Soil Spectroscopy: the present and future of Soil Monitoring

FAO, Rome, 4-6 December 2013

Optimization of VNIRS for field determination of topsoil chemical properties

Jean-Philippe Gras [1,2], Bernard G. Barthès [1], Brigitte Mahaut [2], Séverine Trupin [2]

[1] IRD, UMR Eco&Sols, Montpellier, France.

[2] ARVALIS - Institut du végétal, Boigneville, France.

Context of the study 1/2

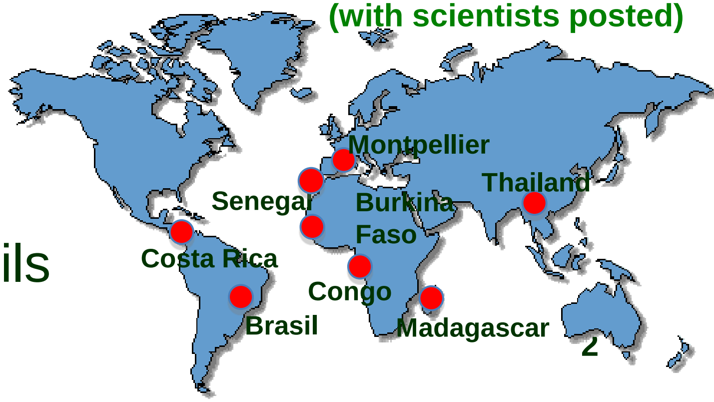
- **Eco&Sols**: French joint research unit "Functional ecology & biogeochemistry of soils & agroecosystems"
  - **Montpellier SupAgro**: international centre for higher education in agricultural sciences
  - **Cirad**: research institute dedicated to agricultural issues in the South
  - **Inra**: research institute dedicated to agricultural issues in France
  - **IRD**: research institute dedicated to Man and its environment in the South

  - Permanent staff > 60

    PhD students & postdocs > 40

  - Some experience in NIR application to soils

Main working sites (with scientists posted)



Context of the study 2/2

- **Arvalis**
  - French technical agricultural institute on cereals and forages
  - Financed and managed by farmers
  - Strong expertise in NIR for grain characterization
  - Proposes/sells conventional soil analyses to its members (farmers)
  - Wants to develop soil characterization by NIR, especially in the field

- **Objectives of the study**
  - Test the interest of field NIR for soil characterization
  - Identify the best procedure for scanning soils in the field

Sample origin

Boigneville, Essonne
wheat, 6 ha, 33 sites
silty cambic Calcisol

La Jaillière, Loire-Atlantique
rape, 5 ha, 23 sites
clayey sandy loam
gleyic Cambisol

Saint-Symphorien, Landes
maize, 12 ha, 51 sites
Podzol

Feuges, Aube
rape, 10 ha, 43 sites
clayey rendzic Leptosol

Witternheim, Bas-Rhin
maize, 5 ha, 22 sites
sandy loam
leptic Fluvisol

Baziège, Haute-Garonne
wheat, 7 ha, 29 sites
loamy cambic Fluvisol

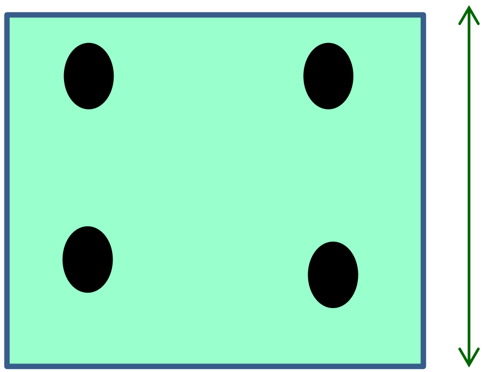
All sampled fields were cropped

Sampling

- 201 sites (1 m²)
- Soil depth: 0-20 cm
- Sampling in winter (Nov 2011-Jan 2012), rather wet conditions
- ASD LabSpec spectrophotometer with contact probe

Spectral acquisition procedures 1/5

1 site



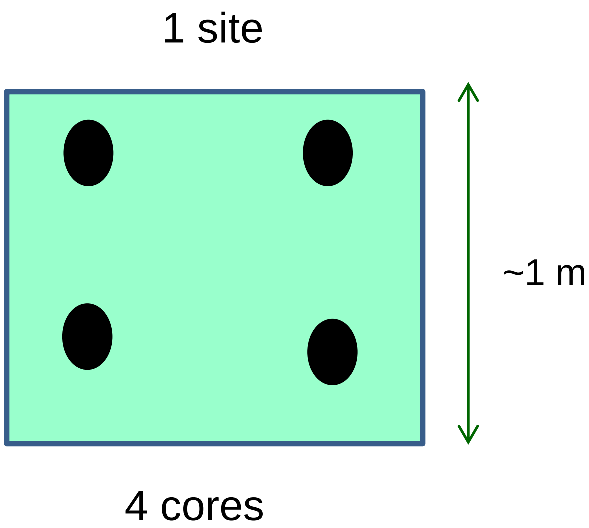
~1 m

4 points

SURFACE: **4 spectra** directly on the soil surface

(planed down using a knife, after possible residues had been removed)

