Soil Health:
Linking Comprehensive Soil Assessment With Agronomic Management Decisions

Harold van Es

Cornell CALS College of Agriculture and Life Sciences

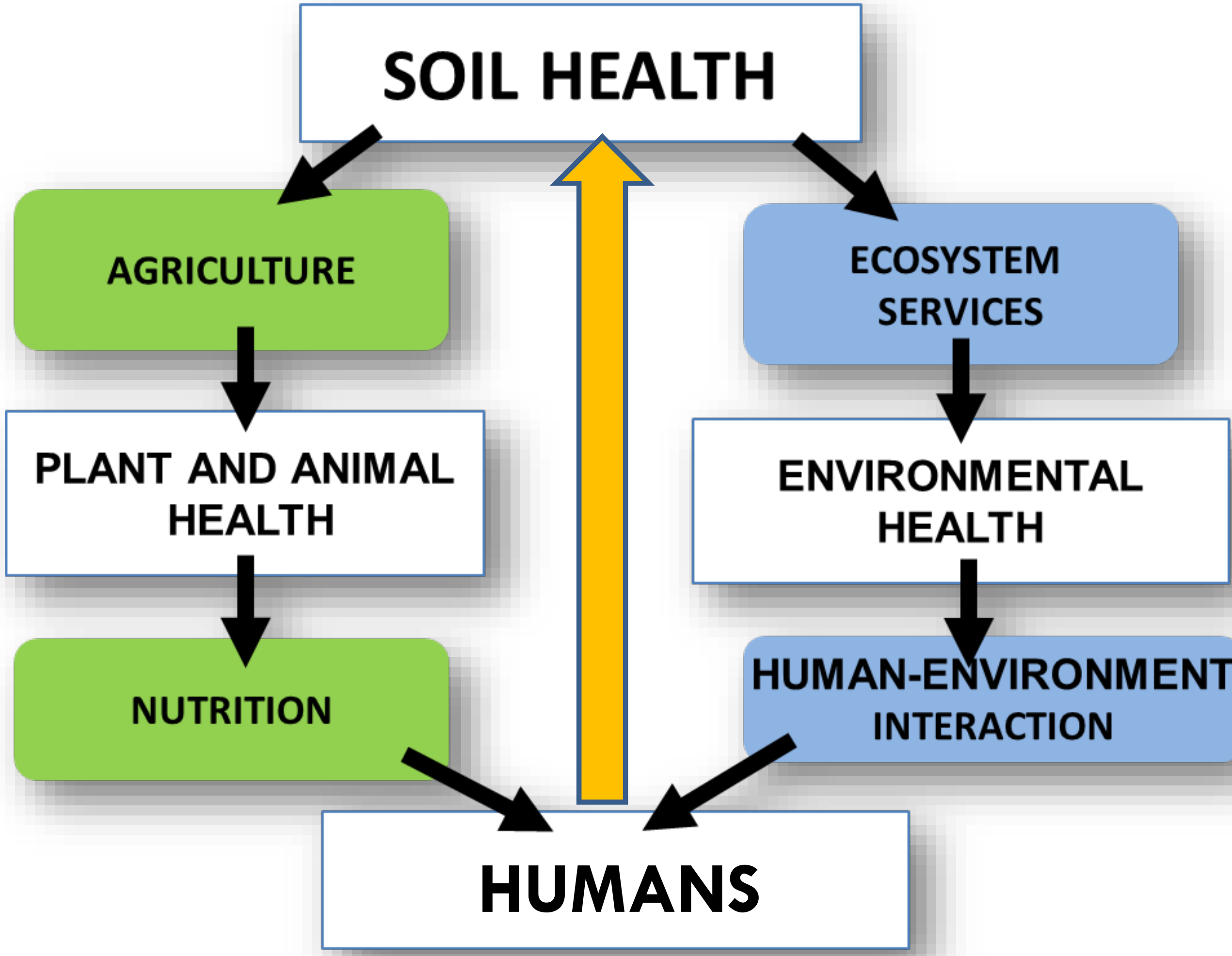
Contributions from:
Joseph Amsili
Kirsten Kurtz
Robert Schindelbeck

Soil Health is…

"the capacity of the soil to function…."

