Improved Ability to Monitor Soil Carbon Stocks

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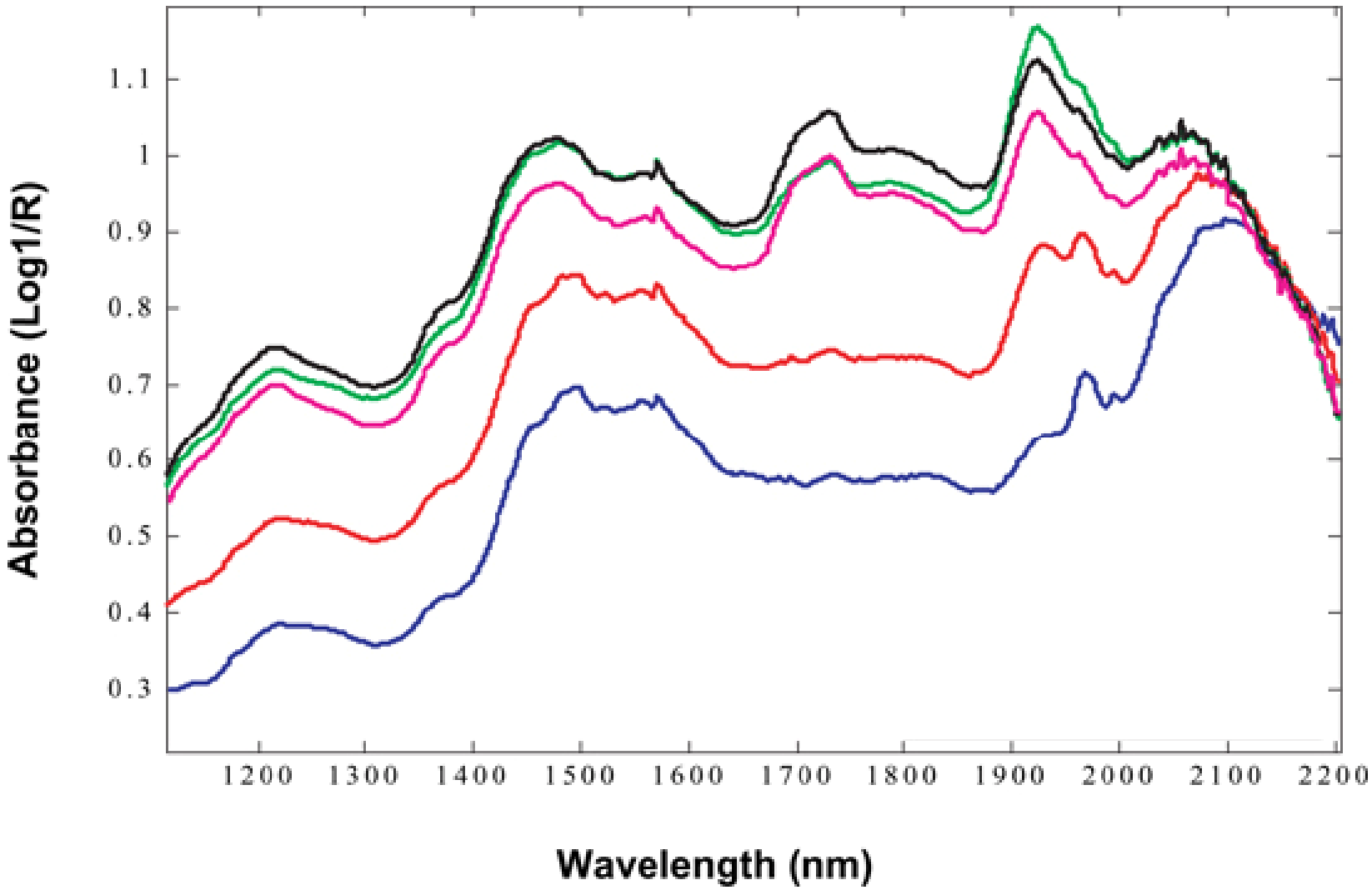
The Measurement Problem

- Sampling Variable Landscapes
  - Difficulty in obtain representative samples
  - Error due to spatial variance often larger than analytical variance.
  - Spatial variance often related to spatial structure which is also good to understand.
  - Greater frequency of measurement can help address these issues.

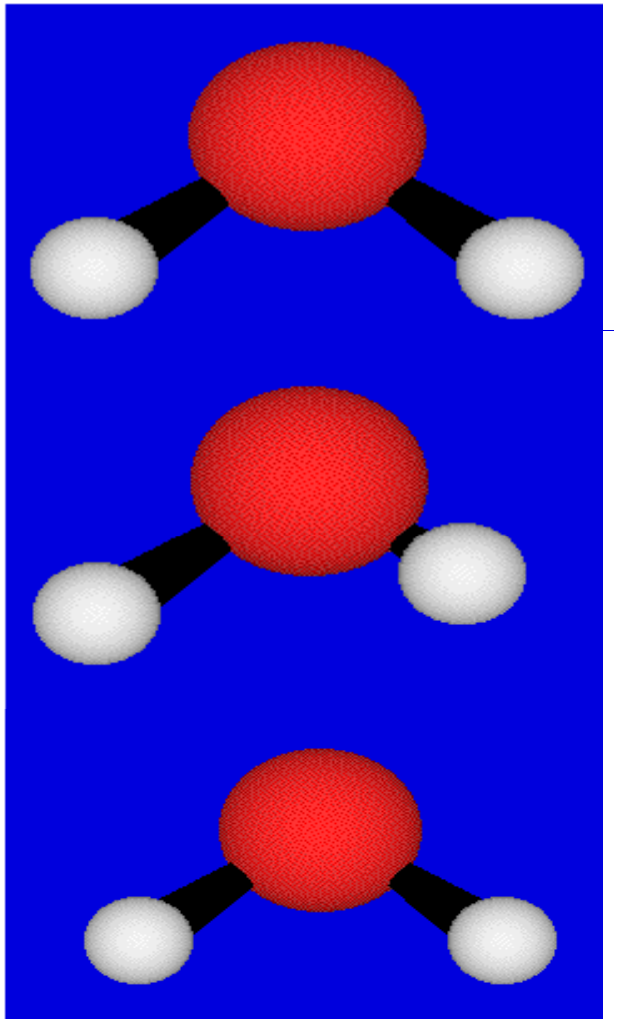
How we can measure properties of soil by shining a light on it?