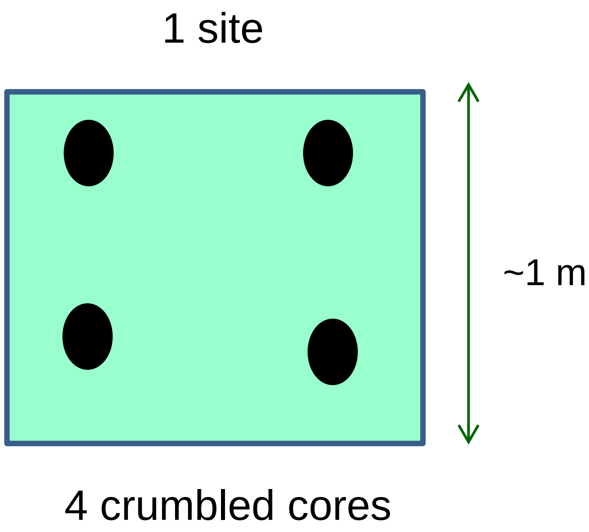
Spectral acquisition procedures 2/5



COREraw (raw auger core):
4 cores x 3 spectra/core (3-, 10- & 17-cm depth) = **12 spectra**

COREcut (cut auger core, with smooth surface):
4 cores x 3 spectra/core (3-, 10- & 17-cm depth) = **12 spectra**

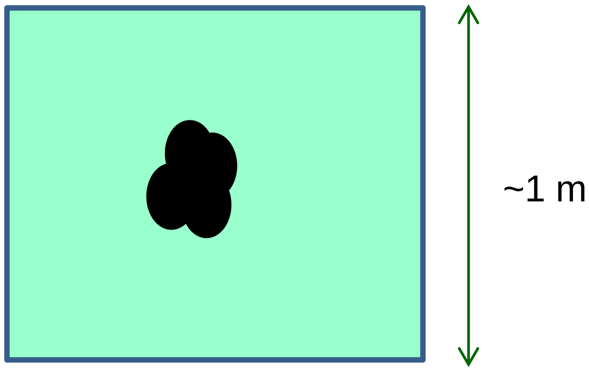
Spectral acquisition procedures 3/5



CLODraw (clods resulting from core crumbling):
4 bunches of small clods x 3 spectra/bunch = **12 spectra**

Spectral acquisition procedures 4/5

1 site

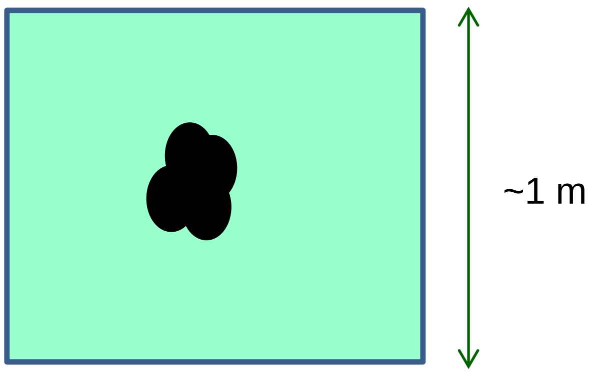


1 average bunch resulting
from 4 crumbled cores

CLODav (mixing of clods from the 4 cores): **4 spectra**

Spectral acquisition procedures 4/5

1 site



1 average bunch resulting
from 4 crumbled cores

CLODav (mixing of clods from the 4 cores): **4 spectra**

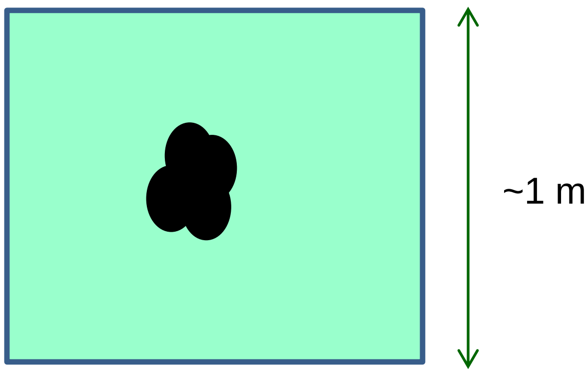
CLODav+0.5 (bagged, scan after a half-day): **4 spectra**

CLODav+1 (bagged, scan the next morning): **4 spectra**

could spectrum acquisition wait a few hours, or the next morning?
(e.g. spectrometer left at the field edge or in a shed, respectively)

