Near infrared reflectance spectroscopy and molecular tools to evaluate land use impact on soil quality
A case study in a tropical ecosystem (altitude plains, Lao PDR)

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Soil Interfaces in Changing world – ISMOM 2011
Montpellier, 26th June -1st July 2011
Recent land use changes in the Plain of Jars, Lao PDR

Monitoring of land use changes impact on soil properties

Main outputs regarding Near Infrared Reflectance Spectroscopy (NIRS) predictive potential

Conclusions
Plain of Jars (900-1200m)

- 3 western districts (Pek, Phoukout and Paxay) of Xieng Khouang province, north-eastern Lao PDR
Plain of Jars (900-1200m)

- About 80,000 ha of savannah grasslands with pine trees on hills summit
- Main farming system: rice production in paddy fields
- Limited possibilities to extend paddy areas
- Limited agricultural production in the upland due to soil constraints (low pH, deficiencies in main nutrients, severe aluminium toxicity)
- Only 5% of total surface is cultivated, 80% in paddy rice fields
- Extensive livestock system in the uplands
Main changes in the uplands

- Since 1990’s
  Reforestation (pine trees) policy and upland rice production attempts based on plowing with disks

- Since 2000’s
  Attribution of large concessions to private companies for cash crops production (cassava, corn, jatropha); land preparation based on deep soil plowing

- Since 2005
  Conception and promotion of Conservation Agriculture (CA) / Direct-seeding Mulch-based Cropping (DMC) systems based on:
  * Permanent / maximum soil cover
  * Minimum soil disturbance (no-tillage)
  * Diversified crops rotations

Little information regarding agricultural practices impact on soil quality...
- Ban Poa experimental site
<table>
<thead>
<tr>
<th>Land Use</th>
<th>Rep</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAS</td>
<td>17</td>
<td>Savannah grassland dominated by <em>Themeda triandra</em> and <em>Cymbopogon nardus</em> species</td>
</tr>
<tr>
<td>CV</td>
<td>27</td>
<td>Land preparation based on ploughing using discs and burying of crop residues</td>
</tr>
<tr>
<td>DMC</td>
<td></td>
<td>No-tillage; direct seeding after mechanical and chemical control of cover crops</td>
</tr>
<tr>
<td>DMC 1</td>
<td>27</td>
<td>Year 1: &quot;fing+pig&quot;, then 3y rotation rice+sty / corn+fing+pig / soy bean +oat+buck</td>
</tr>
<tr>
<td>DMC 2</td>
<td>27</td>
<td>Year 1: &quot;fing+sty&quot;, then 3y rotation rice+sty / corn+sty / soy bean +oat +buck</td>
</tr>
<tr>
<td>DMC 3</td>
<td>27</td>
<td>Year 1 &quot;ruzi+pig&quot;, then 3-year rotation rice+sty / corn+ruzi / soy bean +oat +buck</td>
</tr>
</tbody>
</table>

**Treatments**
- 1 single experimental site but covering a high variability of:
  - soil textural classes
  - Soil colors
### Indicators

= variables allowing to translate a complex reality into more simple and readable forms (Mitchell et al, 1994)

<table>
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<tr>
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<tr>
<td>Soil texture and chemical properties</td>
<td>Soil analysis in laboratory</td>
<td>Texture, pH, Organic C, total N, avail P, CEC, Base (Ca, Mg, K, Na), BS</td>
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<td>Soil structure quality</td>
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<td>Soil microbial abundance &amp; diversity</td>
<td>Molecular tools (qPCR, B-RISA)</td>
<td>Total soil DNA, bacterial and fungal DNA, bacterial fingerprints</td>
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- Indicators of soil structure quality

  - Bulk density (Da) measured on undisturbed soil samples (3 replicates / treatment)
Indicators of soil structure quality