Soils: Complex collection of chemical bonds

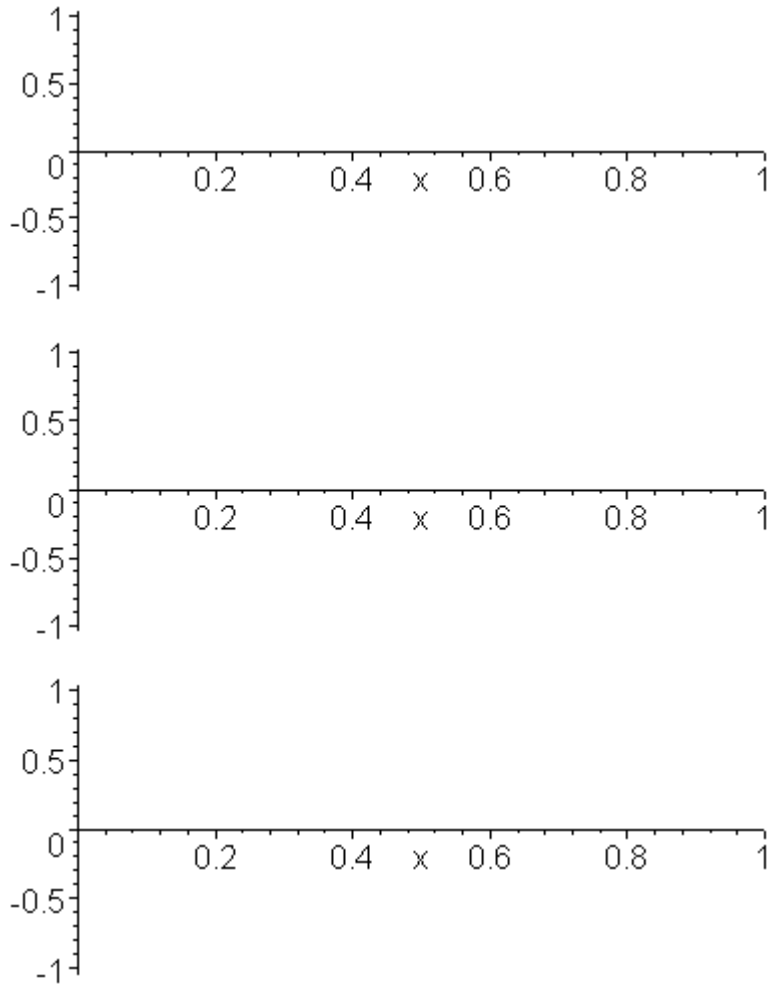
Infrared Spectroscopy



Oscillation Modes for Water



Harmonics of oscillation modes



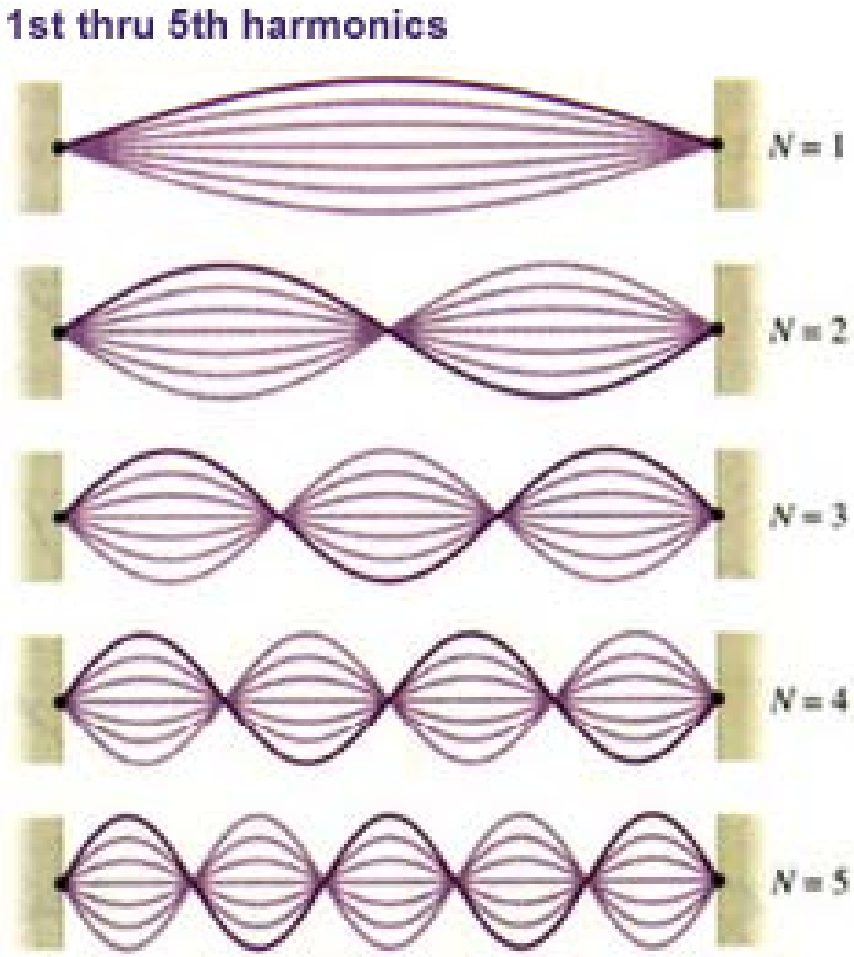
Fundamental mode

Second harmonic mode

Third harmonic mode

Observation of chemical bonds can also be made by way of harmonic frequencies

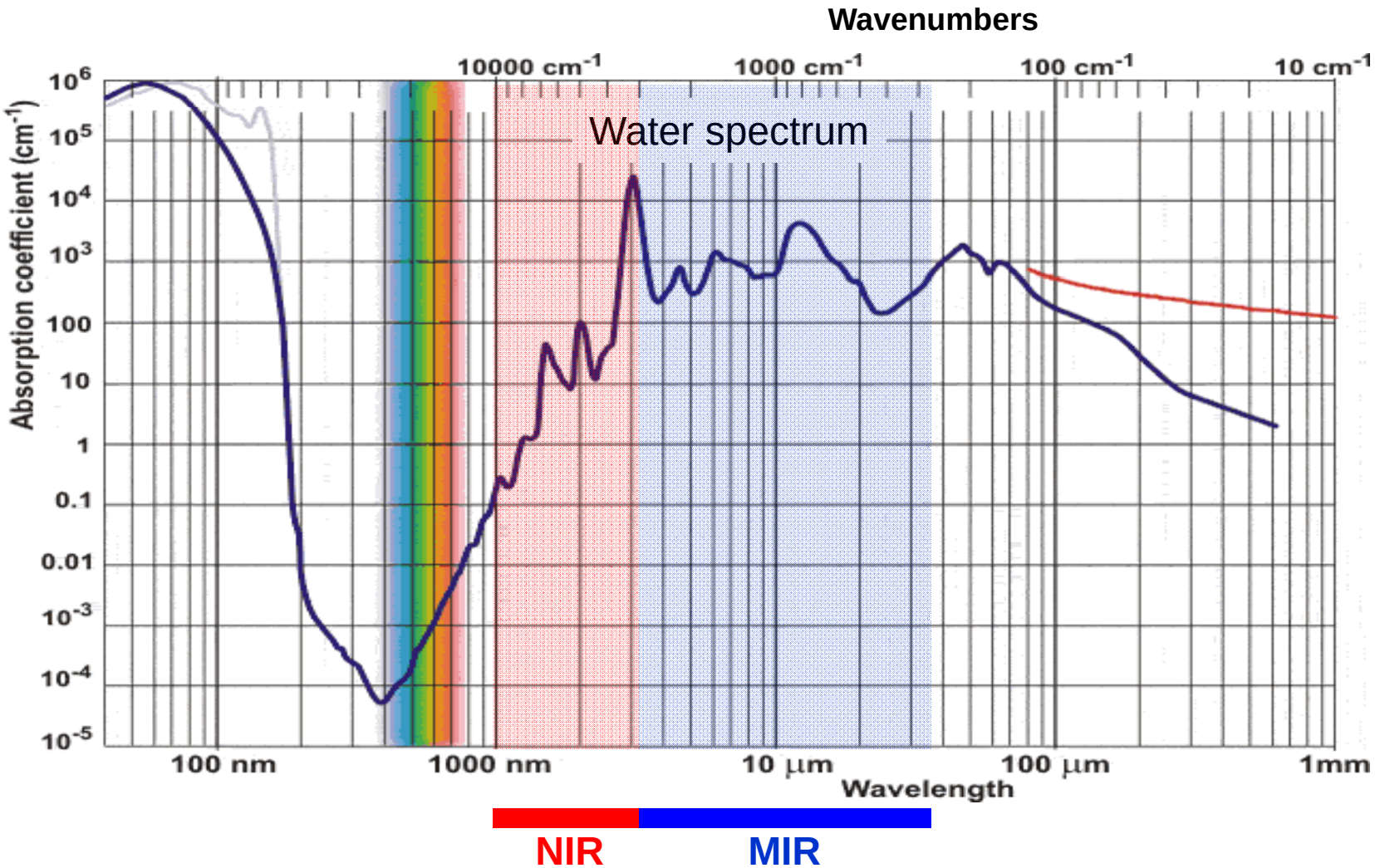