Spectral acquisition procedures 4/5

1 site



1 average bunch resulting from 4 crumbled cores

CLODav (mixing of clods from the 4 cores): **4 spectra**

CLODav+0.5 (bagged, scan after a half-day): **4 spectra**

CLODav+1 (bagged, scan the next morning): **4 spectra**

CLODav_dry (same but air dried): **4 spectra**

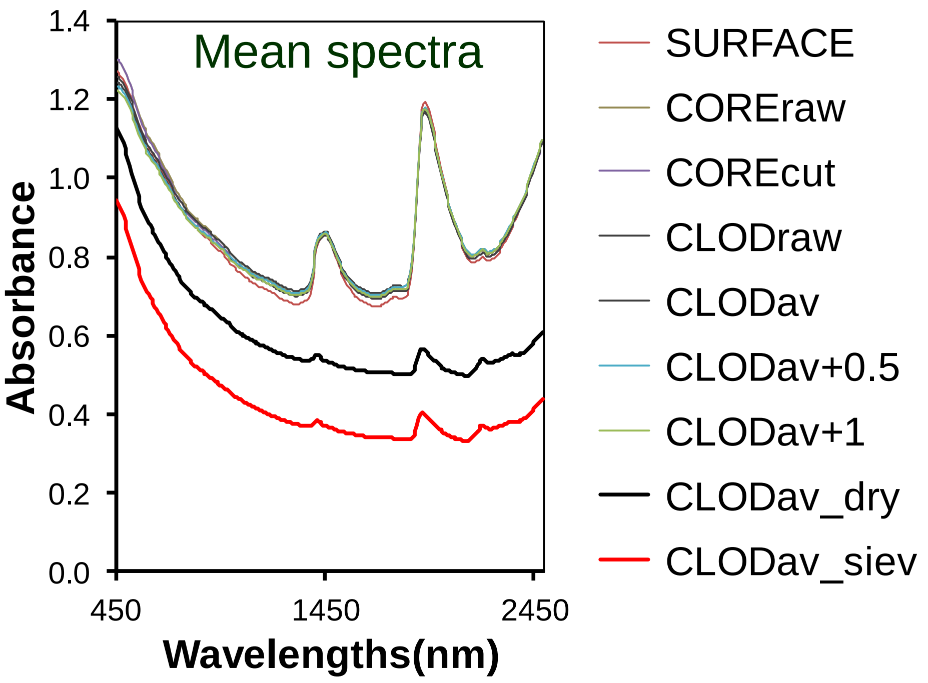
CLODav_siev (air dried and 2 mm sieved): **2 spectra**

lab conditions

Spectral acquisition procedures 5/5

- SURFACE 4 spectra
- COREraw 12 spectra
  COREcut 12 spectra
- CLODraw 12 spectra
- CLODav 4 spectra
  CLODav+0.5 4 spectra
  CLODav+1 4 spectra
- CLODav_dry 4 spectra
  CLODav_siev 2 spectra

For each combination of 1-m² site and procedure, **all spectra were averaged for spectral analysis**



Spectral acquisition procedures 5/5

• SURFACE	4 spectra
• COREraw	12 spectra
COREcut	12 spectra
• CLODraw	12 spectra
→ • CLODav	4 spectra
CLODav+0.5	4 spectra
CLODav+1	4 spectra
• CLODav_dry	4 spectra
CLODav_siev	2 spectra

For each combination of 1-m² site and procedure, **all spectra were averaged for spectral analysis**