- Water stable aggregates
- Yoder method (1936) adapted by different authors (Haynes, Castro Filho et al, Madari et al)
- 7 classes of aggregates obtained after wet sieving of soil samples through 6 sieves (mesh of 8, 4, 2, 1, 0.5 and 0.25 mm)
- 3 replicates per treatment
- 4 aggregation parameters:
  - Macro (0.25-19mm) and micro (<0.25mm) aggregate content
  - Mean Weight Diameter (MWD)
  - Mean Geometric Diameter (MGD)
  - Aggregate Stability Index (AS)
- Indicators of microbial abundance and diversity

**Total microbial community**

Soil DNA quantification (agarose) = total soil microbial biomass

**Molecular fingerprint** (B-ARISA)

**Bacterial and fungal abundance** (qPCR 16S and 18S rDNA)

Genetical structure of bacterial communities

Principal component analysis

Adapted from Pascault. 2010 and Raniard. 2009
- **Indicators**
  
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**Near Infrared Reflectance Spectroscopy (NIRS) predictive ability?**
- **Near infrared reflectance spectroscopy**
  - Soil sampling in June 2009
  - Bulk of 5 soil samples for each treatment
  - *In situ* air-dried and passed through 2mm mesh sieve
  - NIRS analysis in France (CNRS-CEFE)
  - Crushing of soil samples using a Cyclotec crusher (1mm mesh sieve)
  - Soil placement in reading cells (quartz) and then measurement of reflected light in a spectrophotometer (NIRSystems 6500)
- Near infrared reflectance spectroscopy

- Spectral field from 400-2500 Nm, interval of measurement every 2 Nm, producing a spectrum made up of 1050 values of absorptance
- Predictions using winISI II software (v 1.50)
NIRS ability to predict soil texture

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Nb</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
<th>SEC</th>
<th>R²</th>
<th>SECV</th>
<th>1-VR</th>
<th>RPD</th>
<th>Math treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay (%)</td>
<td>108</td>
<td>13,80</td>
<td>65,20</td>
<td>38,57</td>
<td>14,93</td>
<td>3,27</td>
<td>0,95</td>
<td>3,72</td>
<td>0,94</td>
<td>4,02</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>106</td>
<td>11,80</td>
<td>34,40</td>
<td>17,71</td>
<td>4,07</td>
<td>1,84</td>
<td>0,80</td>
<td>2,21</td>
<td>0,71</td>
<td>1,84</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>106</td>
<td>13,50</td>
<td>72,80</td>
<td>43,70</td>
<td>15,77</td>
<td>2,58</td>
<td>0,97</td>
<td>4,00</td>
<td>0,94</td>
<td>3,95</td>
<td>2, 10, 10, 1</td>
</tr>
</tbody>
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SD: Standart deviation; SEC: Standart Error of Calibration
SECV: Standart Error of Cross Validation; 1-VR: % of variance explained by model
RPD: ratio SD/SECV; Math treatment: Derivate, Gap, Smooth 1, Smooth 2

- Highly satisfactory for clay and sand
- Useful to predict texture-related indicators (water holding capacity)
Linear regression between lab and NIRS values for Clay (%)

\[ y = 1.0098x - 0.3768 \]