(Doran and Parkin, 1993)

Importance of Soil Health



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Soil and Food: The Basic Ingredients

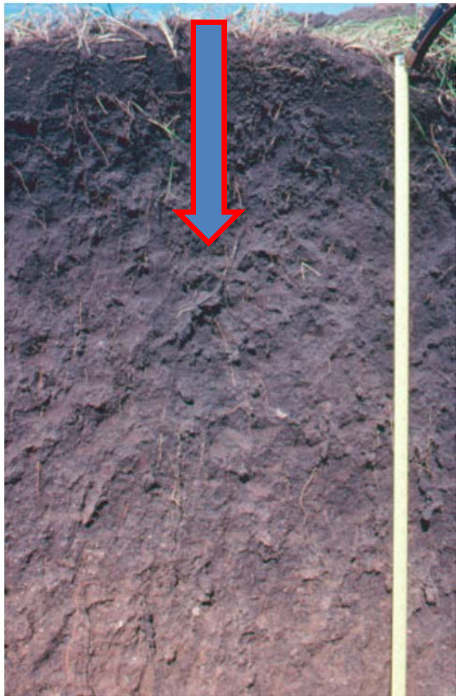


Photo: USDA-ARS

Photo: USDA-FS

Soil = f(minerals, water, air, organisms, sun)

soils build over time (net gains)

Stock of Total (non-crystalline) Phosphorus

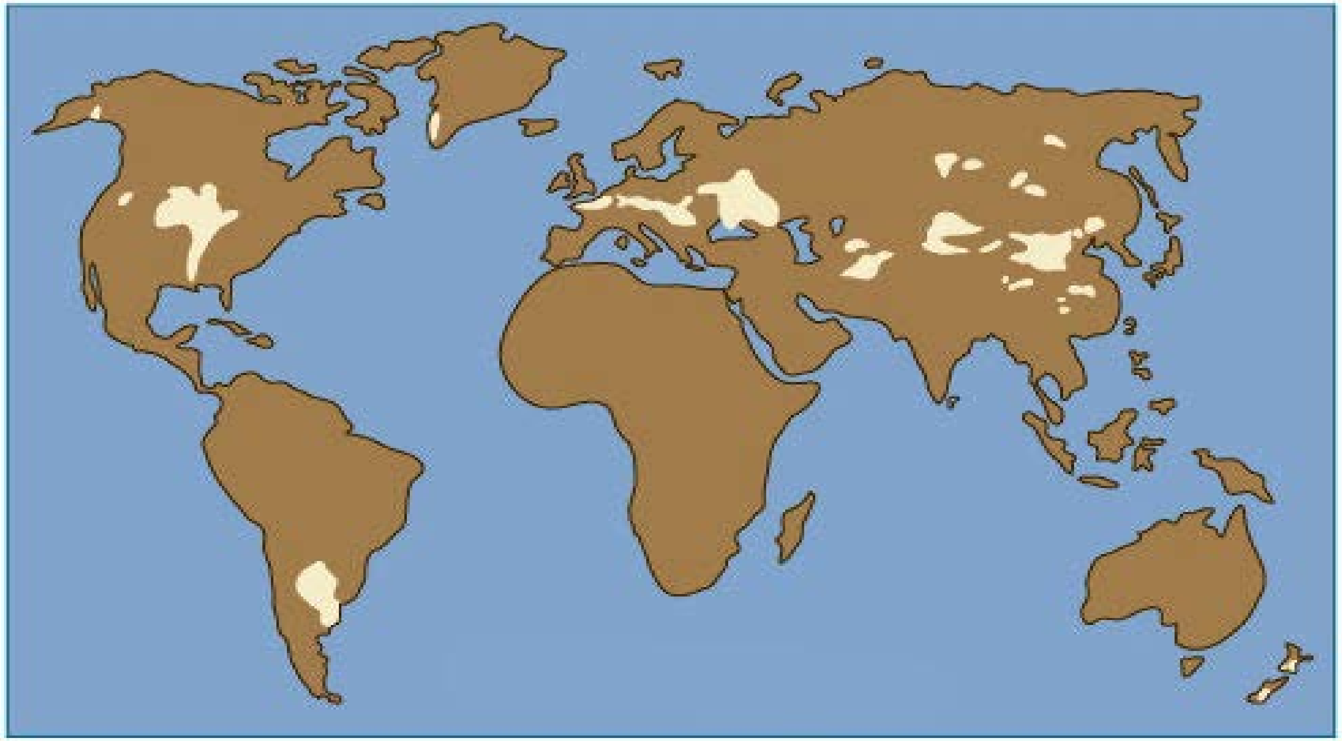
5 soils in Indiana (Sommers and Nelson, 1972)

