Visible-Near Infrared Spectroscopy for Soil Property Measurement

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Great Demand for Soil Property Data

That is the data I need but

What is the mean, variance, confidence limits

How do we satisfy the needs?
More Samples and Measurements

- Equipment
- Time
- Money

Time may be greatest limitation

Are there alternatives?
Visible Near Infrared Spectroscopy

Rapid technique to evaluate certain soil properties

Applications in field? and/or laboratory
VNIR and Light Interaction with Matter

- Specular Reflectance
- Diffuse Reflectance
- Absorption
- Transmission
- Diffuse Transmission (Forward Scatter)

Fiber Optic
Spectral Radiometer
Soil
Visible Near Infrared Spectroscopy

Atomic Bond Energy

Vibration
Bending
Rotation
Visible Near InfraRed Spectroscopy

- Amount of interaction with a specific component is proportional to quantity of the component
- Soil minerals
  - Si-O bonds
  - Al-O bonds
  - Bond energy varies with mineralogy
- Organic matter
  - C-O bonds
  - C-H bonds
  - Color
Reflectance Spectra of Clay Minerals

VNIR Spectra for Three Horizons

- A
- Btg
- 2Btg

Wavelength (nm)

Reflectance

250 500 750 1000 1250 1500 1750 2000 2250 2500
Quantitative Soil Analysis with VNIR

- Quantity of property predicted from calibration models developed from VNIR spectra and laboratory measurements
  - Hyper-variate analysis
  - Various statistical methods used

- Large spectral library needed

- Global models?

- Family of models
  - Parent material
  - MLRA or other regional stratification
  - Taxonomy
Soil Properties Predicted with VNIR

- Sand, silt, clay
- Organic C, organic matter, total C
- C:N ratio
- Biomass
- Exchangeable Ca, Mg, K
- Fe
- P
- pH
- Water content
- Electrical conductivity
Benefits of VNIR for Soil Analysis

- Low per-sample cost
- High throughput: hundreds, even thousands of samples per day with automation
- Little or no sample preparation (analysis of field moist soils is possible?)
- Possible to perform the analysis in the field
- Single spectrum to predict quantity of multiple soil properties
MLRA 113 – The Central Claypan Regions
Missouri Claypan Landscapes
Clay Content

Calibration Test Data

Estimated Clay (%) vs. Measured Clay (%)

 Calibration

- Estimated Clay (%)
- Measured Clay (%)

Test Data

- Estimated Clay (%)
- Measured Clay (%)
Organic Carbon

Calibration Test Data

Estimated OC (%) vs. Measured OC (β)

Calibration

y = 1.043x + 0.005341
R² = 0.9453

Test Data

y = 1.193e-008x - 1.193e-008
R² = 0.9616
Cation Exchange (NH₄OAc)

Calibration Test Data

Calibration

Test Data
Exchangeable Calcium

Calibration Test Data

Estimated Ca (meq 100g⁻¹) vs. Measured Ca (meq 100g⁻¹)

- Calibration: y = 1x + 1.25e-006, R² = 0.8152
- Test Data: y = 0.9938x - 0.2978, R² = 0.785

Estimated Ca (meq 100g⁻¹)
pH

R$^2 = 0.74$
PLSR R$^2 = 0.66$
RMSE = 0.4
RPD = 1.6
EC$_{1:1}$

R$^2 = 0.65$
PLSR R$^2 = 0.36$
RMSE = 64.9
RPD = 1.2
VNIR and NRCS SSL

► 5-6,000 samples analyzed each year
  ▪ Pedons from across the U.S. and a few from other countries
► Plan is to collect spectra for each sample
  ▪ Moist and dry
  ▪ Is field use viable?
► Spectral library will be available to the public
  ▪ Probably will need an application to be interested
VNIR and NRCS SSL

► Is accuracy good enough?
  ▪ Depends on the question

► Analysis of a single pedon
  ▪ Not a good technique

► Analysis of multiple sites of same soil to estimate mean and data confidence
  ▪ May be good enough

► VNIR not to replace standard analytical methods
  ▪ Good to increase replicates
VNIR Summary