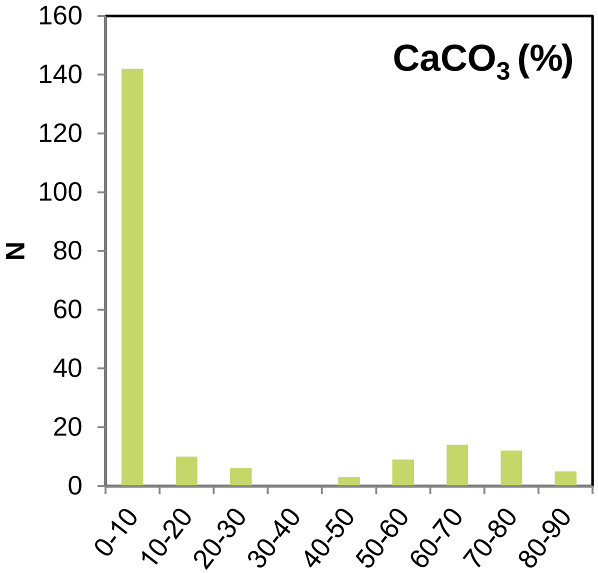
Reference analyses on CLODav samples

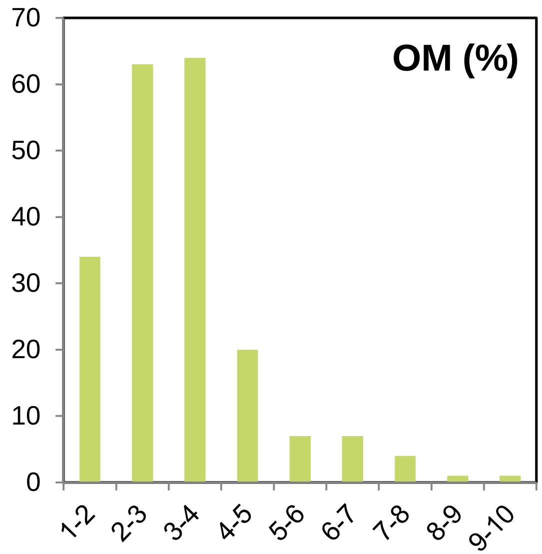
• $CaCO_3$	volumetric method
• organic matter	sulfochromic oxidation
• total N	dry combustion
• available P	Olsen method
• exchangeable K	NH_4 extraction + ICP measurement

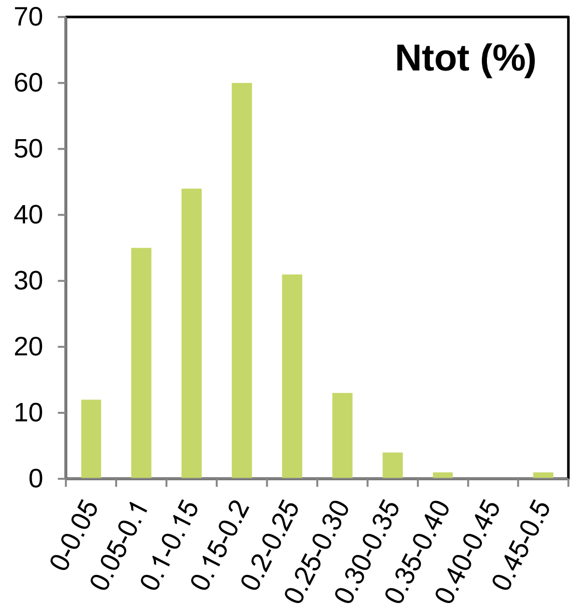
Ranges of measured properties 1/2

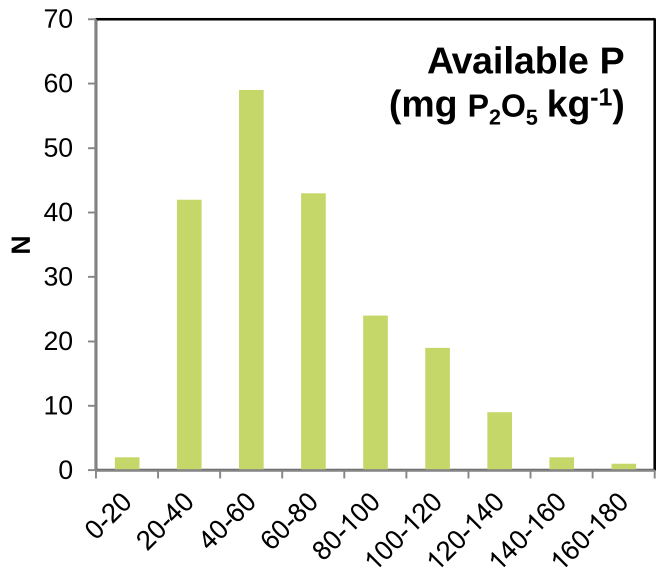
Sites	N	$CaCO_3$ (%)	OM (%)	N_{total} (%)	Avail. P (mg P_2O_5 kg^{-1})	Exch. K (mg K_2O kg^{-1})
Boigneville (Paris region)	33	0 – 28	2.3 – 3.4	0.14 – 0.22	22 – 69	263 – 513
Feuges (center-east)	43	46 – 85	**2.4 – 8.0**	0.13 – 0.34	31 – 114	**52 – 476**
Witternheim (east)	22	0 – 5	2.3 – 3.9	0.13 – 0.22	**18 – 178**	371 – 684
La Jaillière (west)	23	0	2.0 – 4.7	0.12 – 0.33	31 – 130	151 – 260
Saint-Symphorien (south-west)	51	0	**1.6 – 9.2**	**0.04 – 0.46**	**18 – 139**	31 – 273
Baziège (south)	29	0 – 9	1.1 – 1.8	0.07 – 0.13	21 – 116	133 – 306
Total	**201**	**0 – 85**	**1.1 – 9.2**	**0.04 – 0.46**	**18 – 178**	**31 – 684**

