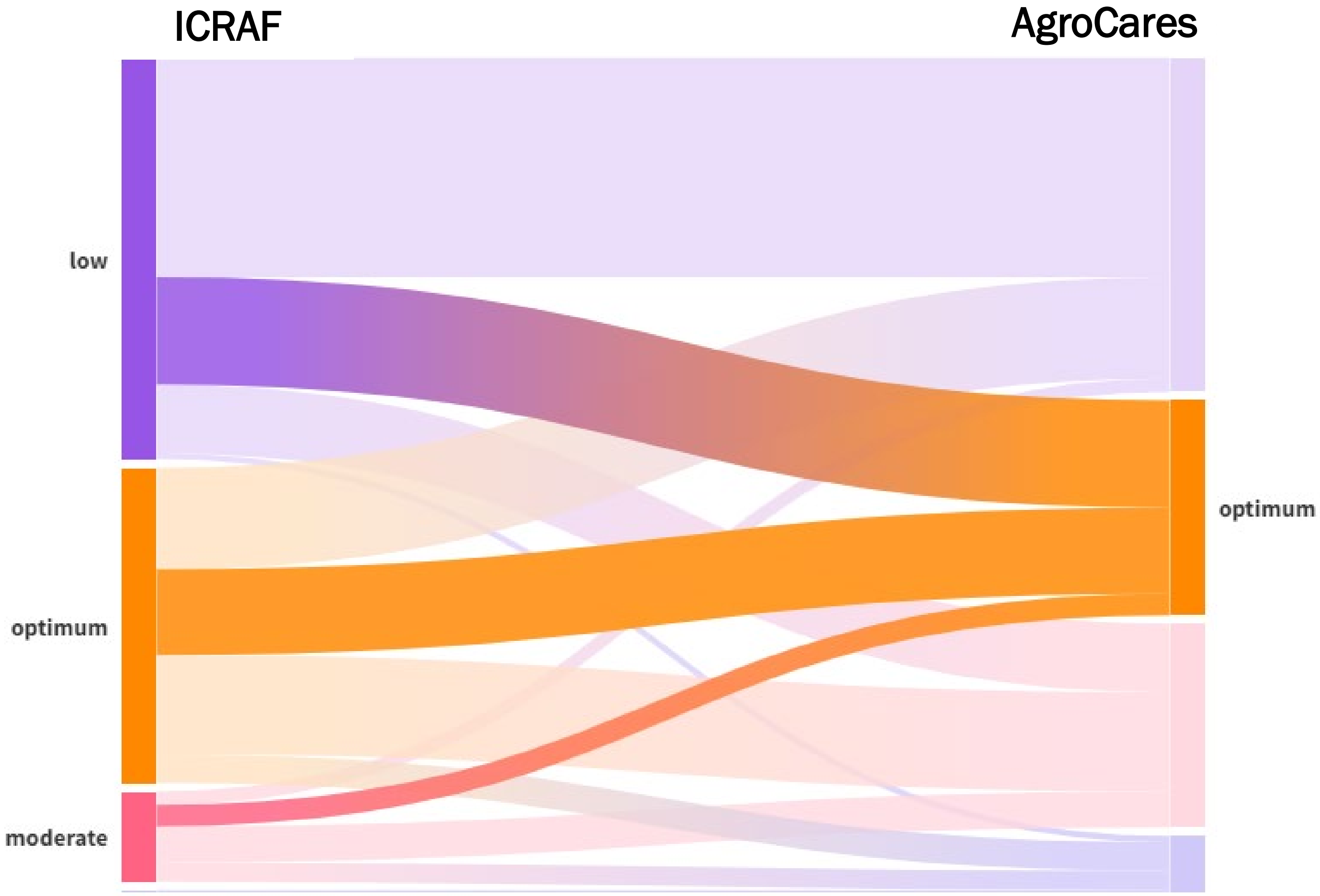
Experience & Preliminary Findings

Comparison of Methods – Classifications

[preliminary – not for citation]

Soil Organic Carbon (%)

Low	<1.2
Optimum	1.2 - 1.7
Moderate	1.7 - 3
High	>3.0



Classifications based on critical values provided by ICRAF; not specific to maize

Uganda CLASS

Soil Component Design & Implementation

- **All methods** implemented on one randomly selected maize plot per household, allowing for direct comparison
  - →In 1/3 of households, a second plot (on the same parcel) was selected for Agrocares measurement to enable assessment of intra-parcel heterogeneity of soil properties
- One roving "soil enumerator" per district, trained in soil sampling protocols and use of the tools