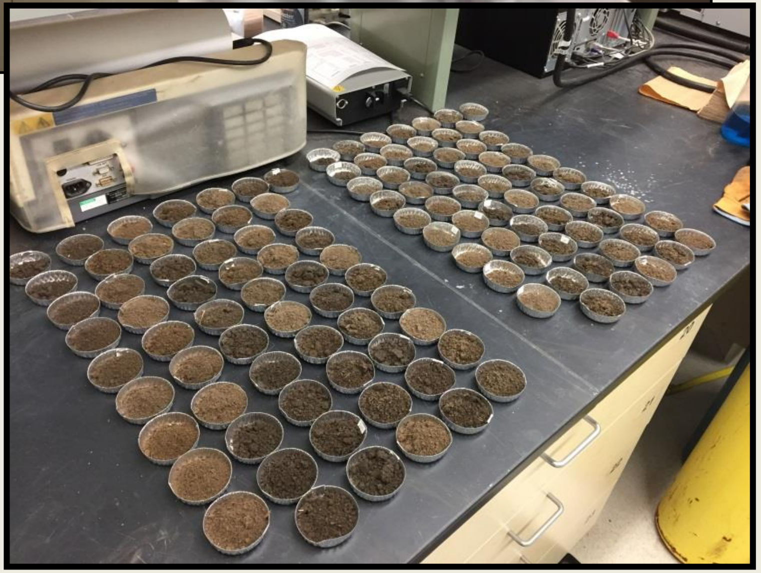
Soil Health and Soil Sensing

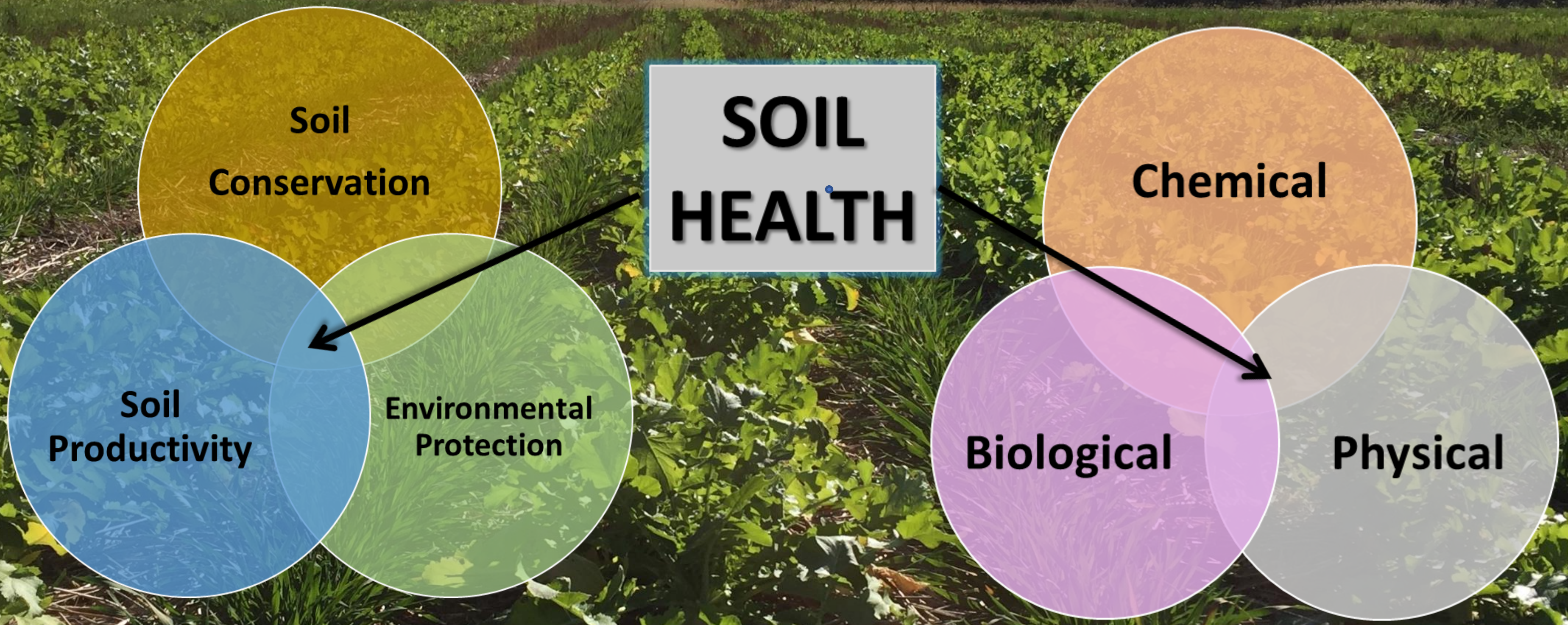
Kristen Veum, USDA-ARS, Columbia MO

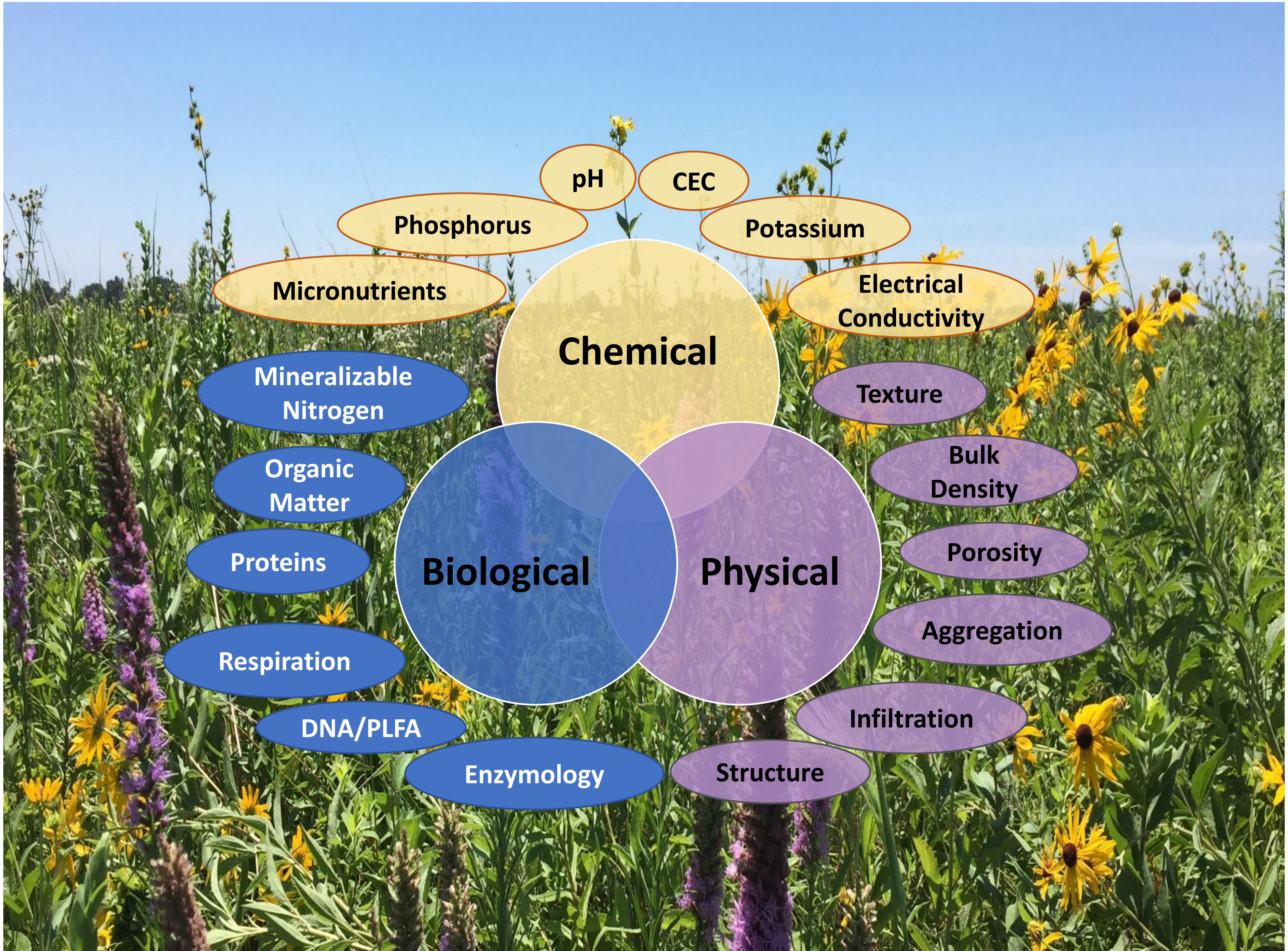
USDA

Veum
Soils Lab
USDA-ARS



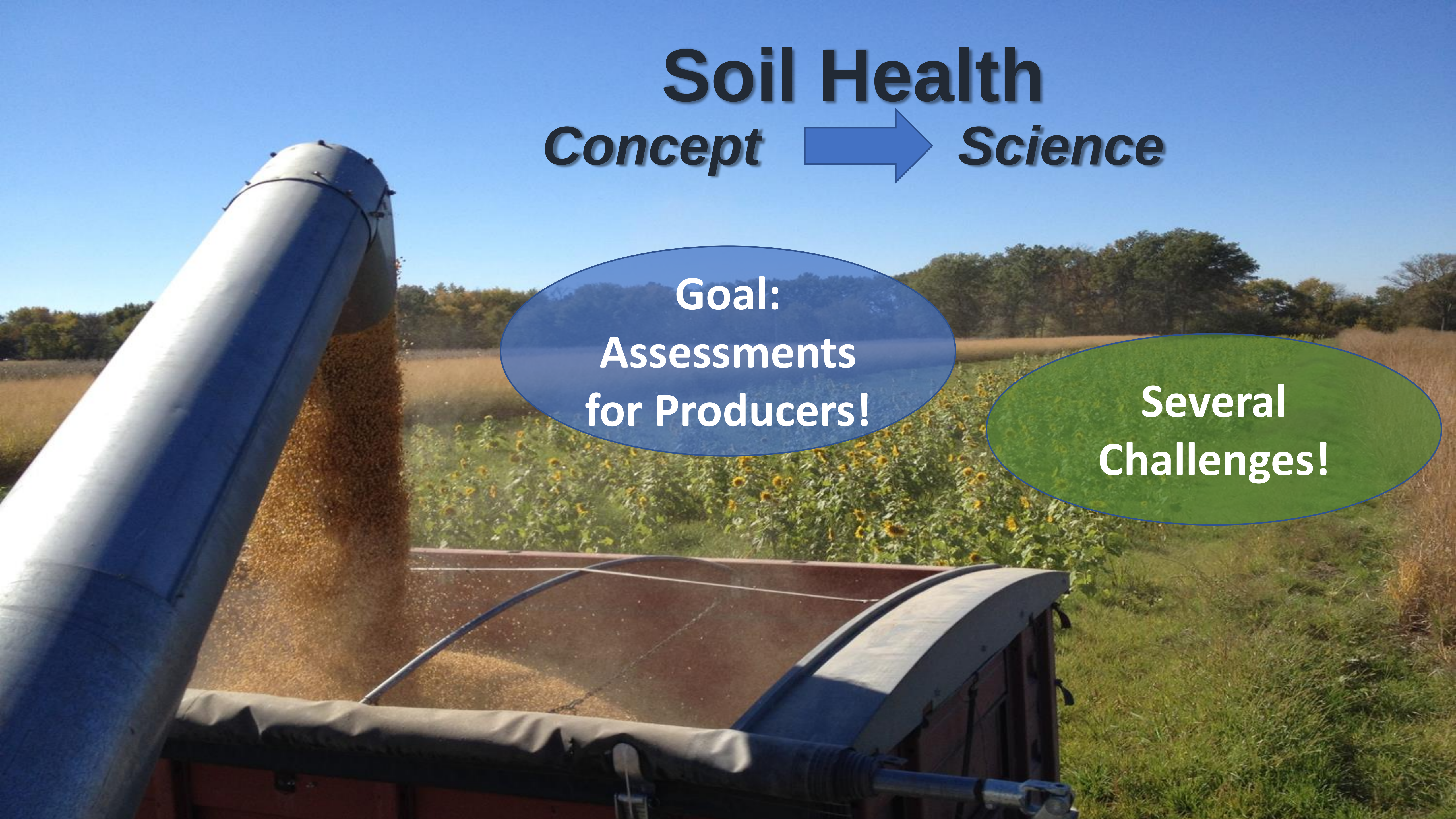
Soil Health Assessment
Concept to Science




pH
CEC
Phosphorus
Potassium
Micronutrients
Electrical Conductivity
Chemical
Mineralizable Nitrogen
Texture
Bulk Density
Organic Matter
Proteins
Biological
Physical
Porosity
Aggregation
Respiration
Infiltration
DNA/PLFA
Enzymology
Structure