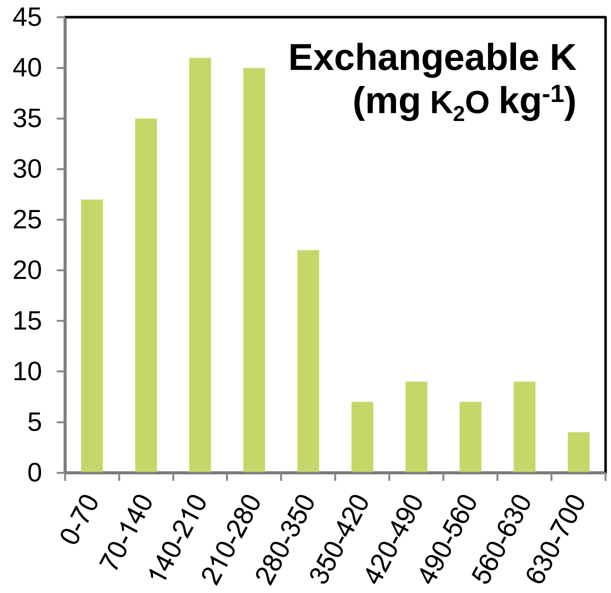
Ranges of measured properties 2/2











Development of predictive models

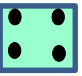
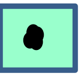
- Spectral range
  - noisy range removed (350-450 nm)
  - detector change ranges suppressed (996-1004 &1824-1834 nm)
  - every other 8 points kept (i.e. every 8 nm)

- Data analysis
  - WinISI (Infrasoft International)
  - mPLS
  - four-group cross validation
  - 42 pretreatments tested (SNV, MSC, etc.)

Objective: optimizing the scanning procedure, not building robust model

- Statistical parameters
  - SECV
  - bias and slope
  - R^2cv
  - RPDcv

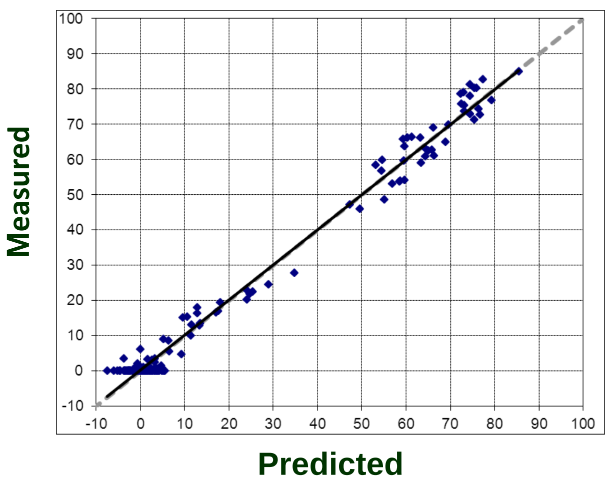
Comparison of predictive models: calcium carbonate (%)

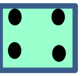
Procedure (reps)	SECV	Bias	Slope	R^2	RPD	*F-test*
SURFACE (4)	3.60	-0.06	1.00	0.98	7.4	*B*
COREraw (12)	**3.01**	**0.07**	**1.00**	**0.99**	**9.1**	***A***
COREcut (12)	3.20	0.01	0.99	0.99	8.5	***A***
CLODraw (12)	3.34	0.02	1.00	0.98	8.1	***A***
CLODav (4)	3.90	-0.09	1.00	0.98	7.1	*B*
CLODav+0.5 (4)	3.74	-0.09	0.99	0.98	7.3	*B*
CLODav+1 (4)	4.01	-0.03	1.00	0.98	6.9	*B*
CLODav_dry (4)	3.25	0.03	0.99	0.99	8.4	***A***
CLODav_siev (2)	3.16	-0.06	1.00	0.99	8.6	***A***

- Δ RPD = 2.2 => wide range
- All procedures with RPD >>> 2
- F-test:

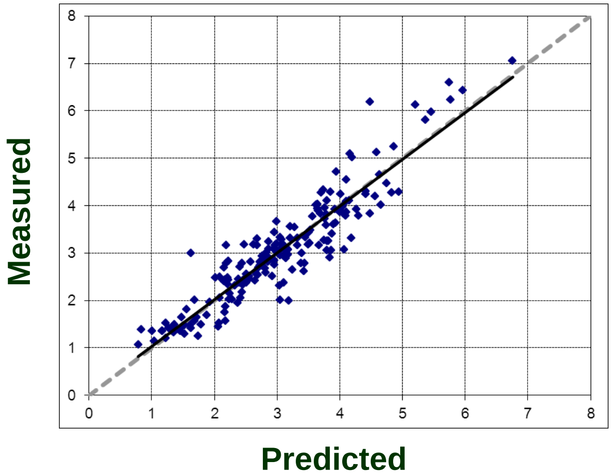
  CORE (and CLODraw) better



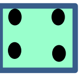
Comparison of predictive models: organic matter (%)

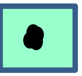
Procedure (reps)	SECV	Bias	Slope	R^2	RPD	*F-test*
SURFACE (4)	0.48	-0.020	0.98	0.82	2.4	*B*
COREraw (12)	**0.42**	**-0.002**	**0.99**	**0.86**	**2.8**	***A***
COREcut (12)	0.42	-0.002	0.97	0.86	2.7	***A***
 CLODraw (12)	0.45	-0.015	0.96	0.83	2.4	***A***
 CLODav (4)	0.54	0.002	0.96	0.78	2.2	*B*
CLODav+0.5 (4)	0.55	0.012	0.96	0.77	2.1	*B*
CLODav+1 (4)	0.53	-0.002	0.94	0.80	2.2	*B*
CLODav_dry (4)	0.48	0.010	0.96	0.81	2.3	*B*
CLODav_siev (2)	0.51	0.013	0.98	0.80	2.3	*B*