- Viable method for evaluation of soil properties
- Data are spectra
  - Property values depend on calibration model
- Not a replacement for standard methods
  - Lower precision
- Rapid data collection allows greater replication
- Does the property fit the analytical theory?
Rapid Soil Carbon Assessment of the U.S. for Conservation Planning and Model Validation
Objectives

► Evaluate US soil carbon stocks as effected by
  - land cover
  - agricultural management
  - ecosystem state

► Inventory soil carbon stocks for U.S.
2 Phase Program

1. National soil carbon inventory developed from SSURGO
   - Tabular
   - Spatial (map)
   - Validation against existing NSSC pedon data

2. Collection of soil carbon and other data for evaluation of carbon stocks for Benchmark and other important soils
   - replicate sites stratified within soil group by steady-state agricultural management, land cover, and ecosystem state
Phase 1

National Soil Carbon Inventory
Developed from SSURGO

Short-term Product
STATSGO SOC Estimates
1:250,000 scale; published in 2001
SSURGO SC Estimates to 1 m

- National soil carbon inventory
  - Organic
  - Inorganic (CaCO$_3$)
- Adjust C for map unit from land cover data
  - SSURGO – low, representative value (RV), high
  - RV value for “dominant” land use for map unit
  - Adjust carbon stocks based on land cover
SSURGO SC Estimates to 1 m
Validation

- NCSS pedon data
  - 27,000+ pedons with measured soil carbon and other data for carbon stock calculations
  - Additional data being incorporated from university laboratories
  - Stratified by land cover to enhance accuracy for validation

- Overlay appropriate pedons on SSURGO map units to compare point measurements to aggregated data
NSSC Pedons
Phase 2

Collection of soil carbon and other data for evaluation of carbon stocks for benchmark and other important soils
Nationwide Effort

► All land uses and ecosystems
  • Cropland
    ▶ Tillage systems
  • Pasture
  • Range
  • Forest
  • Wetlands
  • Floodplains
Sites – 1st stratification = soil

- Benchmark and other important soils
  - Grouping of similar soils based on properties that influence carbon dynamics
    - Texture, drainage, mineralogy, etc.

- Additional groups to ensure all important ecosystems are included and to maximize spatial coverage
Stratification within Soil Groups

- Land use/management/ecosystems expected to have similar influence on carbon dynamics
  - Steady state conditions
    - End result not rate
- Evaluate dominant, “optimum”, and “worst case” conditions
  - “Minor” permutations not addressed
Replication for Statistical Confidence

- NCSS pedon data suggests need about 25 replicates (sample points) per soil-ecosystem combination for 80% confidence in mean
- Clustered sample design
- More replicates for extensive soil groups

A – soil/management A
B – soil/management B
X – sample point

MLRA XX

50 km

20 m
Total Sample Points

- 7,000 sites
- 35,000 sample points
- 1,440 soil-ecosystem combinations
- **Goal:** Minimal number of soil-ecosystem combinations to represent range of conditions
- 2 year project
- Better than 6 months
Sites

- Randomized NRI points within appropriate map units
  - Soil group confirmed on site
  - Steady-state ecological state/management system confirmed
- ARS and university research sites
- Existing pedon data (NCSS database)
- May also be used for ESD state and transition model data collection
  - Vegetation
  - Dynamic soil properties
Data Collection

- By horizon to 1 m
  - 0-5 cm depth separated
- Landscape properties
- Soil morphology
  - Series identification
- Total and inorganic C
  - VNIR Spectroscopy
  - Field and office lab
- Bulk density
  - Core, clod, model
- Rock fragments
Who will Do the Work?

► NRCS Soil Scientists
  - 18 MLRA Regions (MO offices)
    ► 1 VNIR spectrometer per MO
    ► Dedicated soil scientist
    ► Assistance from local soil scientist
    ► Consistency in methods is critical

► NSSC staff
  - VNIR model development
  - Data storage and analysis
  - Training
  - QA
Products

- Map of soil carbon stocks based on SSURGO
  - Tabular data – total US carbon stocks
  - Limited ecosystem/management effects
- Statistically valid measurement of soil carbon stocks
  - Mean and confidence limits
  - Land cover
  - Agricultural management
  - Ecosystem state