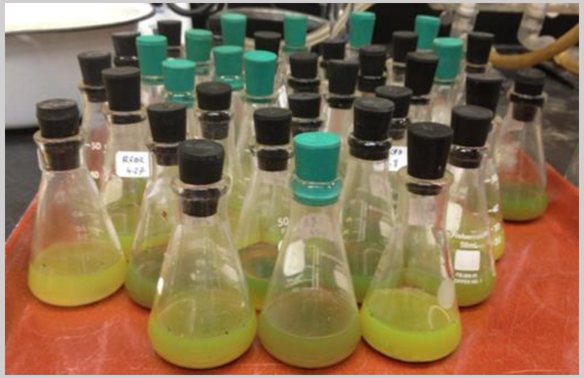
Soil Health

Concept → ***Science***



Cost of Soil Health Analyses

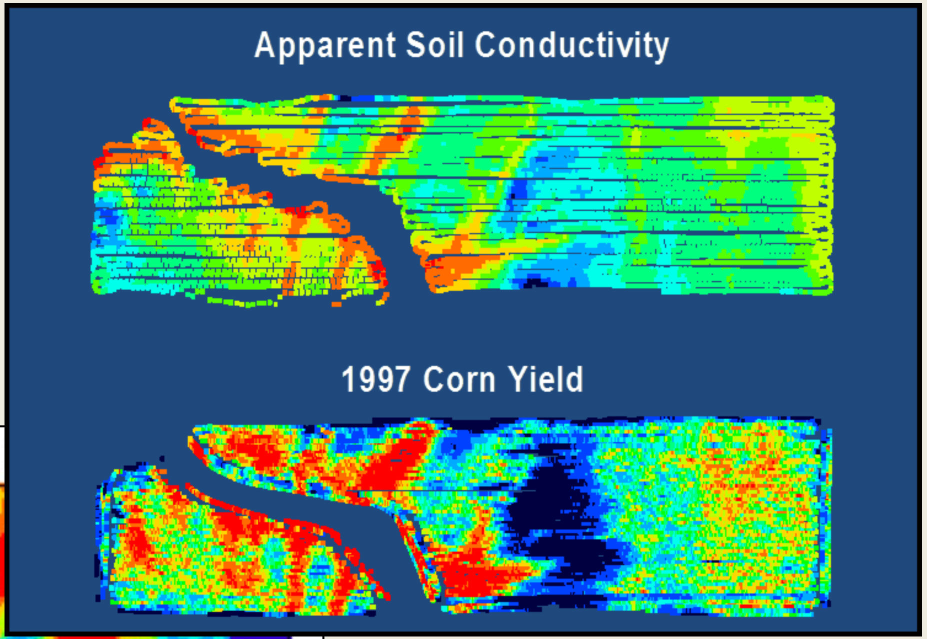
- **Chemical/Nutrient**
  - **Phosphorus $6**
  - **Potassium (CEC) $12**
  - **pH $5**
- **Physical**
  - **Aggregate stability $10**
  - **Bulk density $5**
- **Biological**
  - **Soil Respiration $4-15**
  - **Soil organic matter $6**
  - **Mineralizable nitrogen $12**
  - **Microbial biomass C $10-15**
  - **Enzyme activity $10-15**
  - **Active Carbon $10**
  - **EL-FAME $30**
  - **PLFA $25-50**
  - **DNA $50-100**



Soils vary across the field

Spatial variation

High lab costs



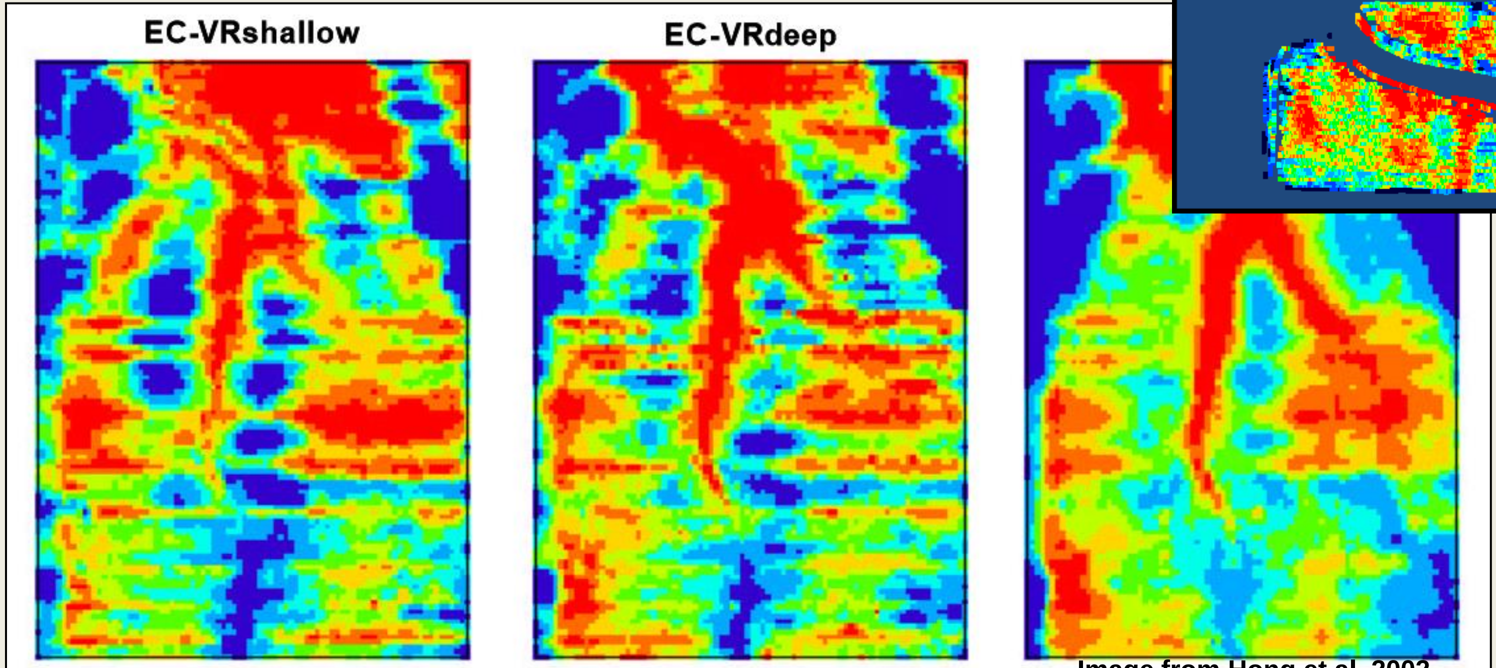


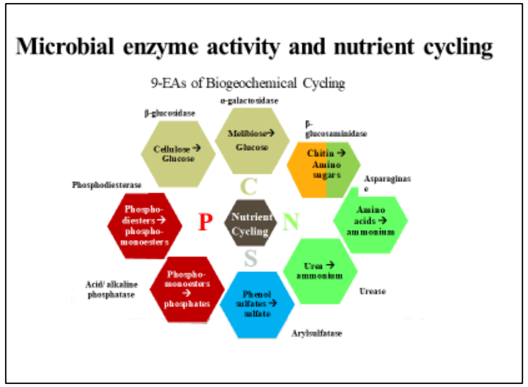
Image from Hong et al. 2002

When we combine the high cost of analysis with the need to understand spatial variability, we have a problem

How do we reduce cost?

- Laboratory
  - Combination testing
  - Cheaper supplies
  - Less supplies
  - Shorter/faster methods
  - Using smaller sample sizes/volumes
  - Less sophisticated/expensive instruments

You still have to collect a sample and send it to a lab



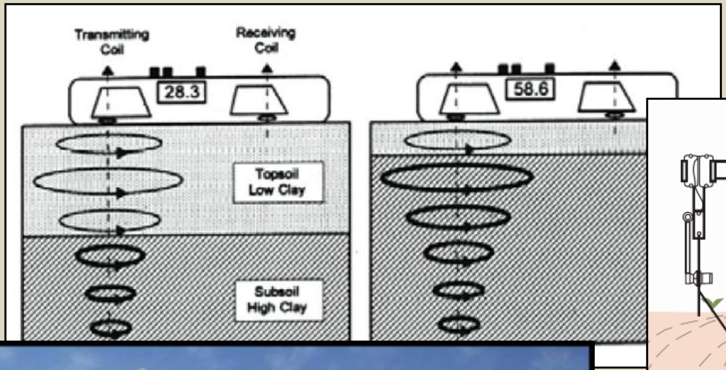
Proximal Soil Sensing
in-field "on-the-go" data collection

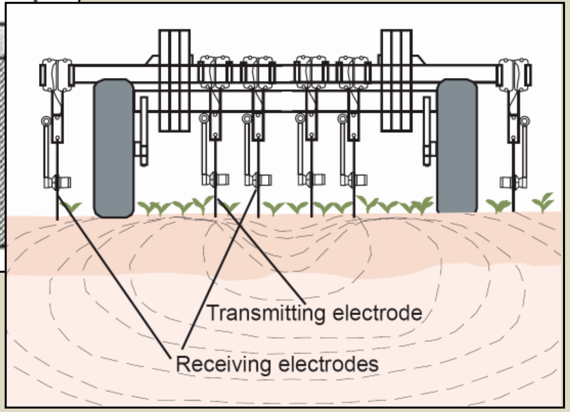
- Non-invasive, non-destructive
- Inexpensive
- High resolution (spatial/temporal)
- Low tech