- Δ RPD = 0.7
- All procedures with RPD > 2
- F-test: CORE and CLODraw better than others, including lab



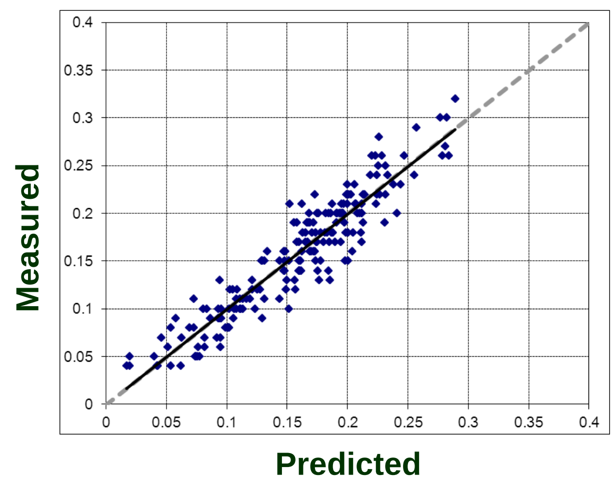
Comparison of predictive models: total N (%)



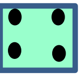


Procedure (reps)	SECV	Bias	Slope	R^2	RPD	*F-test*
SURFACE (4)	0.024	0.000	0.99	0.85	2.6	***A***
COREraw (12)	0.023	-0.001	0.98	0.87	2.7	***A***
COREcut (12)	**0.022**	**0.001**	**1.00**	**0.88**	**2.9**	***A***
CLODraw (12)	0.024	0.004	0.98	0.86	2.7	***A***
CLODav (4)	0.024	-0.001	0.97	0.86	2.6	***A***
CLODav+0.5 (4)	0.025	0.000	0.99	0.84	2.5	*B*
CLODav+1 (4)	0.025	0.000	0.98	0.85	2.6	*B*
CLODav_dry (4)	0.022	0.001	0.98	0.88	**2.9**	***A***
CLODav_siev (2)	0.022	0.000	0.98	0.89	**3.0**	***A***

- Δ RPD = 0.5
- All procedures with RPD > 2
- F-test: delayed scans worst

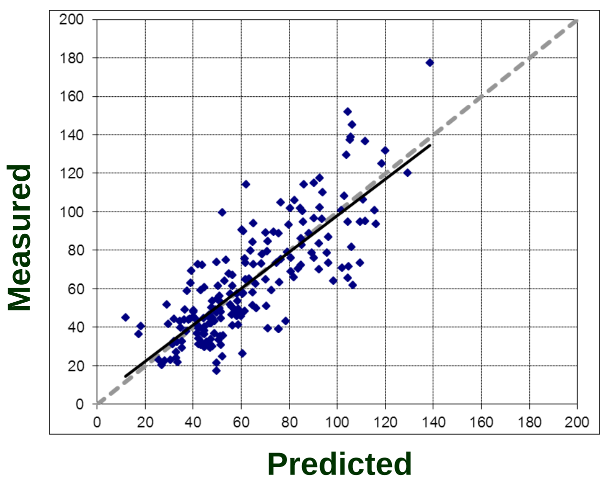


Comparison of predictive models: available P ($mg\ P_2O_5\ kg^{-1}$)

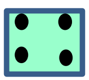



Procedure (reps)	SECV	Bias	Slope	R^2	RPD	*F-test*
SURFACE (4)	18.3	-0.2	0.94	0.59	1.6	*B*
COREraw (12)	17.5	-0.1	0.95	0.65	1.7	***A***
COREcut (12)	18.3	-0.2	0.97	0.59	1.6	*B*
CLODraw (12)	17.8	-0.1	0.94	0.62	1.6	***A***
CLODav (4)	17.9	0.1	0.95	0.61	1.6	***A***
CLODav+0.5 (4)	17.8	0.1	0.93	0.62	1.6	***A***
CLODav+1 (4)	17.3	-0.1	0.94	0.63	1.7	***A***
CLODav_dry (4)	17.0	-0.0	0.89	0.64	**1.7**	***A***
CLODav_siev (2)	16.1	0.0	0.97	0.70	**1.8**	***A***

- Δ RPD = 0.2
- RPD ≈ 1.6-1.8
- F-test: all equivalent except SURFACE and COREcut