Spectral Regions



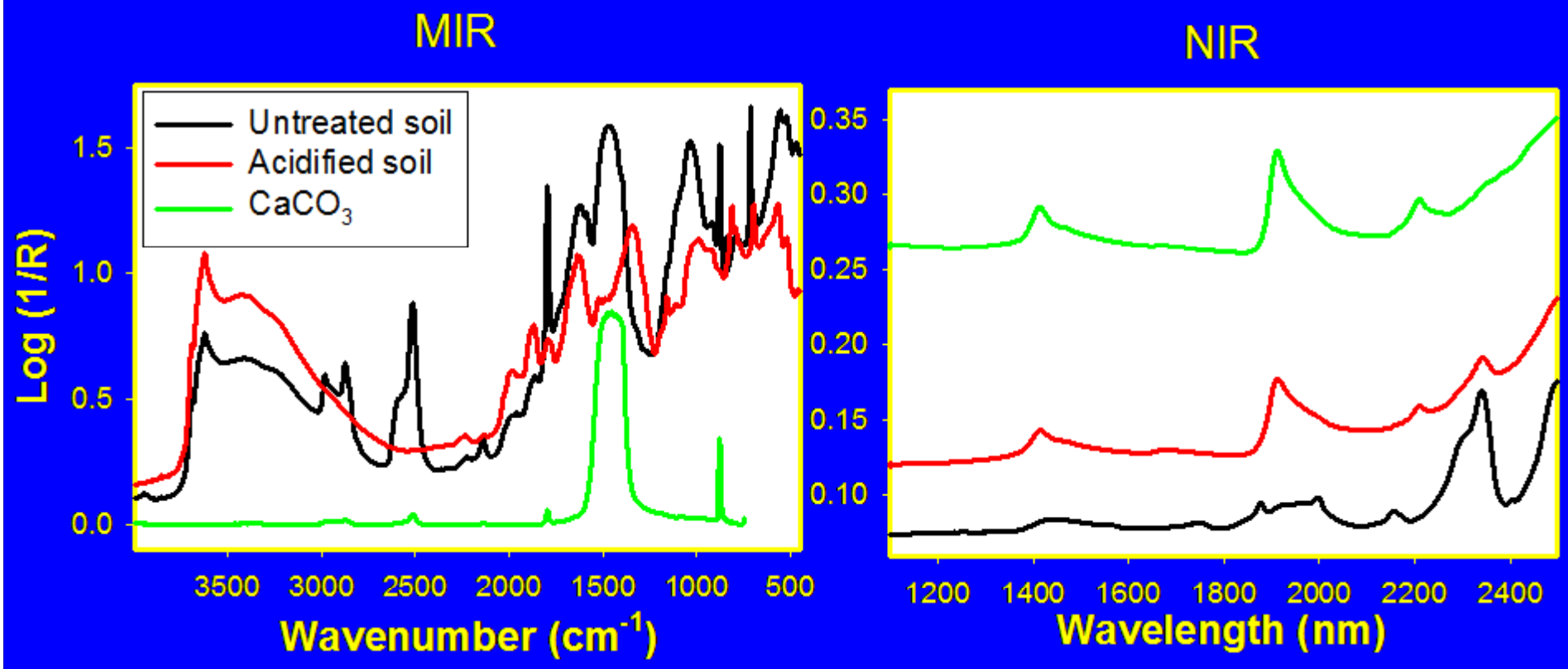
Mid Infrared

Near Infrared

Regions of the Infrared



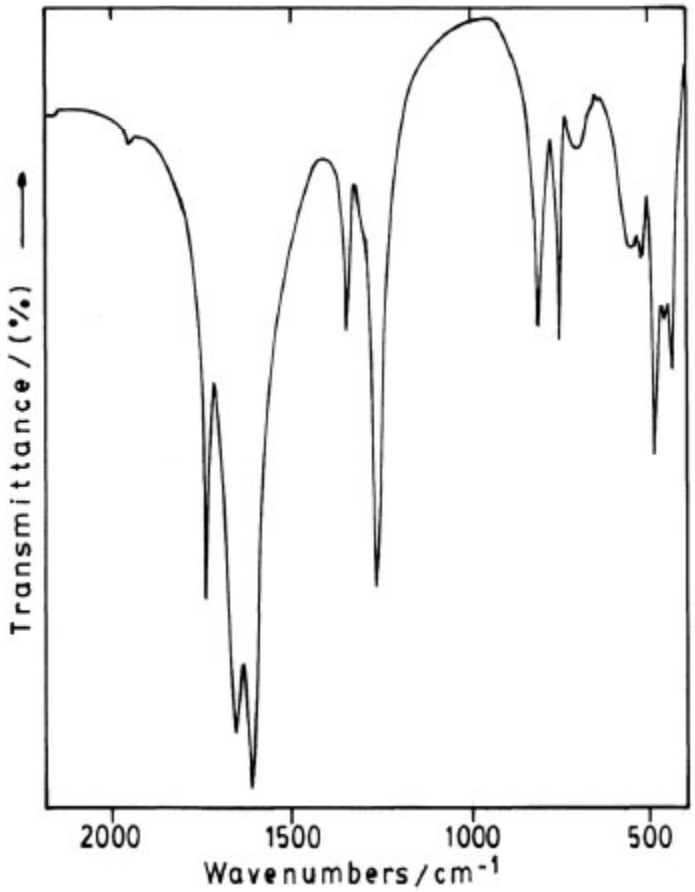
Mid Infrared *vs.* Near Infrared



(2500 to 25,000 nm)

How do we extract information from complex spectra?

Defined spectra

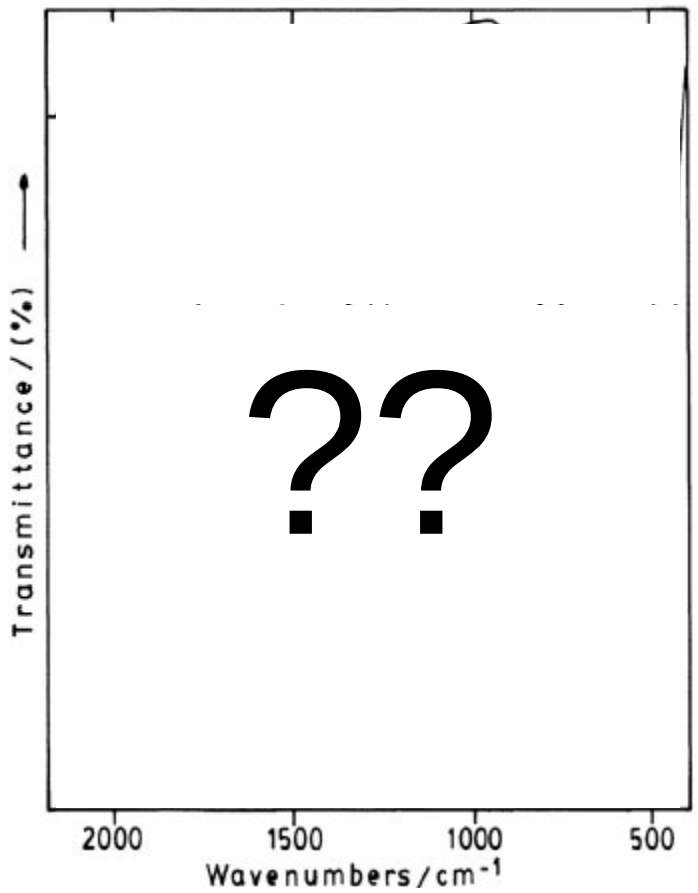


IR spectra for iron oxalate
($Fe_2(C_2O_4)_3 \bullet 4H_2O$)