Soil	Organic C	Total P
	%	ppm
Chalmers SiL	1.89	561
Davidson SiCl	4.09	810
Plainfield LS	0.86	422
Romney SiCL	3.51	820
Russel SiL	1.19	519
Average	**2.31**	**626**

Approximately 3000 kg P/ha in 0-30 cm
~80-100 years of maize production

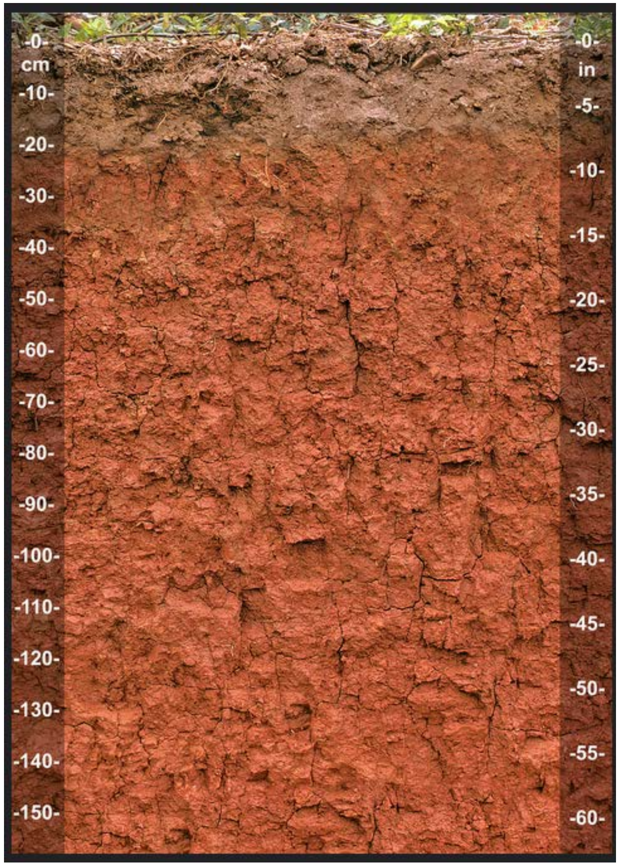
Highly successful soil health formation:

Peri-glacial loess under grassland vegetation store high amounts of nutrients and carbon



Marginally successful soil health formation:

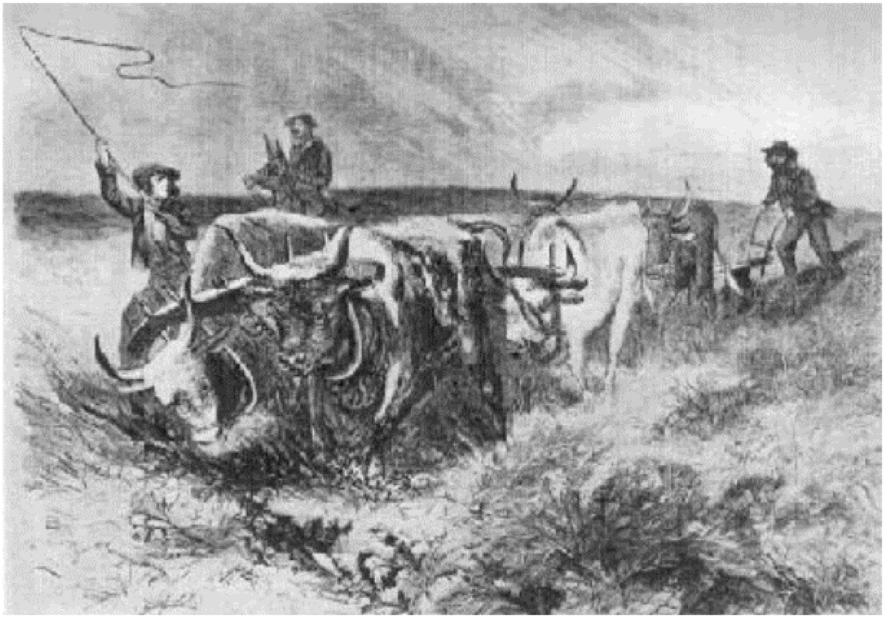
Low-Fertility Soils
store low amounts of nutrients and carbon