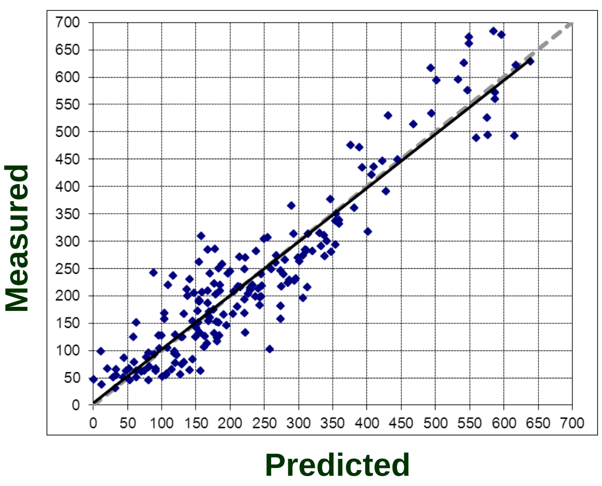


Comparison of predictive models: exchangeable K (mg K_2O kg^{-1})



Procedure (reps)	SECV	Bias	Slope	R^2	RPD	*F-test*
SURFACE (4)	53.8	0.8	1.00	0.88	2.9	***A***
COREraw (12)	53.1	0.6	0.98	0.88	2.9	***A***
COREcut (12)	53.0	0.5	0.98	0.88	2.9	***A***
CLODraw (12)	**51.2**	**0.9**	**0.98**	**0.89**	**3.0**	***A***
CLODav (4)	55.1	1.8	1.00	0.88	2.8	***A***
CLODav+0.5 (4)	55.6	1.1	1.00	0.85	2.7	*B*
CLODav+1 (4)	53.6	-0.4	0.97	0.88	2.9	***A***
CLODav_dry (4)	50.1	-0.6	0.97	0.90	**3.1**	***A***
CLODav_siev (2)	49.1	0.7	0.98	0.90	**3.2**	***A***

- Δ RPD = 0.4
- RPD ≈ 3
- F-test: all equivalent except CLODav+0.5



Uncertainty of NIRS vs. reference methods

Parameter	Uncertainty range of reference methods	Uncertainty range of NIRS (=2 SECV; raw core)
$CaCO_3$ (%)	1 – 5	6
OM (%)	0.2 – 1.0	0.8
N_{total} (%)	0.01 – 0.03	0.04
Available P (mg P_2O_5 kg^{-1})	3 – 9	35
Exch. K (mg K_2O kg^{-1})	5 – 27	106

Discussion

- Good results with raw cores (except for P, always bad)
- Equivalent to lab conditions (< 2 mm)
  and significantly better for SOM (RPD = 2.8 vs. 2.3)
- Counterintuitive (moisture, temperature, coarse particles) but:
  - more replicates (different approaches rather than artifact)
  - sample cohesion
    (higher reflectance => closer link composition-absorbance)

Discussion

- Good results with raw cores (except for P, always bad)
- Equivalent to lab conditions (< 2 mm)
  and significantly better for SOM (RPD = 2.8 vs. 2.3)
- Counterintuitive (moisture, temperature, coarse particles) but:
  - more replicates (different approaches rather than artifact)
  - sample cohesion
    (higher reflectance => closer link composition-absorbance)
- Not useful or not appropriate:
  - Smoothing/cuting the core
  - Core crumbling
  - Delayed scanning (+ requires bagging)
  - Surface scanning

Conclusion and perspectives

- Good results in the field, with cores (except P)
- Here 201 samples
  Calibration set completed up to 1000 samples (raw core)
  representing more variability (soil type, moisture)
- (only cropped soils; no pasture, no forest)
- Analyses completed with texture and pH
- Develop robust calibrations

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
MINISTÈRE DES AFFAIRES ÉTRANGÈRES