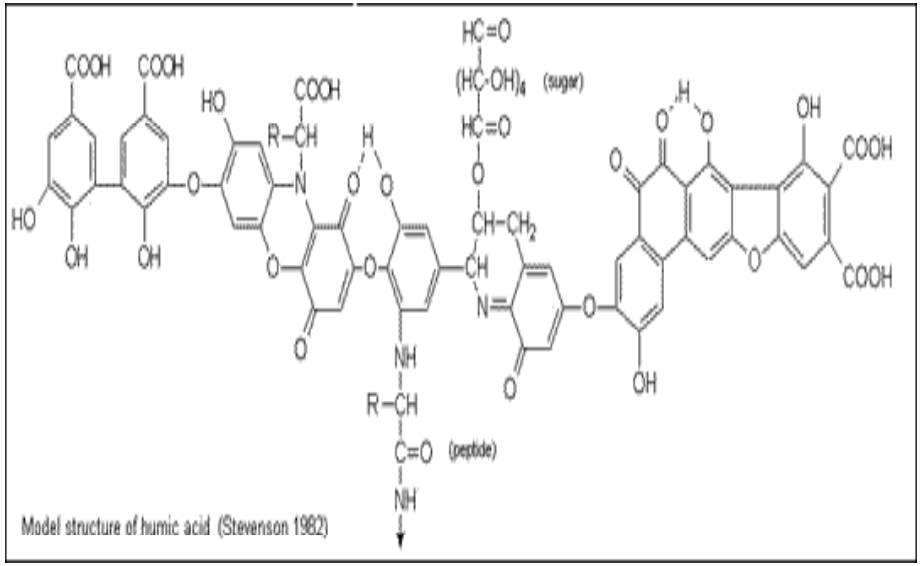
Endmember analysis

- The sample is comprised of spectrally pure elements
- The resulting spectra is a linear combination of spectral elements
- Deconvolve the spectra into endmembers and quantify
- Works well for well defined constituents but what about something like soil organic carbon?

No defined IR spectra



Soil organic matter

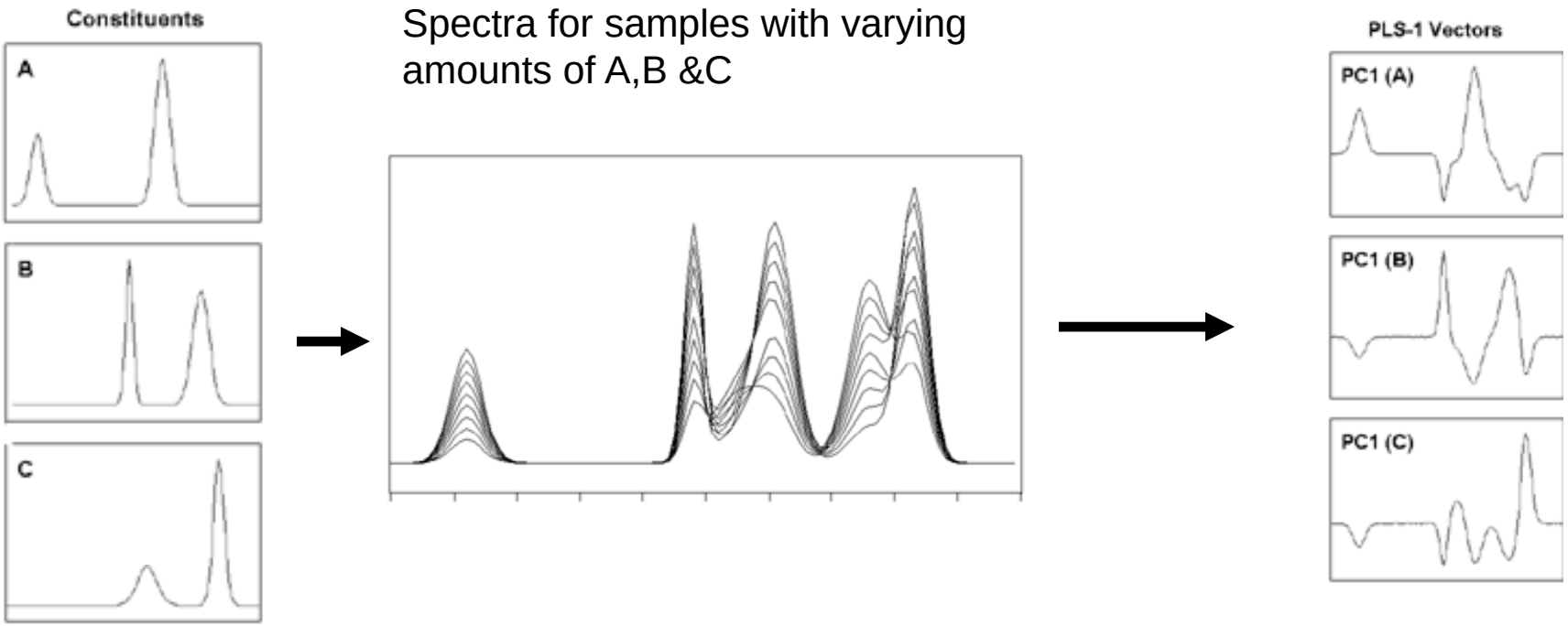


Complex and varied structures of soil organic matter

Chemometrics

- Extracting information from chemical systems by data-mining spectra
- Uses multivariate statistics, applied mathematics, and computer-science tools
- Heavily used in analytical chemistry to extract quantitative data from spectra