Visible, near-infrared spectroscopy (VNIR)

soil biological, chemical and physical attributes:

soil organic C, soil texture, clay mineralogy, aggregate stability, pH, P, K





Electrical conductivity

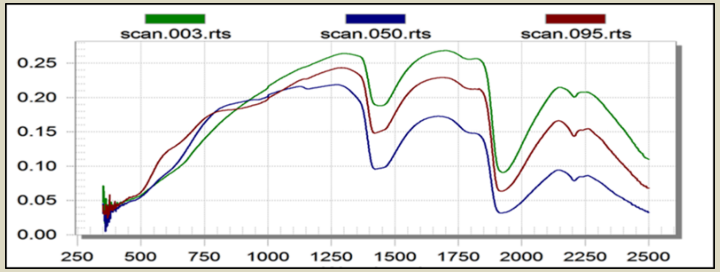
soil physical and chemical attributes:

texture, mineralogy, CEC, and moisture

Penetrometer (Cone Index)

soil physical attributes:

soil texture, bulk density, compaction



Soil Spectroscopy

Nuclear Magnetic Resonance

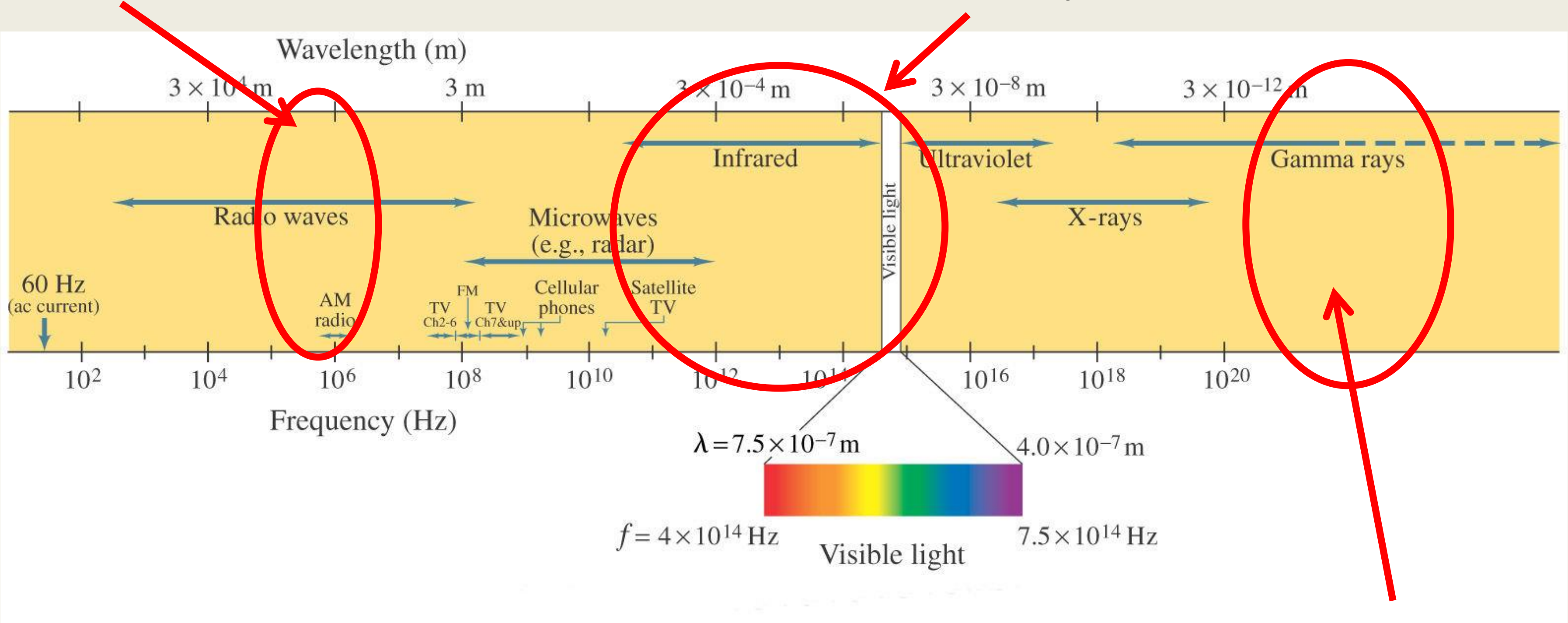
Atomic connections

Oscillation of electrons

Visible and Near-Infrared (VNIR)

Molecular Vibrations, Rotations, Transitions

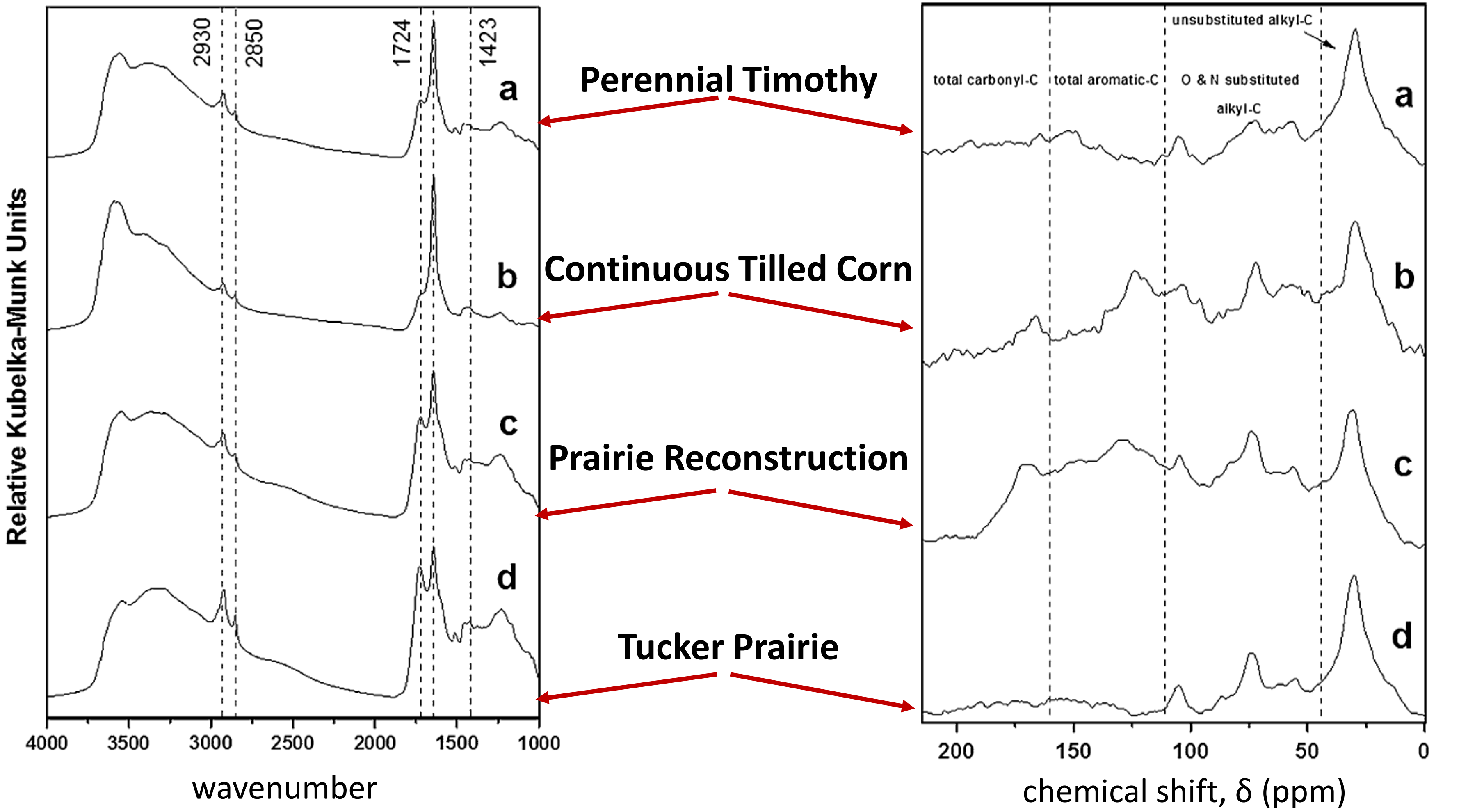
Functional Groups of Molecules



Gamma Rays

Emitted from U, Th, K

Spectral Signatures of Soil Organic Matter



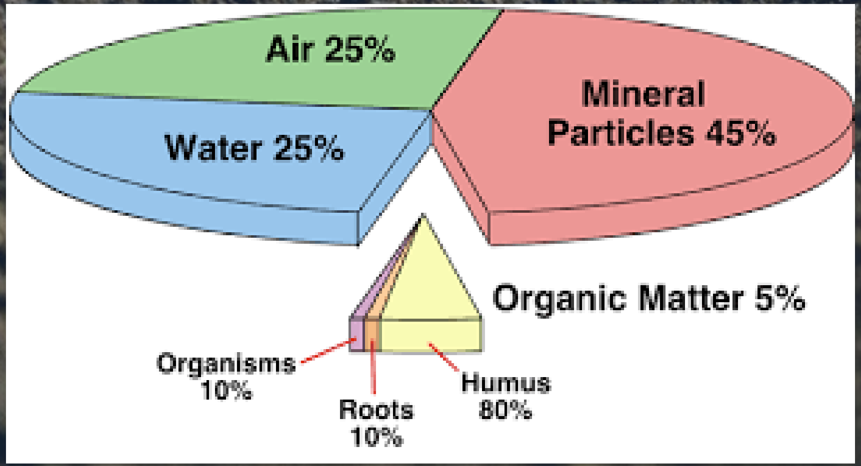
Diffuse Reflectance (DRIFT)
spectra of soil organic matter

^{13}C Nuclear Magnetic Resonance
spectra of soil organic matter

Veum, K. S., Goyne, K. W., Kremer, R. J., Miles, R. J., & Sudduth, K. A. (2014). Biological indicators of soil quality and soil organic matter characteristics in an agricultural management continuum. Biogeochemistry, 117, 81-99.

Why are soil spectra different?

- Organic matter
- Inorganic fraction / minerals
- Air and water



Challenges?