PARRAF

AIRD l'agence

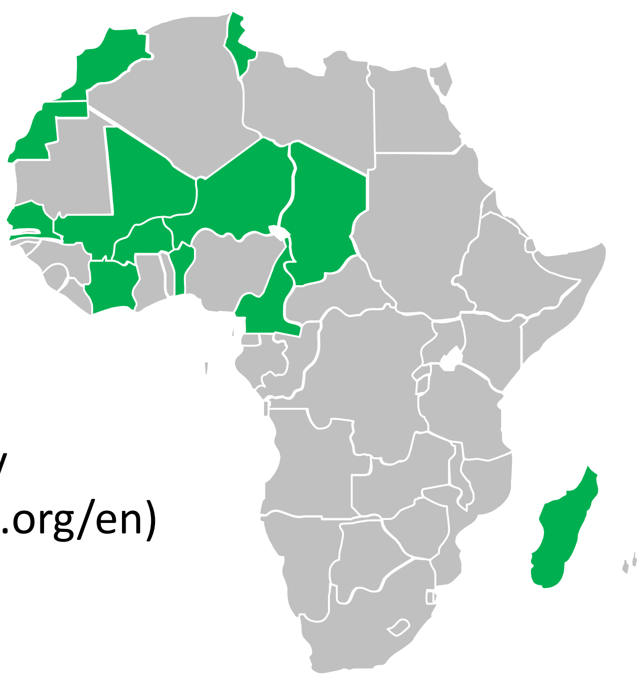
The CaSA network

Carbone des Sols pour une agriculture durable en Afrique

Soil Carbon for Sustainable Agriculture in Africa

Coord.: Pr. T. Razafimbelo
Univ. Antananarivo, Madagascar

21 teams from 11 African countries and France



Activities

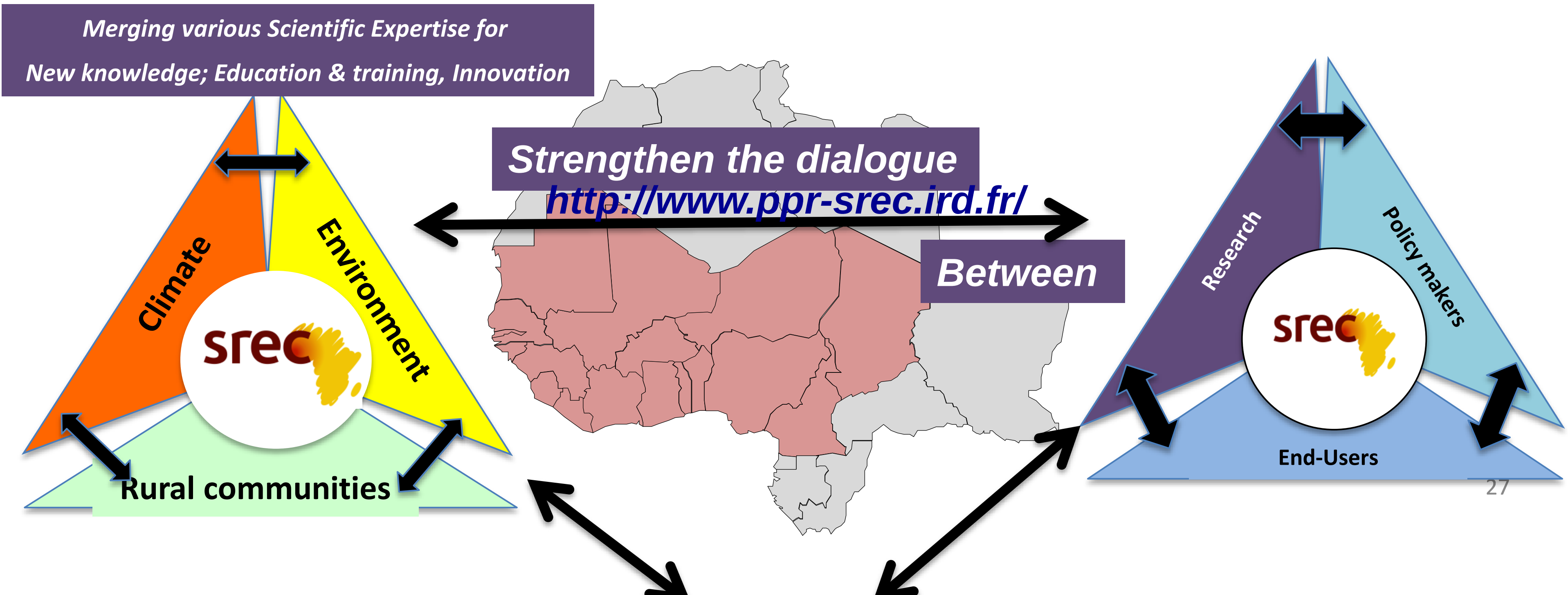
- Axis 1: **Harmonize methodologies** for characterizing soil C
- Axis 2: **Optimize the analysis** of available C data
- Axis 3: **Training**, especially on **NIR and mid-IR** spectroscopy
  Communication (http://reseau-carbone-sol-afrique.org/en)

The Regional Multidisciplinary Platform

“Rural communities, Environment and Climate in West Africa”

Food security & the preservation of natural resources
In the face of climate change

Set up with partners in West Africa



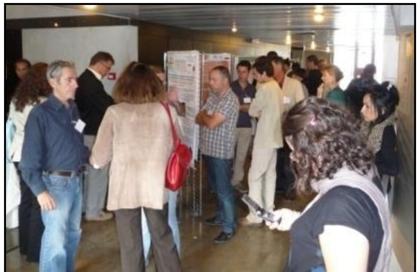
Innovations for the resilience of rural communities and natural resources in West Africa, and for promoting adaptations to climate change

Provide EXPERTISE to decision-makers and end users

Hélio SPIR

French-speaking society for near infrared spectroscopy

- Created in 2003, in Montpellier
- Largest cluster in the world for NIR research in agriculture & environment
- Promoting NIR and structuring a NIR community in France and French-speaking countries
- > 200 members



Thank you for your kind attention