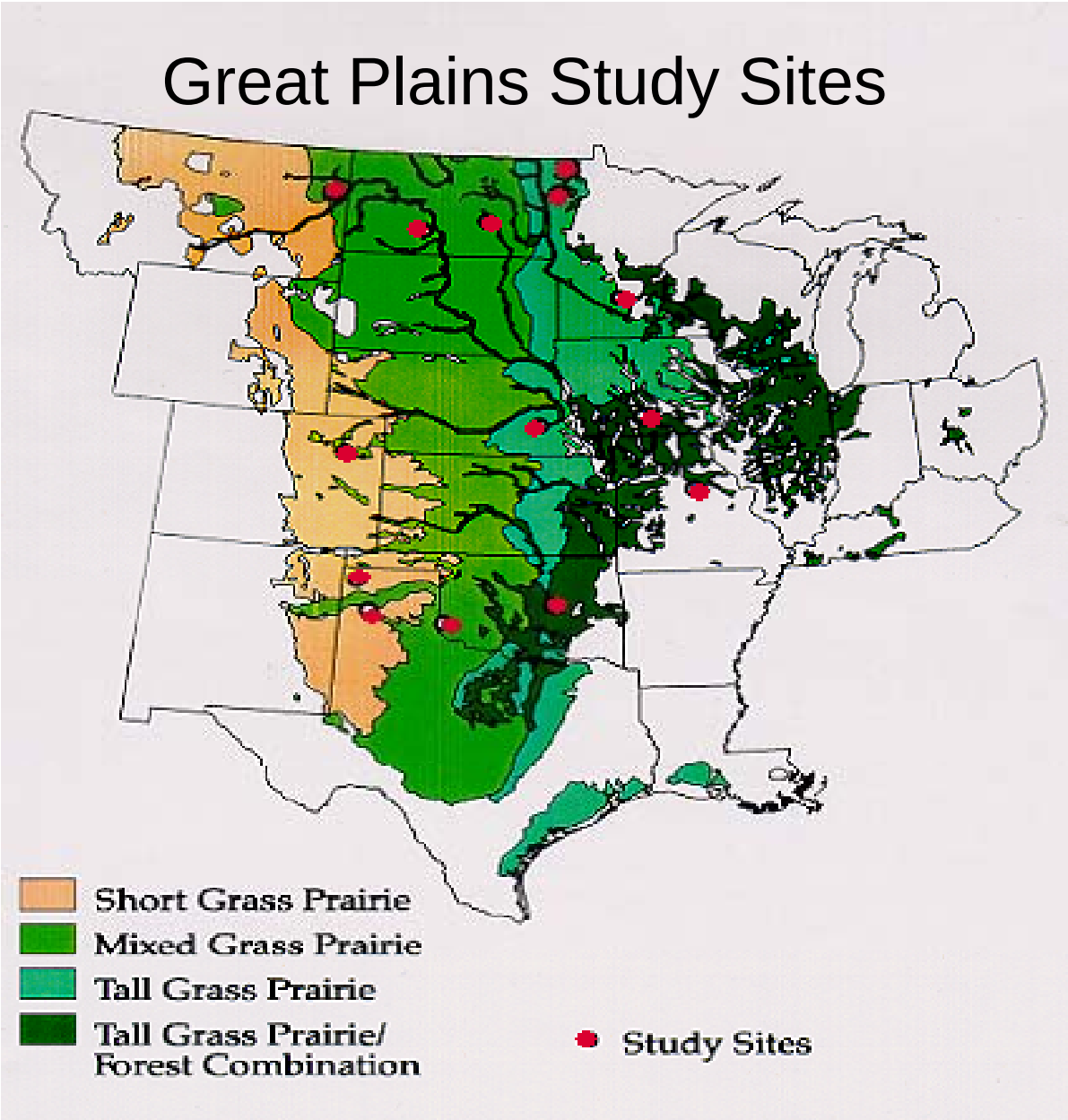
Partial Least Squares Regression



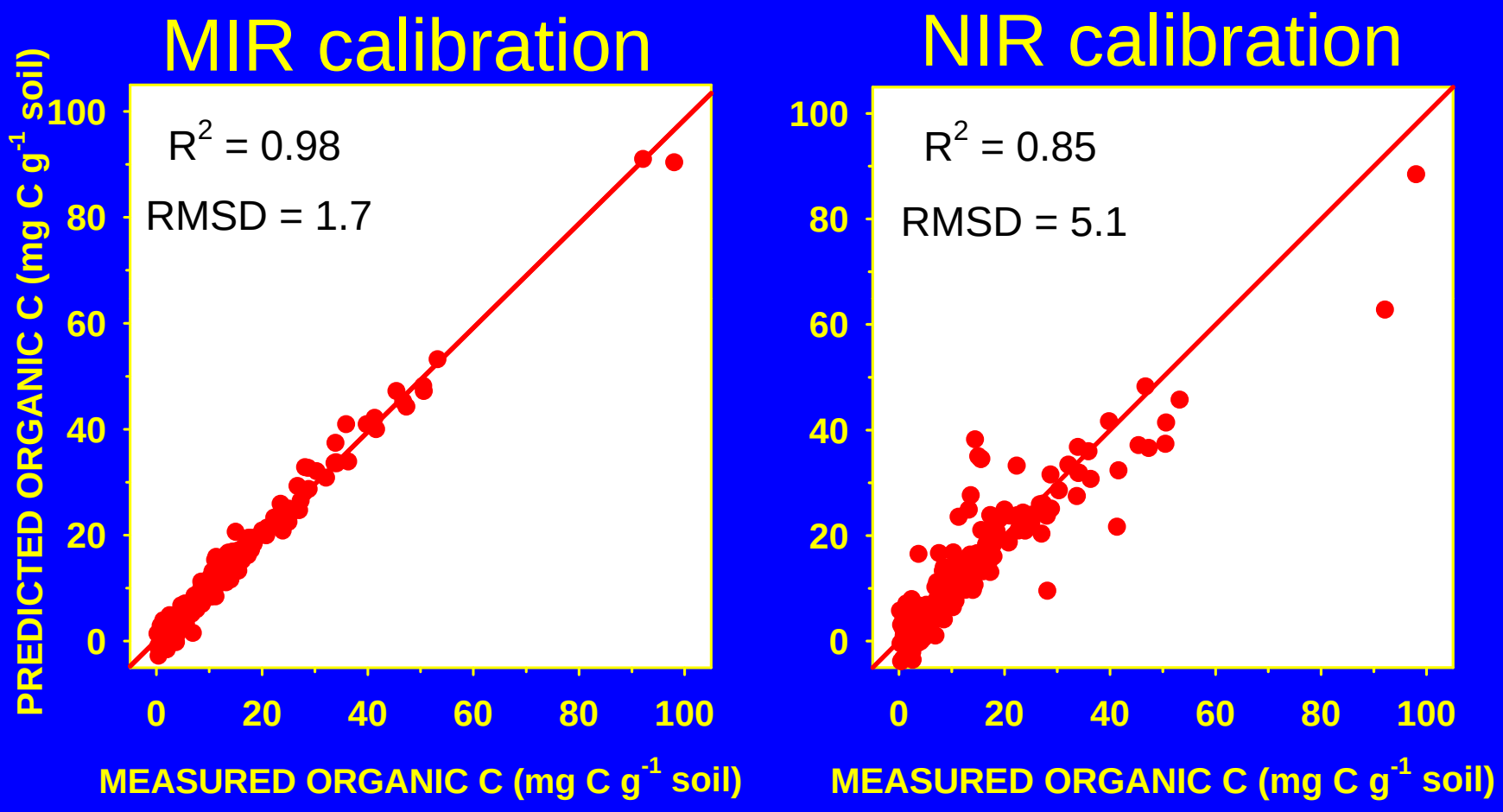
PLS derives a set of factors that are directly related to the constituents.