- Environmental effects: temperature, moisture → interference
- Weak signals (*e.g.*, inorganic nitrogen)

Soil electrical conductivity (EC_a) sensing

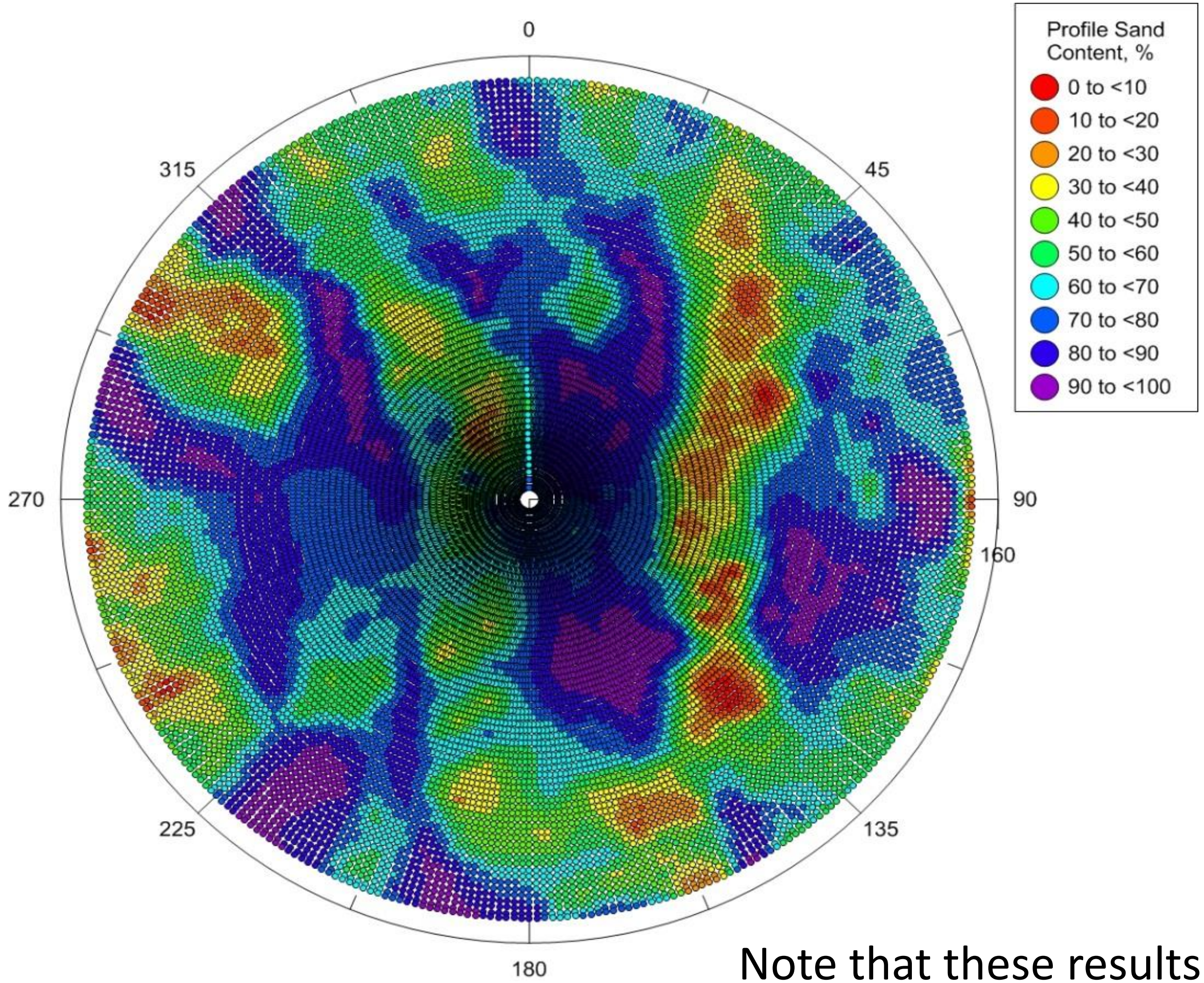
- Most widely used soil sensing technology in precision agriculture
- Several commercial sensors are available