Cecil soil. Source: NRCS

Agricultural Development

- Tillage stimulates OM decomposition, nutrient release
- Structural breakdown and exposed soil promote erosion
- Degradation faster in low fertility forest-derived soils in warmer climates



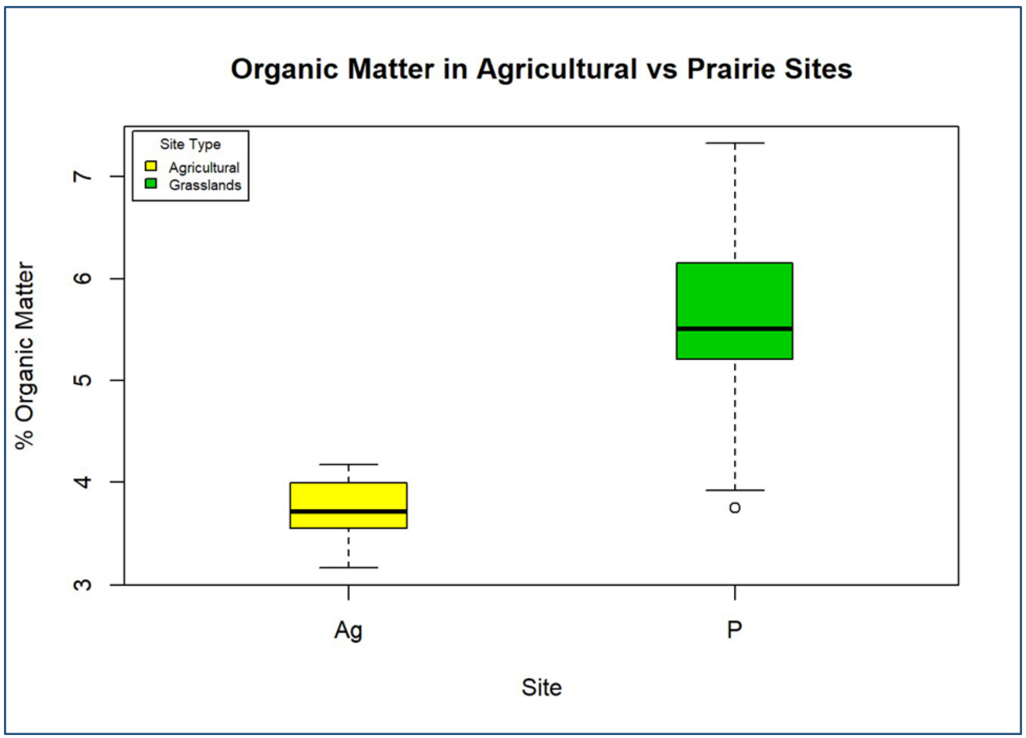
Agricultural Soils

- Less efficient in resource use than natural soils (minerals, water, sun) and lower biomass production than natural system
- Nutrients and energy (C)
  - Mostly removed through harvest (60-80%)
  - Partially recycled (residues or manure)

Result:

- Nutrient and energy (carbon) depletion (net loss)

Agricultural vs. Prairie Soil
(Western US Corn Belt)
Organic Matter



(Kurtz et al., in prep)

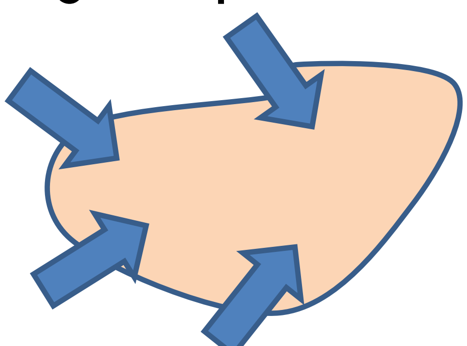
Spatial Dimension of Soil Health

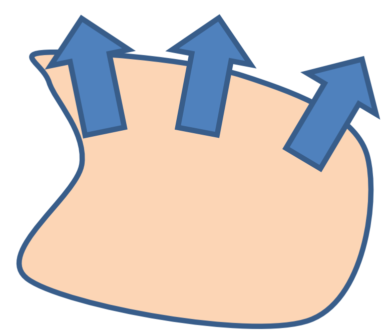
Soil health is a result of in-situ soil building processes, but there are often spatial interconnections:

- Areas of <u>convergence</u> (gaining resources from other areas)
- Areas of <u>divergence</u> (losing resources to other areas)

through…..