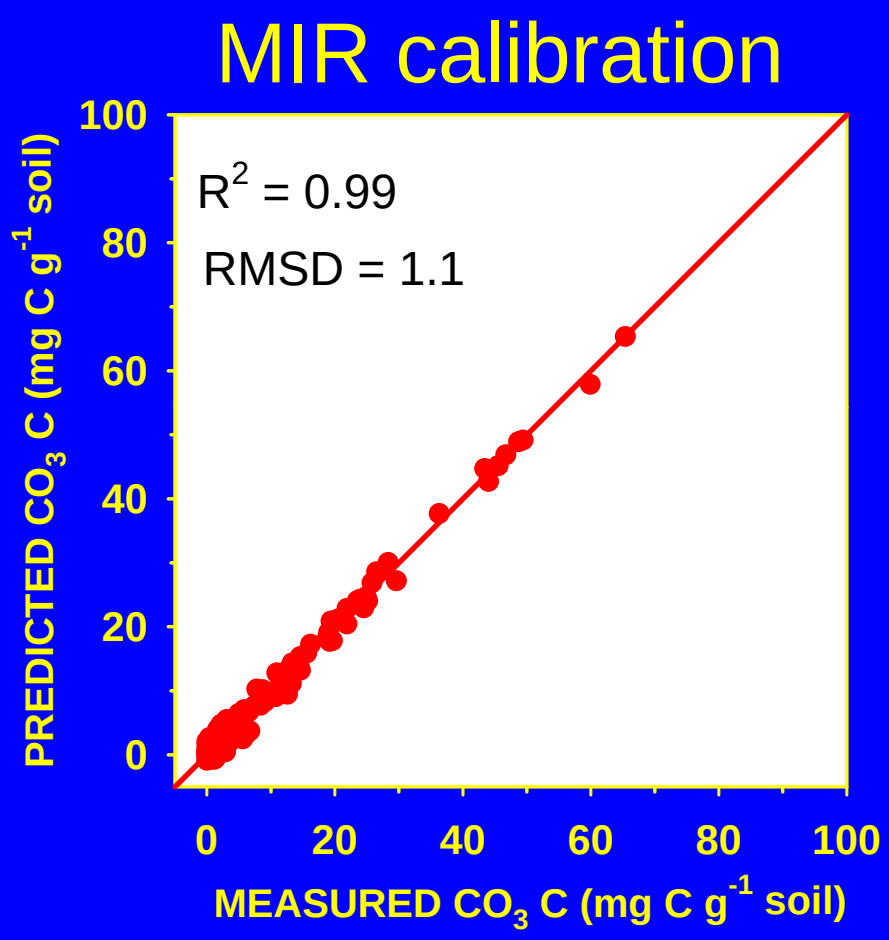
How well does it work for soil?

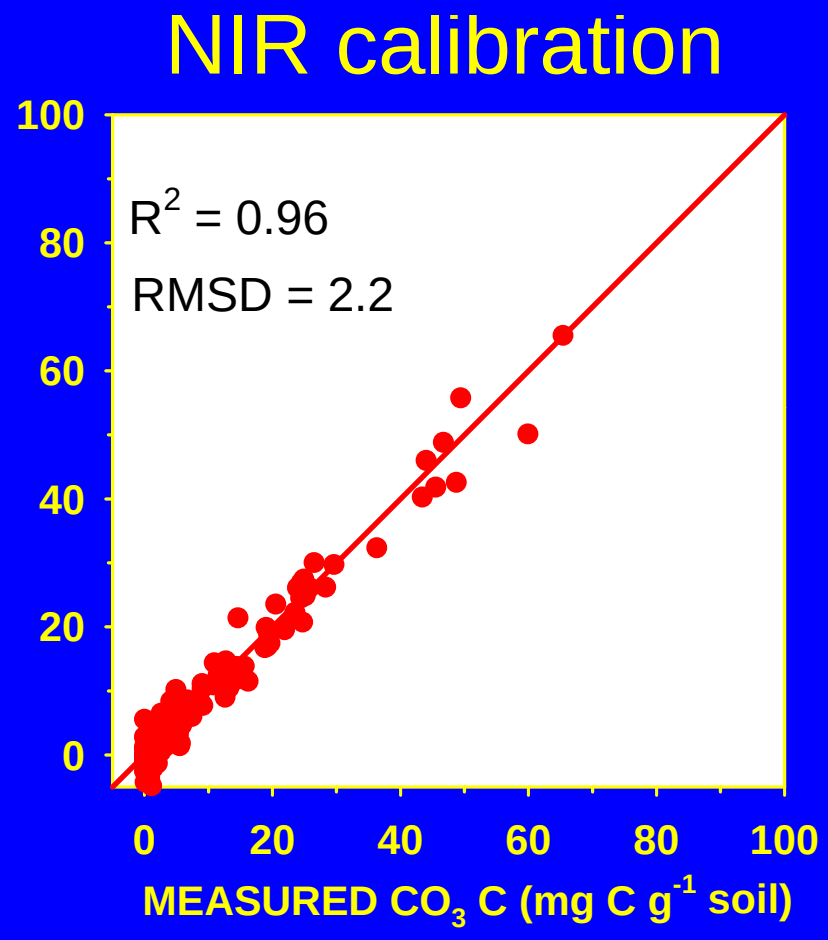
Comparing MIR and NIR



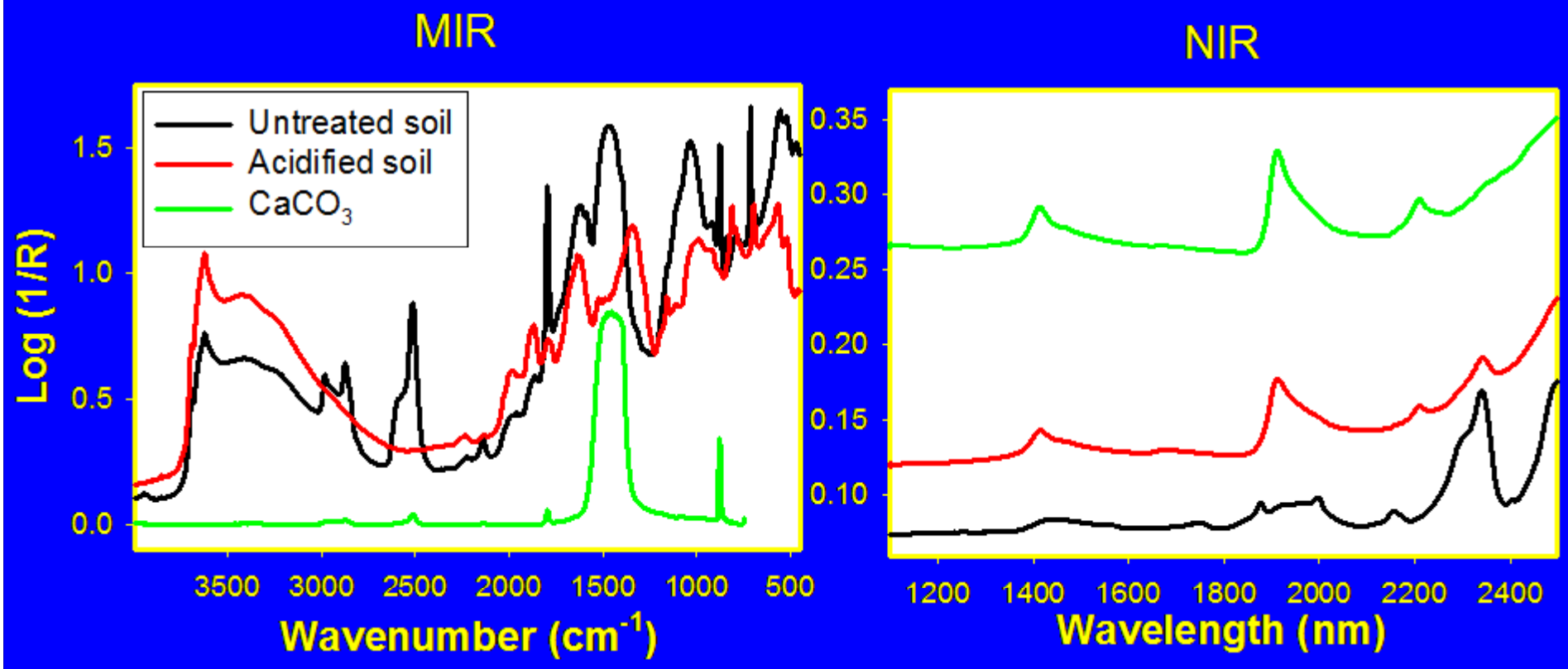
Laboratory Based Measurements


MIR calibration
R^2 = 0.98
RMSD = 1.7
PREDICTED ORGANIC C (mg C g^{-1} soil)
MEASURED ORGANIC C (mg C g^{-1} soil)
0
20
40
60
80
100
NIR calibration
R^2 = 0.85
RMSD = 5.1
MEASURED ORGANIC C (mg C g^{-1} soil)