\[ R^2 = 0.9545 \]
### NIRS ability to predict chemical analytes

<table>
<thead>
<tr>
<th>Constituent</th>
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<th>Max</th>
<th>Mean</th>
<th>SD</th>
<th>SEC</th>
<th>R²</th>
<th>SECV</th>
<th>1-VR</th>
<th>RPD</th>
<th>Math treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Org C (%)</td>
<td>106</td>
<td>2,18</td>
<td>4,40</td>
<td>3,36</td>
<td>0,45</td>
<td>0,14</td>
<td>0,90</td>
<td>0,20</td>
<td>0,80</td>
<td>2,21</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>Total N (‰)</td>
<td>106</td>
<td>1,71</td>
<td>3,42</td>
<td>2,36</td>
<td>0,35</td>
<td>0,14</td>
<td>0,84</td>
<td>0,17</td>
<td>0,76</td>
<td>2,02</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>pH (1:5)</td>
<td>108</td>
<td>4,40</td>
<td>6,13</td>
<td>5,42</td>
<td>0,29</td>
<td>0,21</td>
<td>0,48</td>
<td>0,26</td>
<td>0,22</td>
<td>1,12</td>
<td>2, 10, 10, 1</td>
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<tr>
<td>Ca (me/100g)</td>
<td>108</td>
<td>0,11</td>
<td>5,44</td>
<td>2,50</td>
<td>1,17</td>
<td>0,53</td>
<td>0,80</td>
<td>0,71</td>
<td>0,63</td>
<td>1,64</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>Mg (me/100g)</td>
<td>108</td>
<td>0,04</td>
<td>2,18</td>
<td>0,90</td>
<td>0,43</td>
<td>0,21</td>
<td>0,77</td>
<td>0,27</td>
<td>0,61</td>
<td>1,60</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>K (me/100g)</td>
<td>106</td>
<td>0,05</td>
<td>0,51</td>
<td>0,18</td>
<td>0,08</td>
<td>0,05</td>
<td>0,58</td>
<td>0,07</td>
<td>0,37</td>
<td>1,25</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>Σ base (me/100g)</td>
<td>108</td>
<td>0,35</td>
<td>8,10</td>
<td>3,63</td>
<td>1,66</td>
<td>0,69</td>
<td>0,83</td>
<td>0,98</td>
<td>0,66</td>
<td>1,70</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>CEC (me/100g)</td>
<td>108</td>
<td>1,05</td>
<td>8,28</td>
<td>4,02</td>
<td>1,53</td>
<td>0,76</td>
<td>0,75</td>
<td>0,96</td>
<td>0,61</td>
<td>1,60</td>
<td>2, 10, 10, 1</td>
</tr>
<tr>
<td>Polsen (mg/kg)</td>
<td>108</td>
<td>2,00</td>
<td>18,56</td>
<td>8,96</td>
<td>3,70</td>
<td>2,30</td>
<td>0,61</td>
<td>3,03</td>
<td>0,33</td>
<td>1,22</td>
<td>2, 10, 10, 1</td>
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- Satisfactory for organic C and total N
- Moderately satisfactory for CEC, Ca, Mg and Sum of base
- Poor prediction for Polsen, K, Na and pH
Linear regression between lab and NIRS values for orgC (%)

\[ y = 0.9155x + 0.2988 \]

\[ R^2 = 0.852 \]
NIRS ability to predict overall chemical changes
- Trends of changes given by coinertia analysis

PCA text&chem, select clay, PC1xPC2

PCA NIRS, select clay, PC1xPC2

Significant coinertia analysis
(Montecarlo test  p-value: 0.000999001)
NIRS ability to predict structural elements
- Moderate (Da, 1-VR=0.62) to poor (WSA, 1-VR <0.45) predictions
- But trends of changes given by coinertia analysis

PCA Structure, select clay, PC1xPC2

PCA NIRS, select clay, PC1xPC2

Significant coinertia analysis
(Montecarlo test  p-value: 0.000999001)
NIRS ability to predict microbial abundance and diversity

- Poor predictions for abundance (1-VR < 0.35)
- But trends of microbial diversity changes given by coinertia analysis

PCA RISA, BG analysis, select clay, PC1xPC2

PCA NIRS, select clay, PC1xPC2

Significant coinertia analysis
(Montecarlo test, p-value: 0.000999001)
Conclusions

- NIRS predictive potential difficult to assess on single case study since:
  - 1 sampling site x 1 sampling period
    (1 soil matrice vs diversity of soil matrices and analytes forms)
  - Unique samples processing
    (air-dried vs stove, cyclotec vs mortar,...)
  - Unique samples analysis methods for chemical elements and NIRS (laboratory vs in situ)
As described by other authors (review by Malley et al, 2004) the study confirmed the possibility to successfully determine by NIRS soil texture (clay, sand) and 2 main soil chemical components (organic C and total N)

Qualitative information (trends) provided by NIRS regarding soil chemical properties, structure and microbial diversity changes were satisfactory since all coinertia analysis were significant (Monte carlo test p-value <0.001)

Potential to be used (at least) for soil pre-screening and be integrated into sampling and analysis strategy

Need of more spectral libraries to link NIRS spectrum with structural and microbiota data
Thank you for your attention!