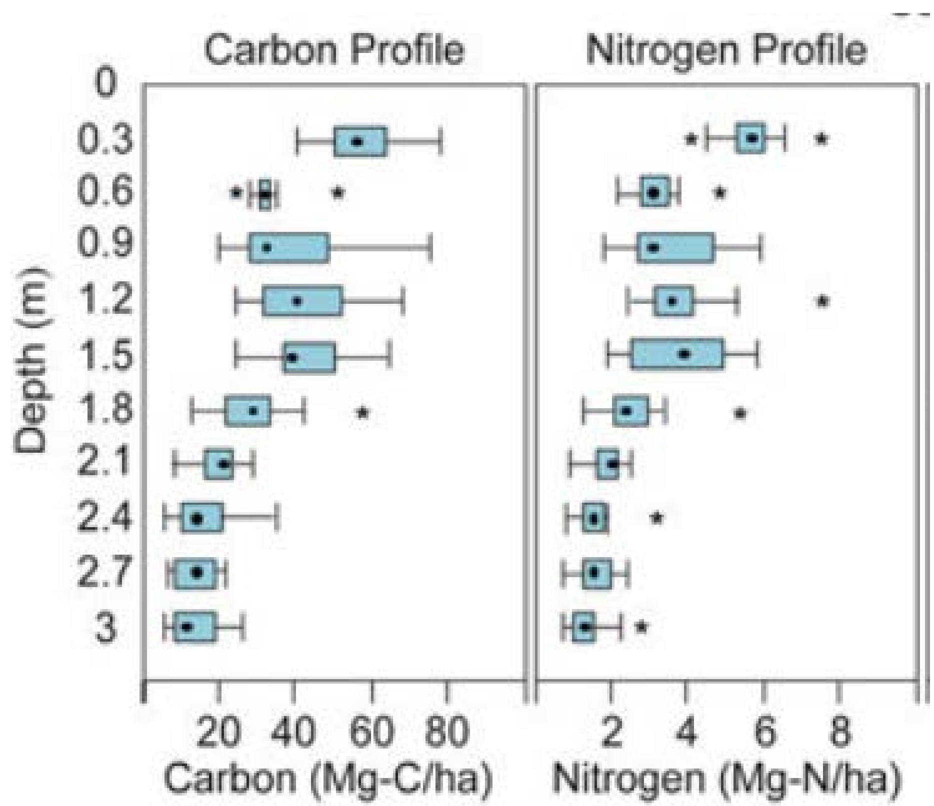
- Natural processes (e.g., erosion-sedimentation, leaching)
- Anthropogenic processes (transfer of organics to other locations)