MIR calibration
R^2 = 0.99
RMSD = 1.1
PREDICTED CO_3 C (mg C g^{-1} soil)
MEASURED CO_3 C (mg C g^{-1} soil)
0
20
40
60
80
100

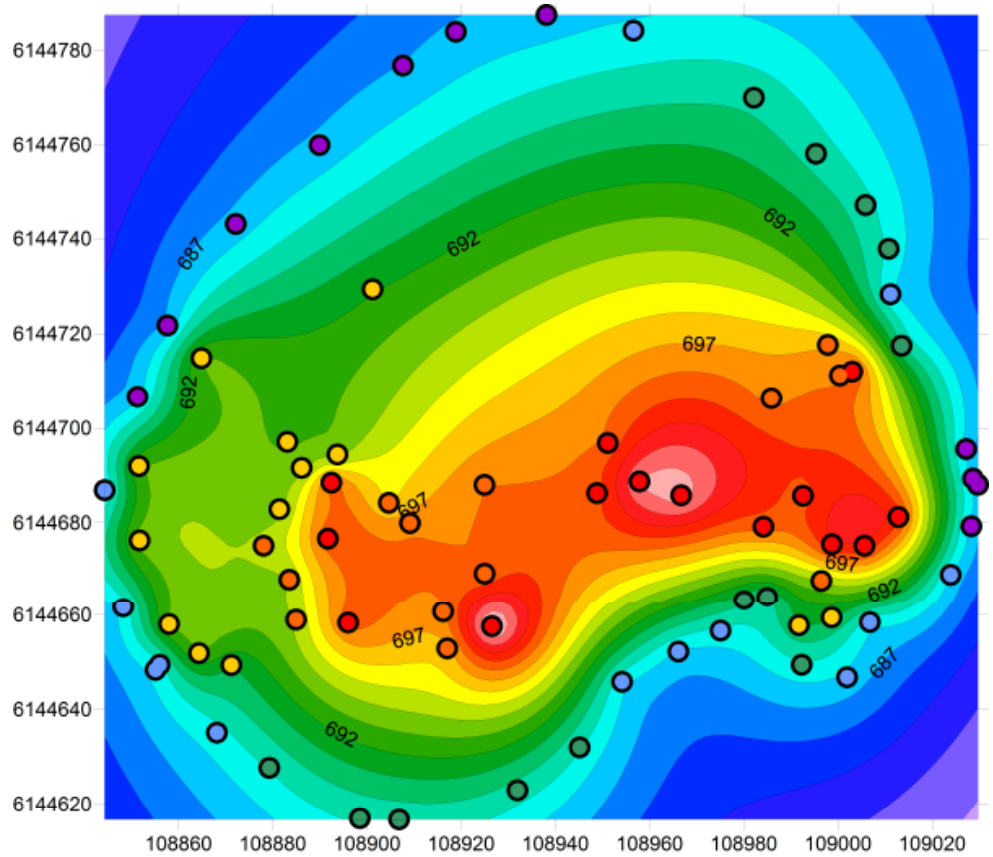

NIR calibration
R^2 = 0.96
RMSD = 2.2
MEASURED CO_3 C (mg C g^{-1} soil)
0
20
40
60
80
100

Mid Infrared *vs.* Near Infrared



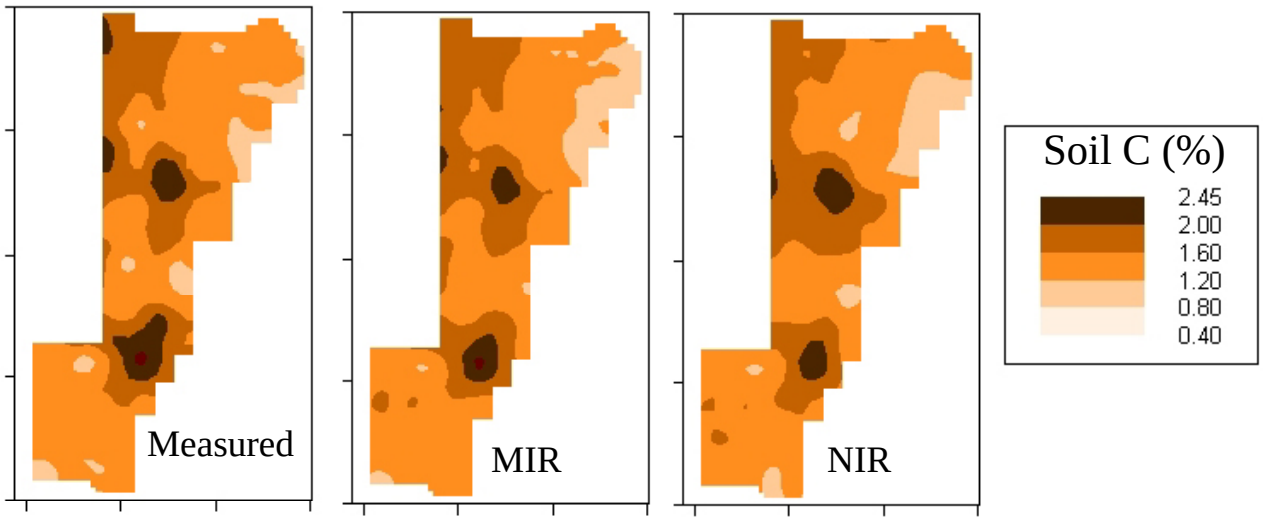
(2500 to 25,000 nm)