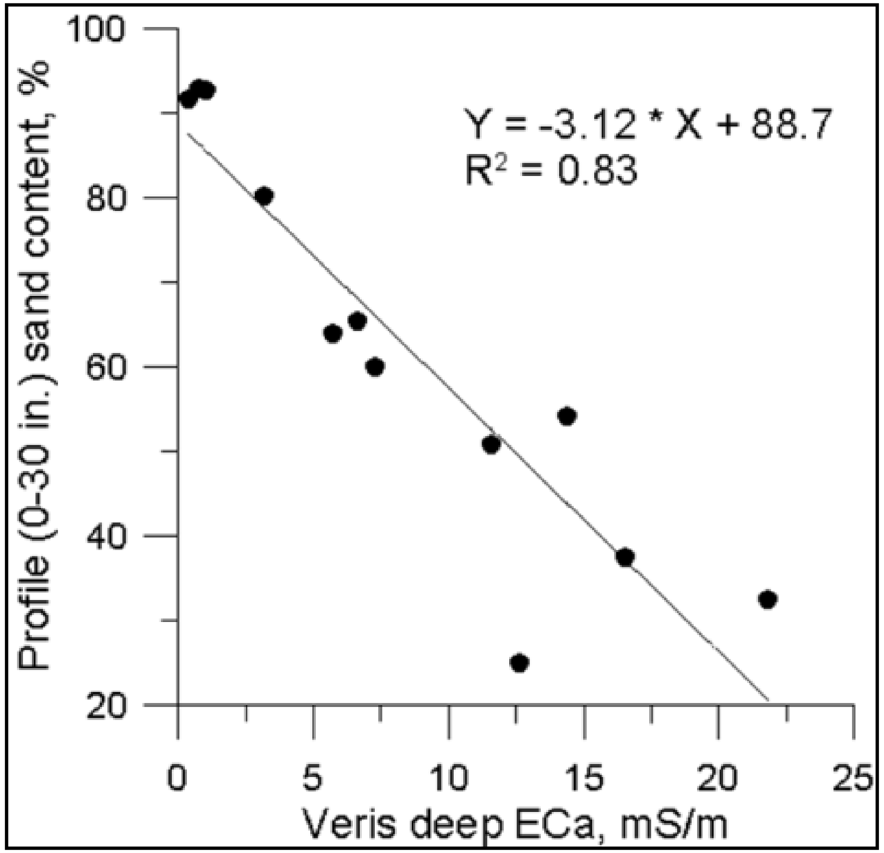
Geonics EM38

Veris 3100 & 3150

DUALEM-2S

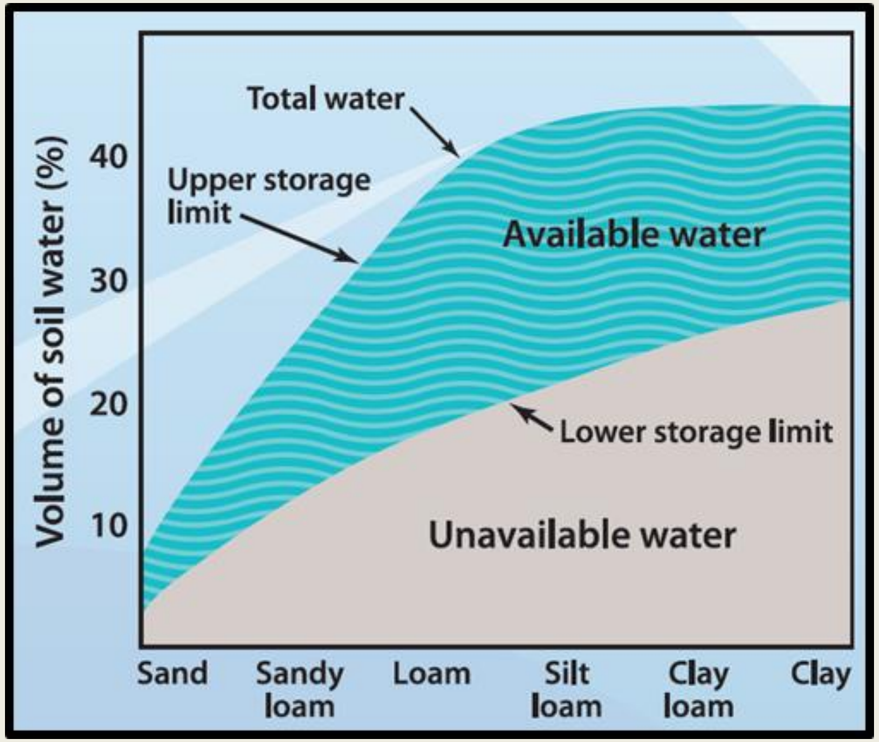
EC_a can map soil texture within fields

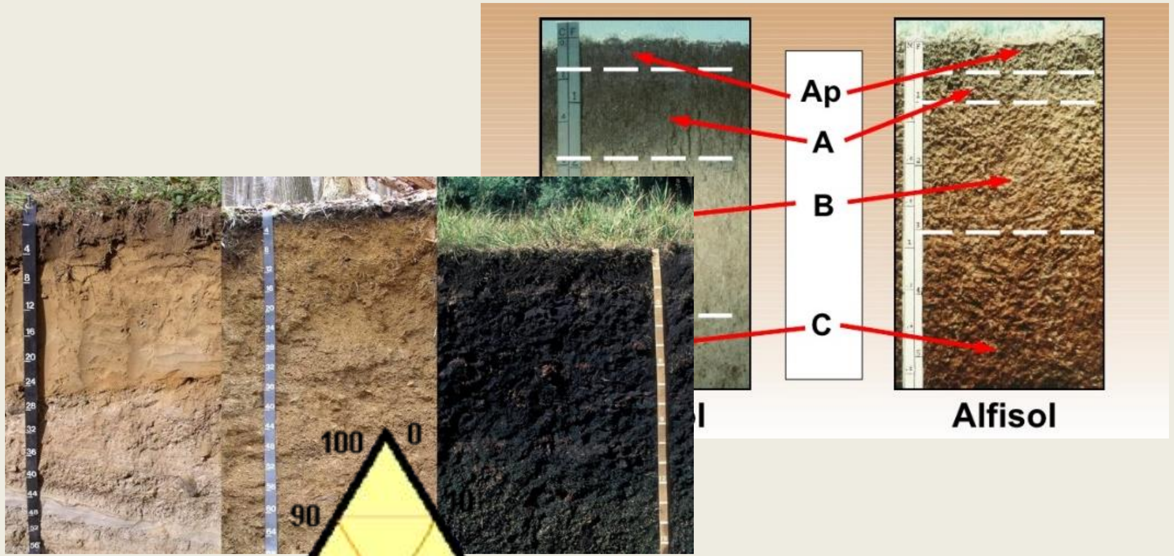


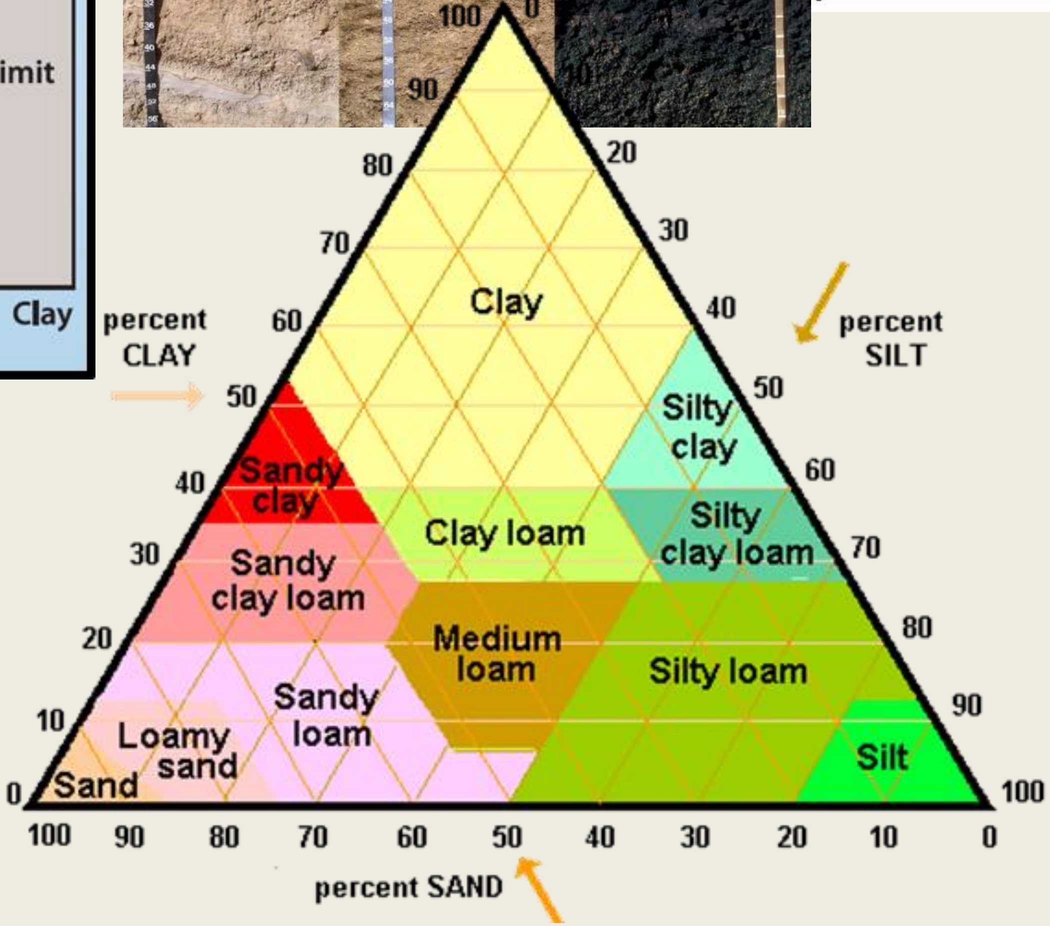


Note that these results required within-field calibration sampling

Nguyen et al., ASABE Irrigation Symposium, 2015

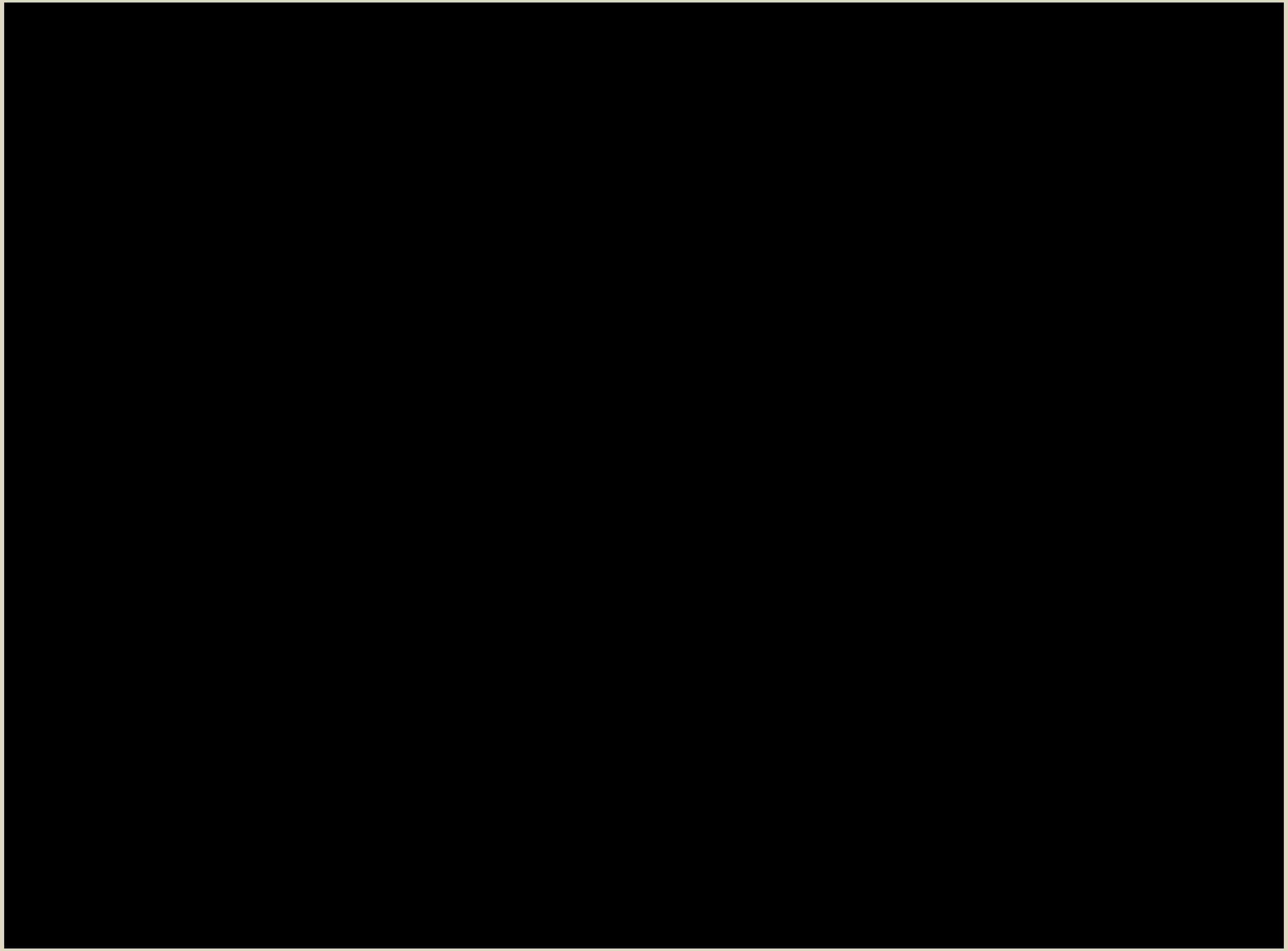






Soil Texture

On-the-Go Sensor Data Collection

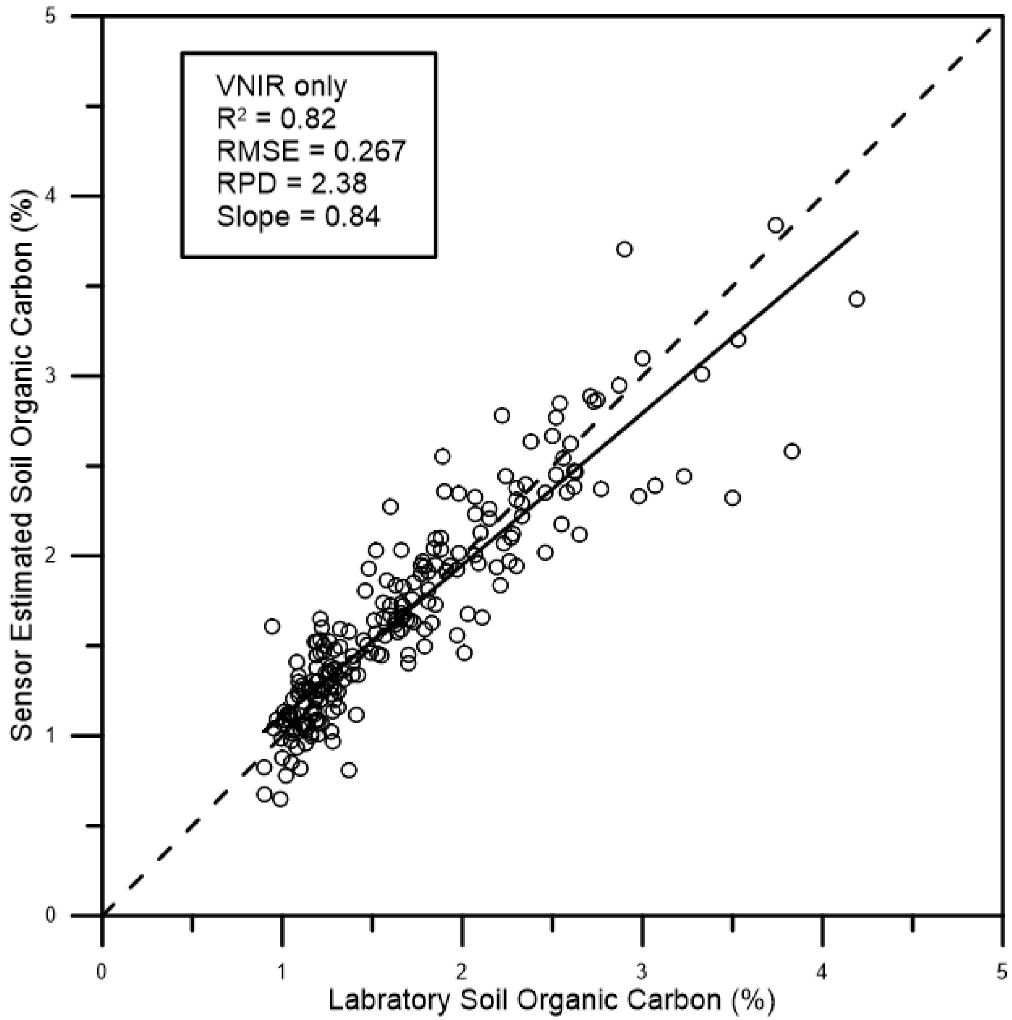


Case studies
Estimating soil health with sensors

Long-term Agroecosystem (LTAR)
site in Centralia, MO

12 row crop and grass systems
sampled at **0-5 cm and 5-15 cm** depth intervals
Lab analysis and soil health scores

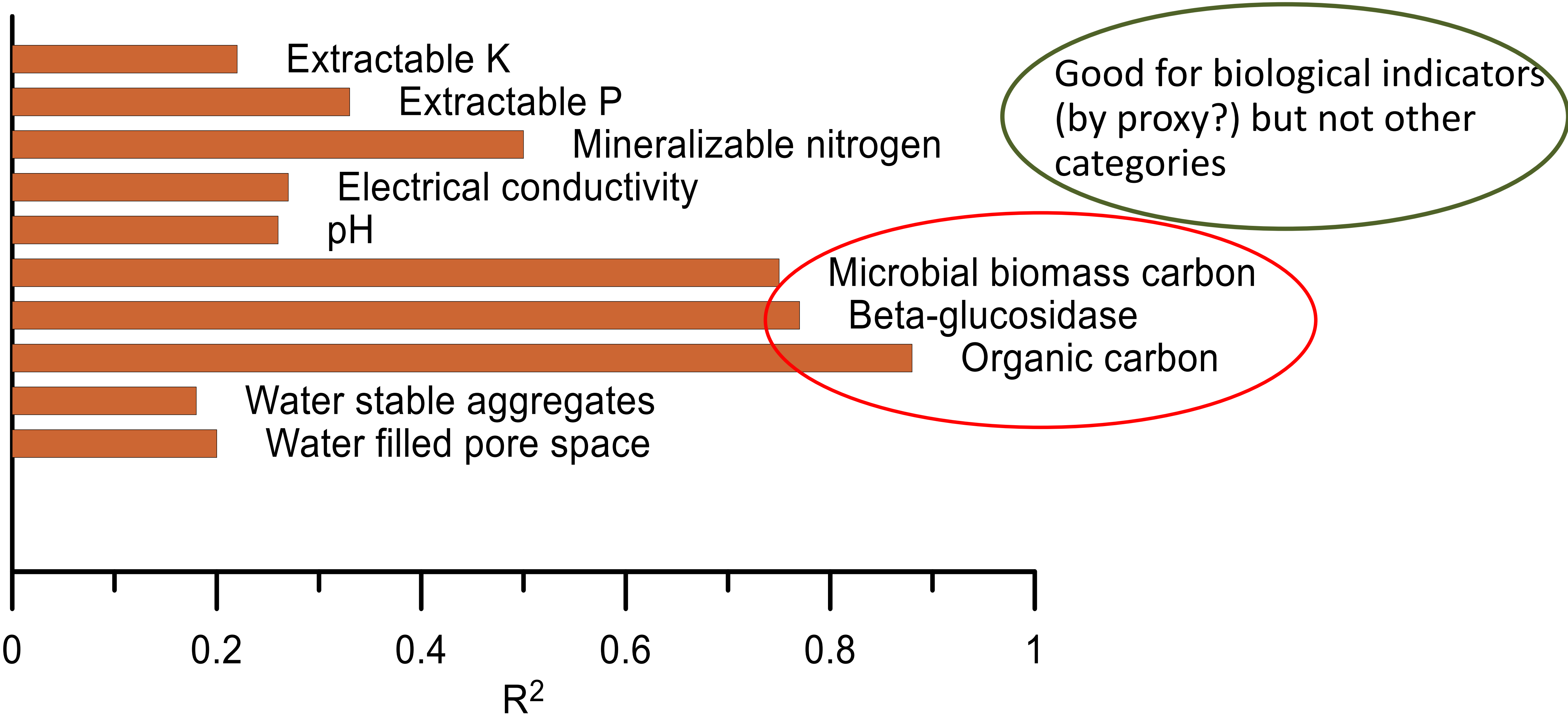
Case study: VNIR spectroscopy for Soil Organic Carbon