Creating Maps by using Geostatistics

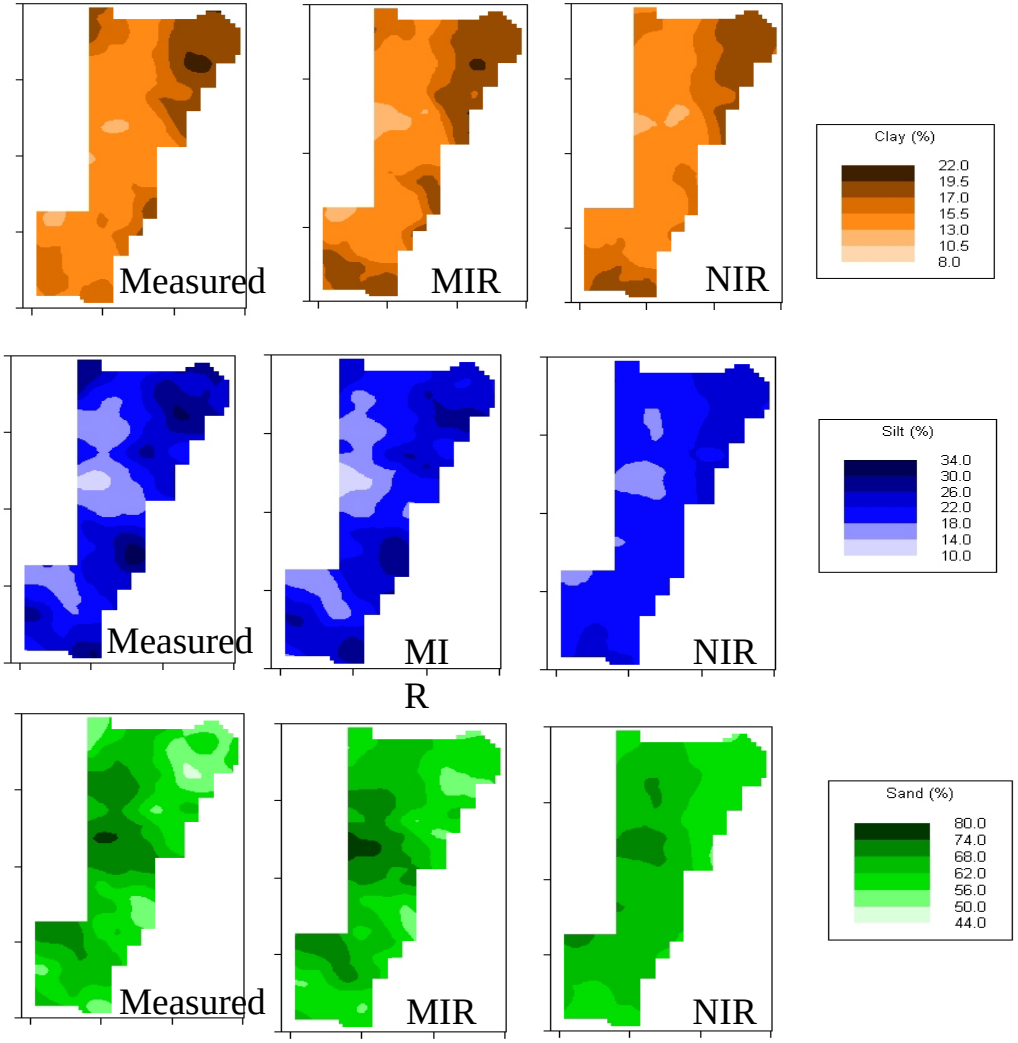


Kriging creates estimates of the property between sampling points based on geostatistical properties

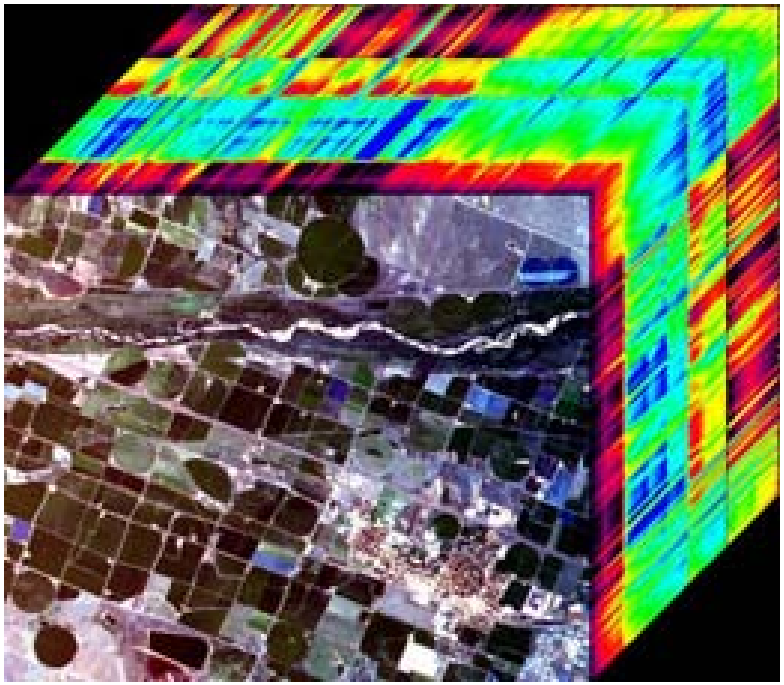
Soil organic carbon



Soil Texture



Study objective: Determine ability to generate soil C maps based on airborne hyperspectral images



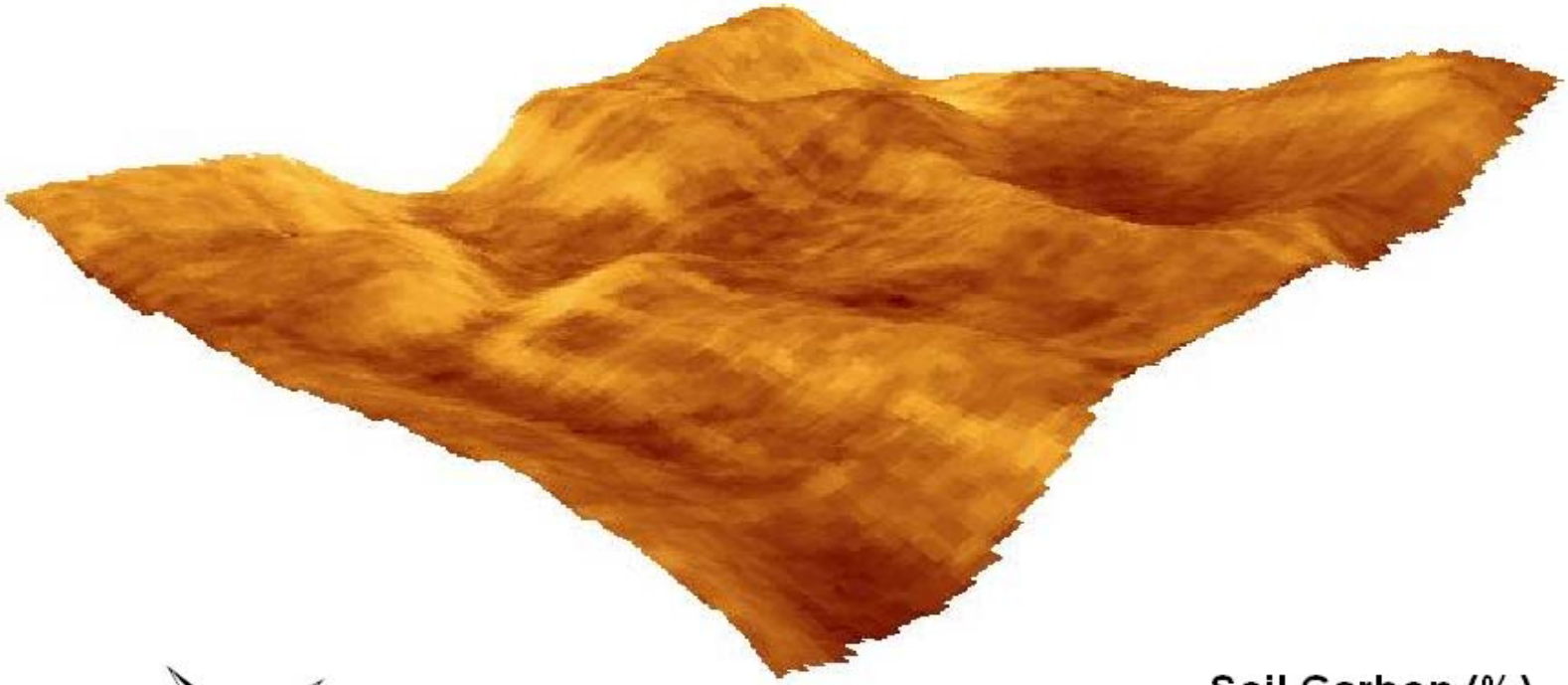
Hyperspectral data cube

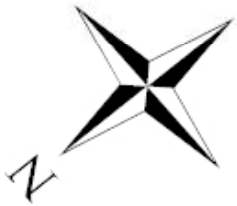
178 Spectral bands between 400 and 2450 nm

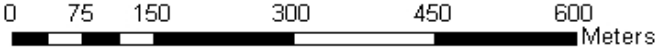
2.5 m pixels

Soil Carbon Map

15x Exaggerated Elevation







Soil Carbon (%)