Lab NIR works for organic matter (not a new idea)

Veum et al., SSSAJ, 2015

Case study: Lab VNIR – Does it work for more than SOC??

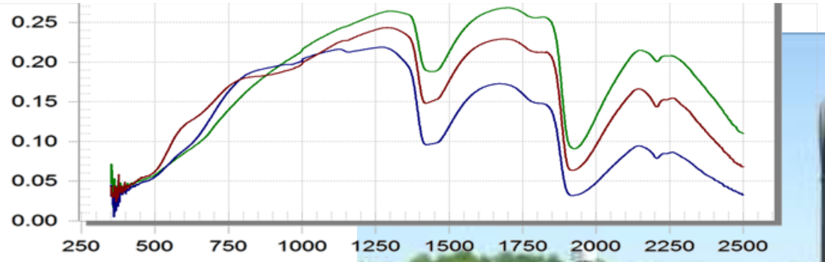


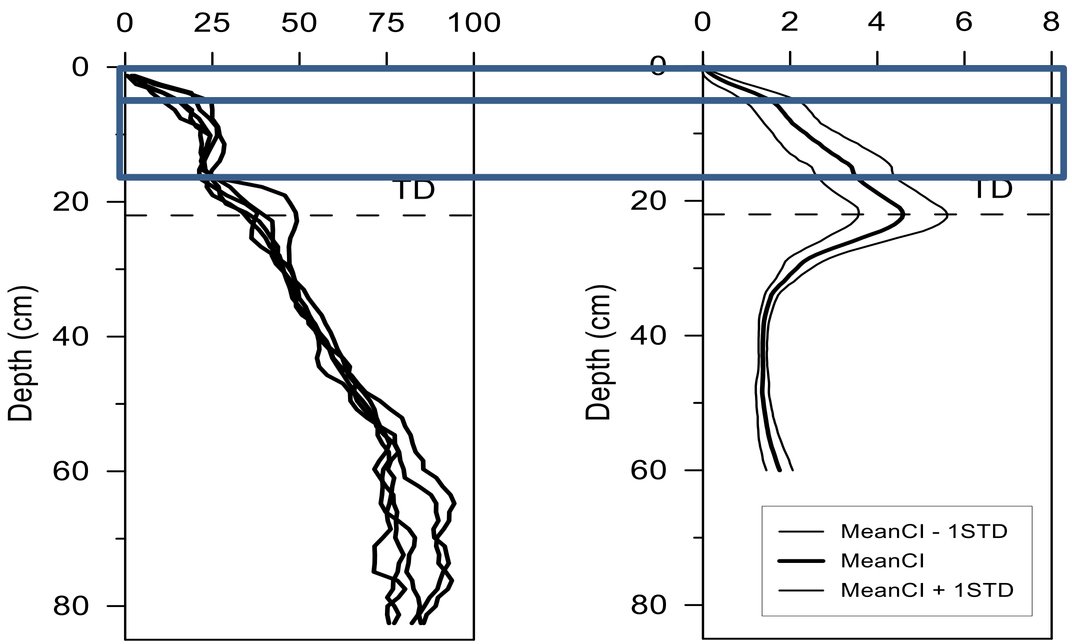
Veum et al., SSSAJ, 2015

What if we put different sensors together?

Sensor Data Fusion

- Lab VNIR spectral data
  - Air dried and ground soil
  - ASD Field Spec Pro
- In-field EC_a and penetrometer (CI) data

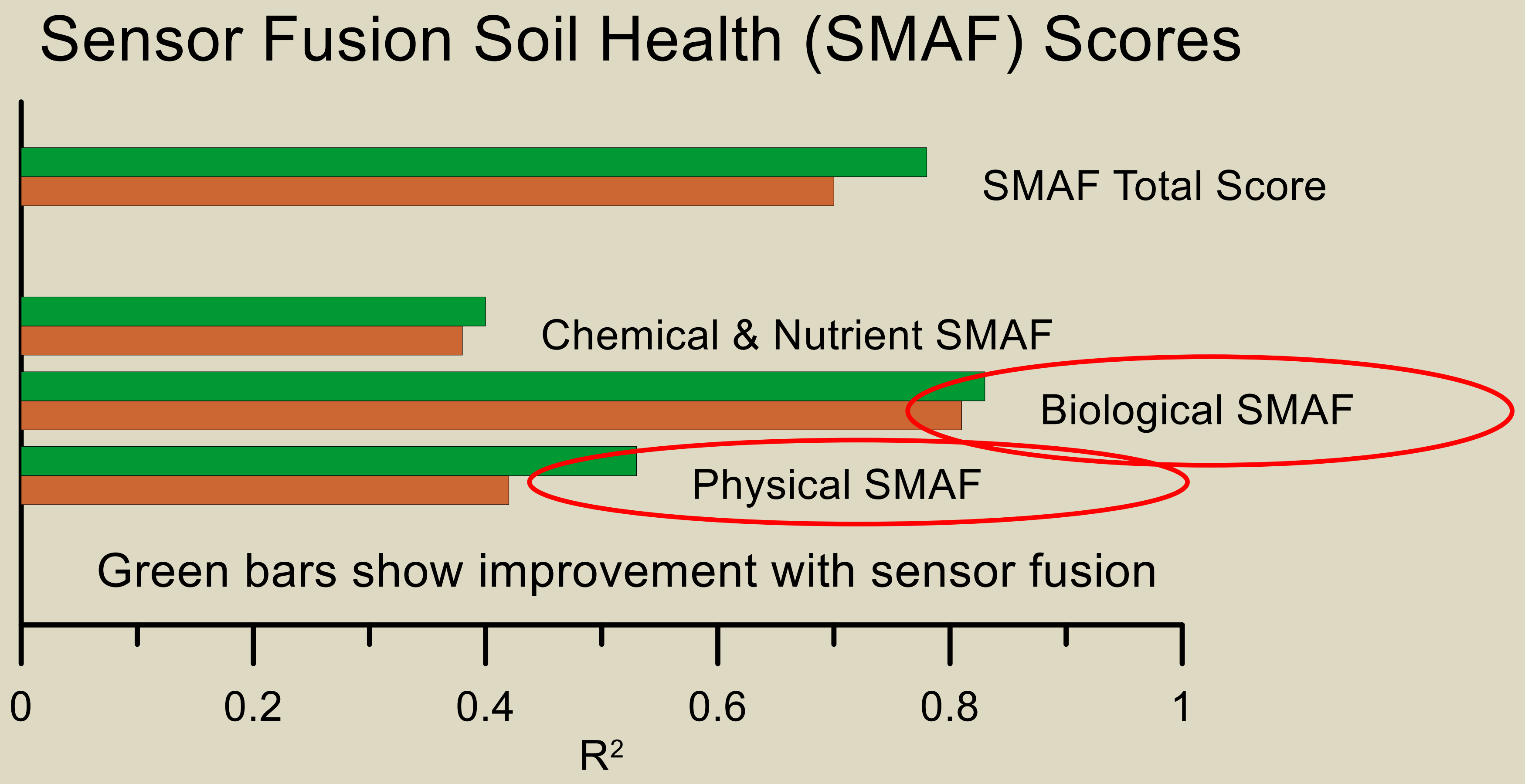




What if we add other sensors?

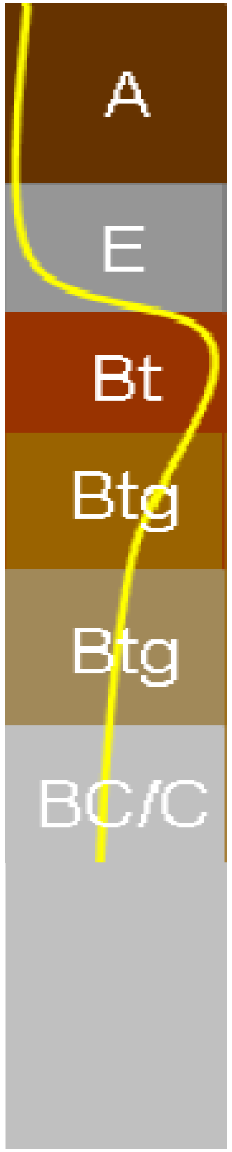
Lab VNIR with **field** EC_a and penetrometer data for **surface soils**

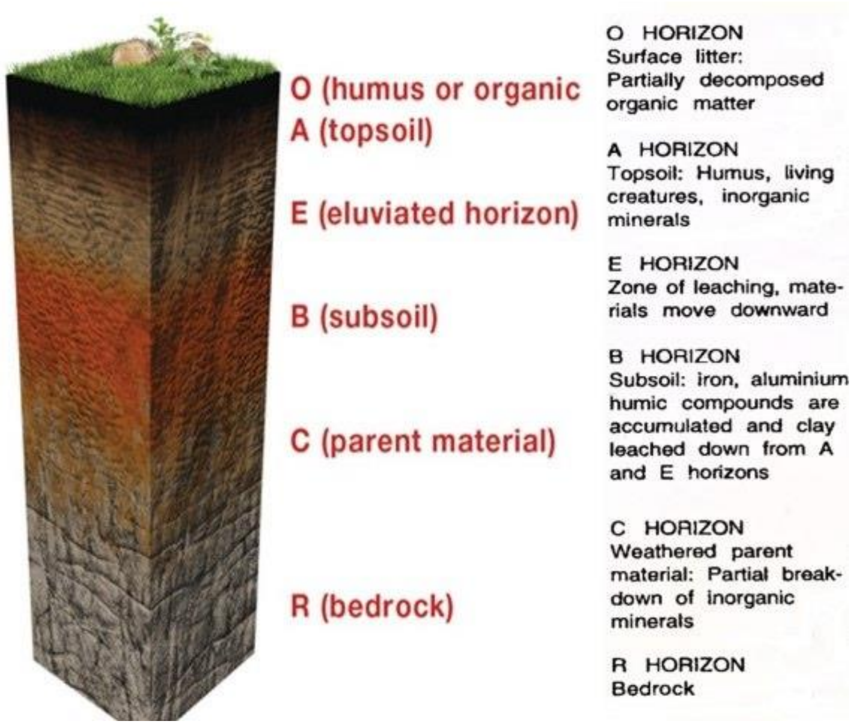
SMAF = Soil Management Assessment Framework



Veum et al. (2017). Sensor data fusion for soil health assessment. *Geoderma, 305*, 53-61.

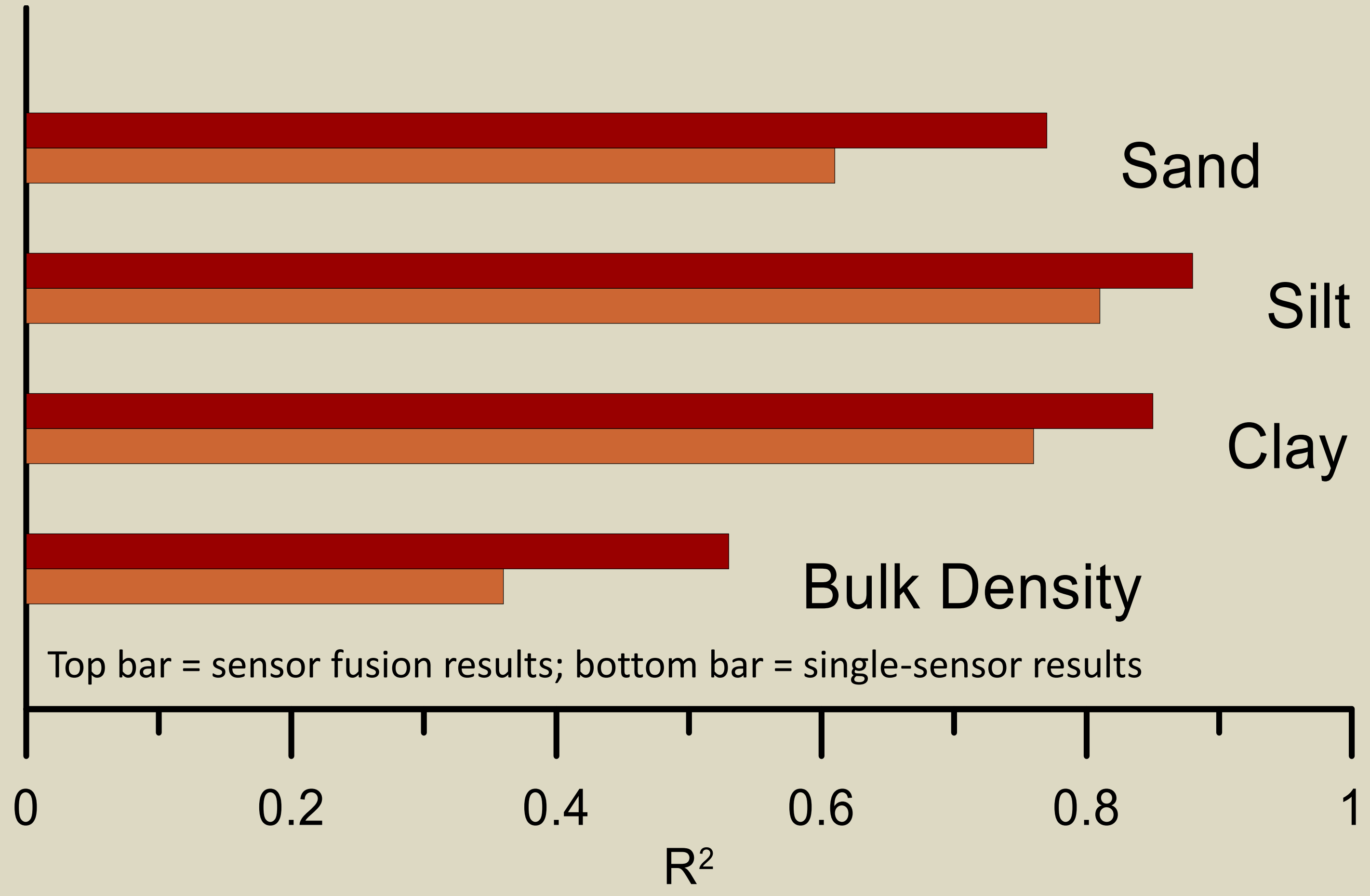
Profile Soil Properties?





How do we get this data without digging a soil pit?

Profile Sensor Data Fusion Results
Lab VNIR with **field** EC, and penetrometer (P4000 Data)



- Combining EC_a, Cone Index, and VNIR data improved estimates of texture fractions and bulk density

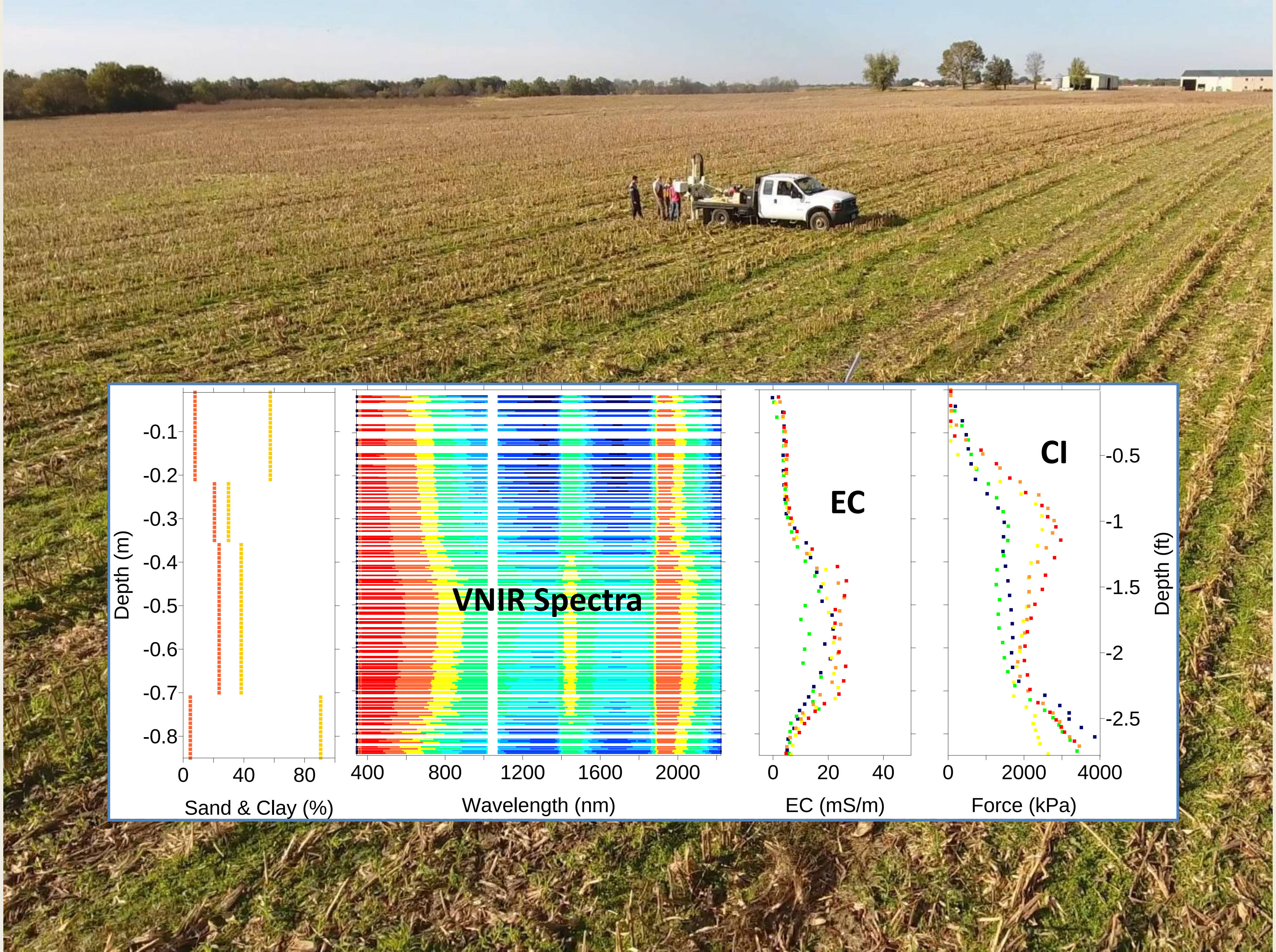
Cho et al., Trans. ASABE, 2017

Field Test: All Data from Field?

In-situ, ***field moist***, soil ***profile*** data

153 locations across 22 fields in MO & IN; 1 m, Veris P4000

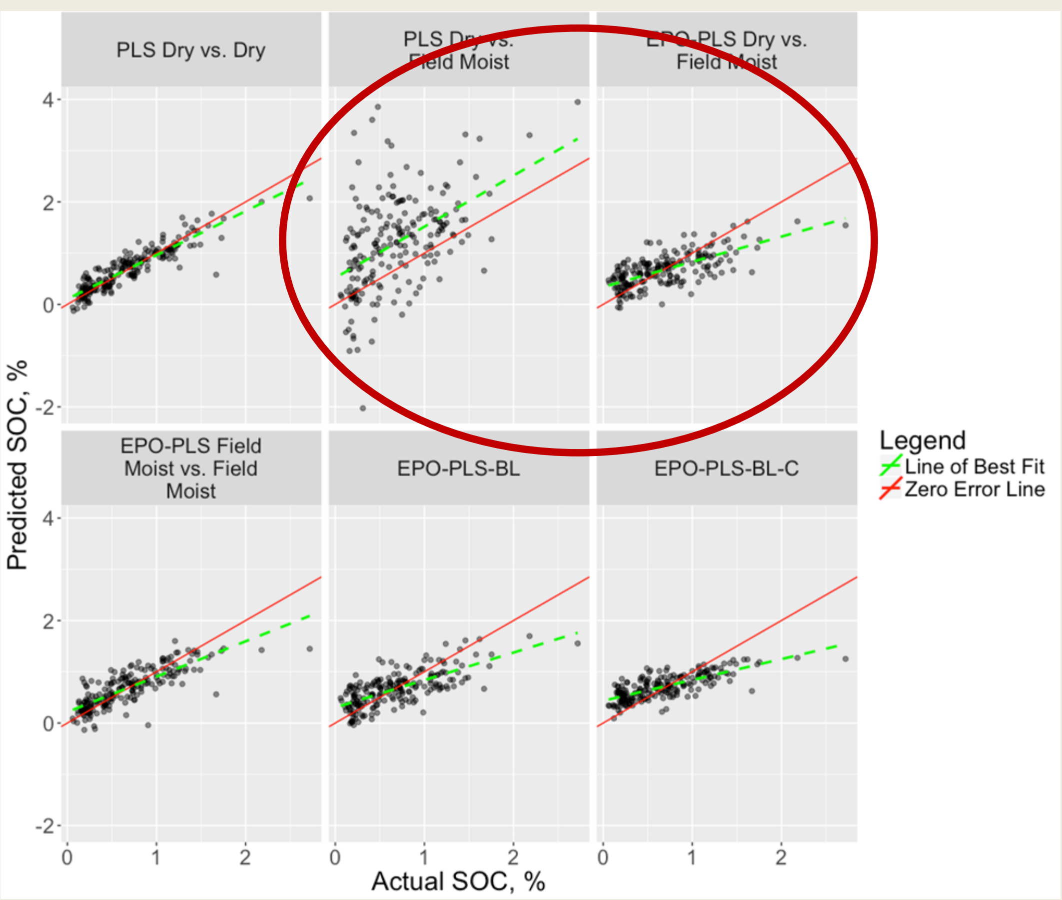
Also scanned dry in the lab for comparison (n=708)



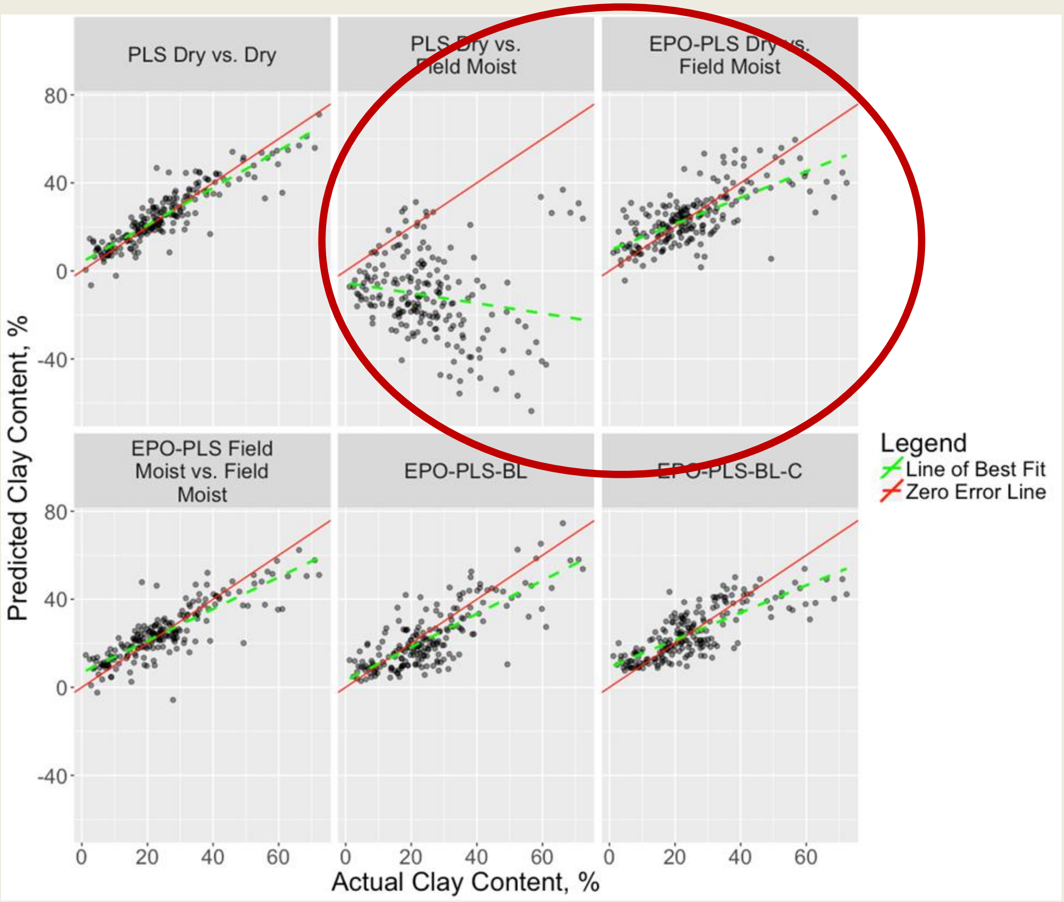
Depth (m)
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
0
40
80
Sand & Clay (%)
VNIR Spectra
400
800
1200
1600
2000
Wavelength (nm)
EC
0
20
40
EC (mS/m)
CI
0
2000
4000
Force (kPa)
-0.5
-1
-1.5
-2
-2.5
Depth (ft)

Is in-field sensor data as good as lab sensor data?

Soil Organic Carbon



Clay Content

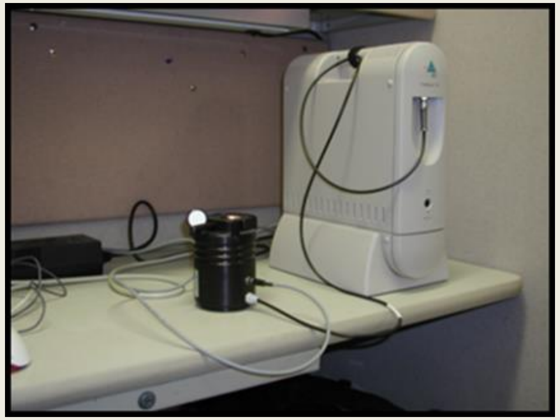


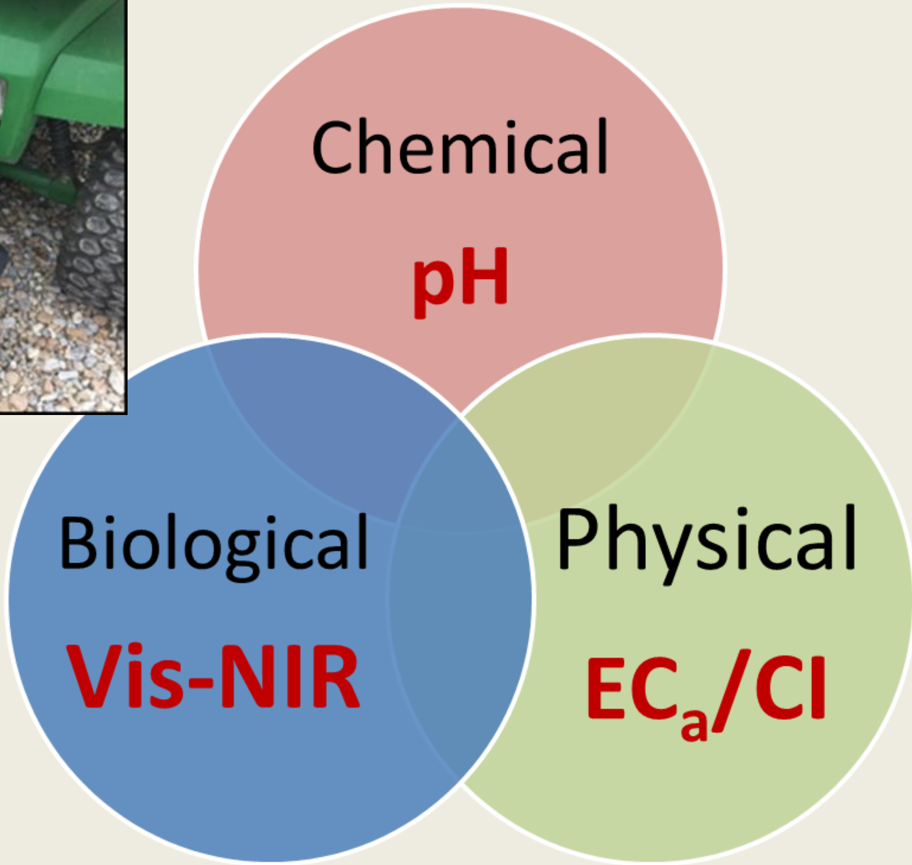
Applied PLSR, EPO, and covariate assisted Bayesian Lasso

Veum et al. (2018) *Sensors*

Long-term goal?

SENSOR BASED SOIL HEALTH ASSESSMENT

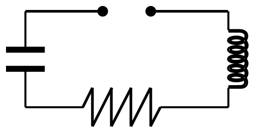




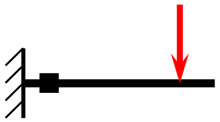
Matching soil health indicators with sensors

- **Physical**
  - Bulk density
  - Water filled pore space
  - Water stable aggregates

Conductivity/ Resistivity

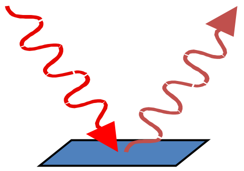


Mechanical Resistance



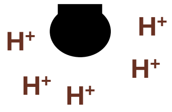
- **Biological**
  - Organic carbon
  - β-glucosidase
  - Microbial biomass carbon

Optical



- **Chemical and nutrient**
  - pH
  - Electrical conductivity
  - Mineralizable nitrogen
  - Extractable P
  - Extractable K

Electro-Chemical



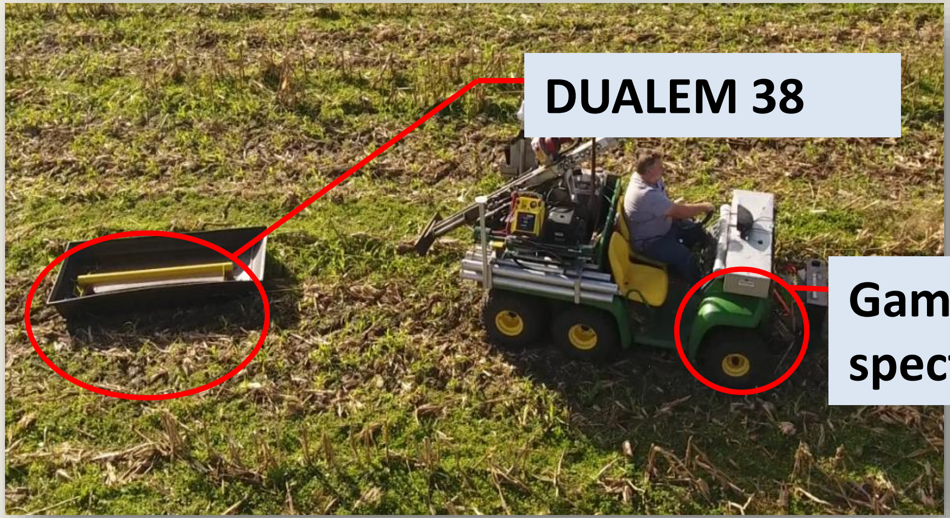
Applicability of proximal soil sensors

Courtesy of Slava Adamchuk, McGill Univ.

Soil property	EC/ER	Optical	Mech.	Sound	Electro Chem
Soil texture (clay, silt and sand)	Good	OK		Some	
Soil organic matter or total carbon	Some	Good			
Soil water (moisture)	Good	Good			
Soil salinity (sodium)	OK				Some
Soil compaction (bulk density)			Good	Some	
Depth variability (hard pan)	Some		OK	Some	
Soil pH		Some			Good
Residual nitrate (total nitrogen)	Some	Some			OK
Other nutrients (potassium)		Some			OK
CEC (other buffer indicators)	OK	OK			

Thank you!

Kristen.Veum@usda.gov



USDA