(hydro) biogeochemical convergence areas

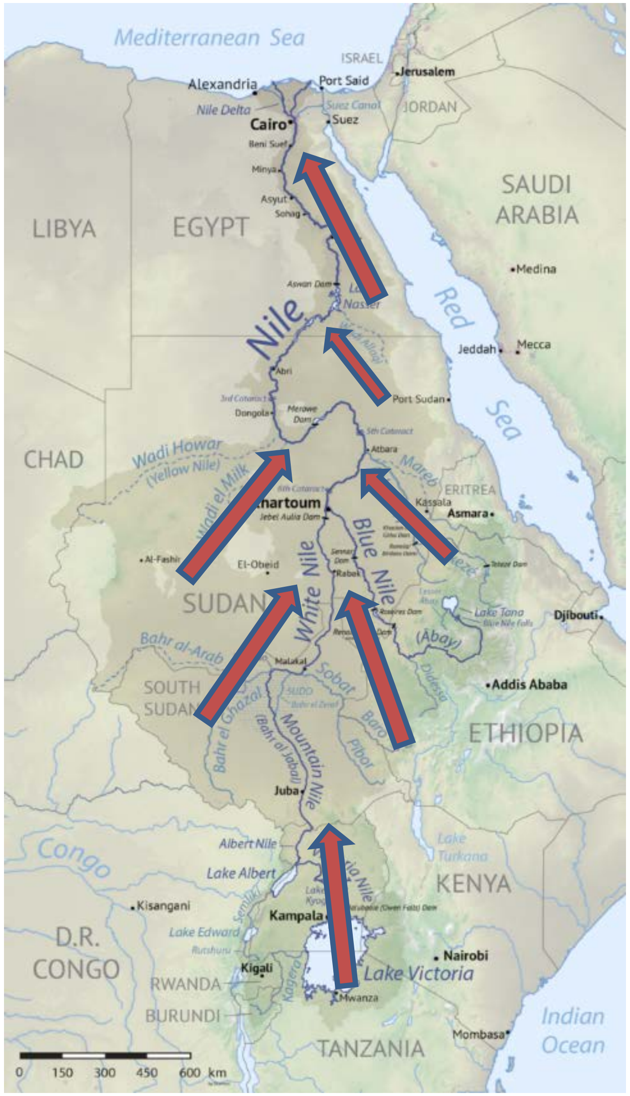
- Areas in catchments where water, nutrients and energy (mostly as organic matter) converge, emanating from hydro-bio-geochemical loss areas.
- Mostly aggrading areas in floodplains and deltas, or smaller concave landscape positions.

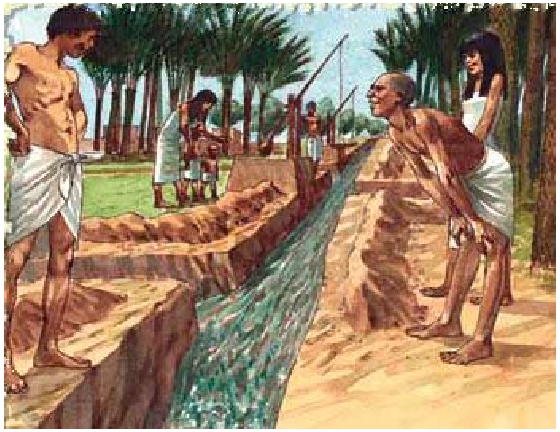


D'Elia et al., 2017

Natural Nutrient + Carbon Convergence Area:

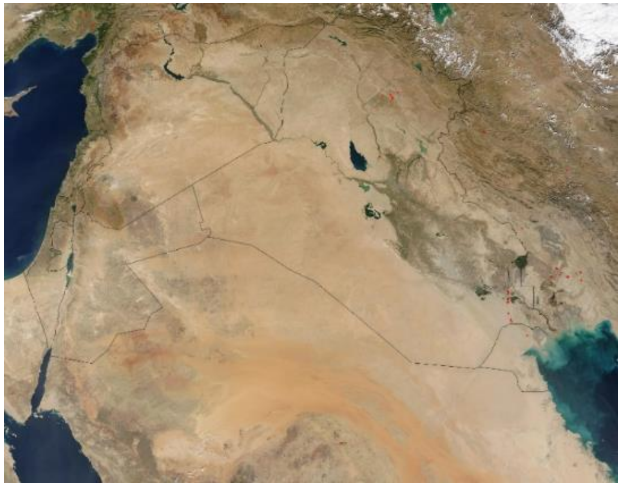
Lower Nile Valley

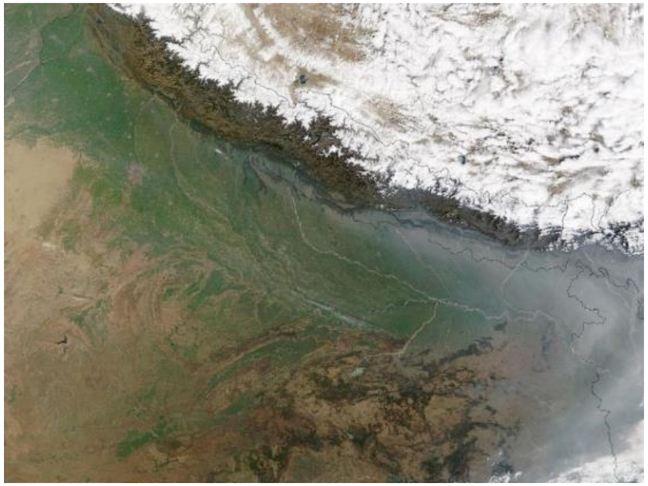




Other Nutrient + Carbon Convergence Zones:

Mesopotamia, Indo-Gangetic Plain, North China Plain,



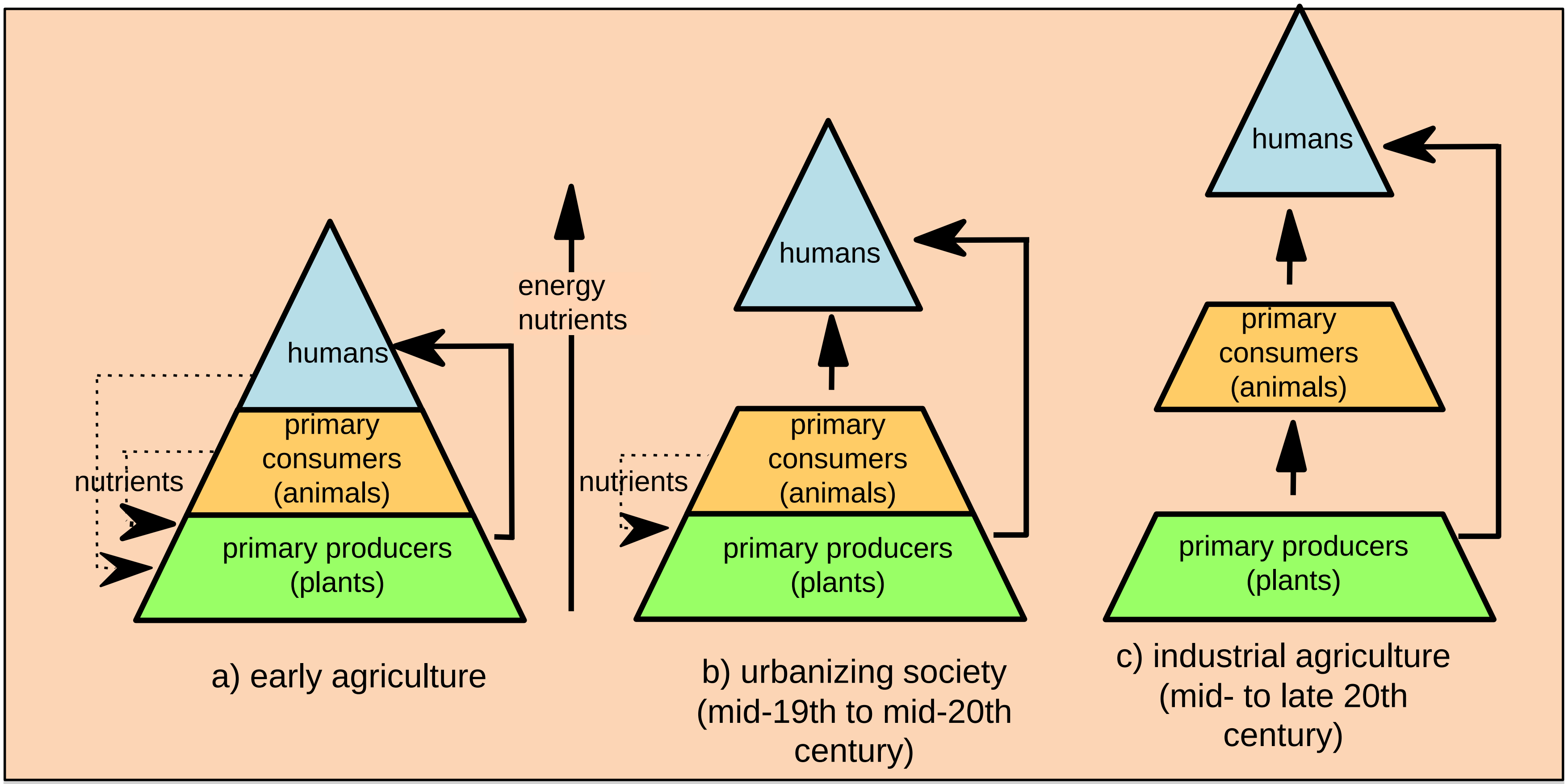


Most Agricultural Lands Are in Areas of Nutrient and Carbon Divergence + Losses

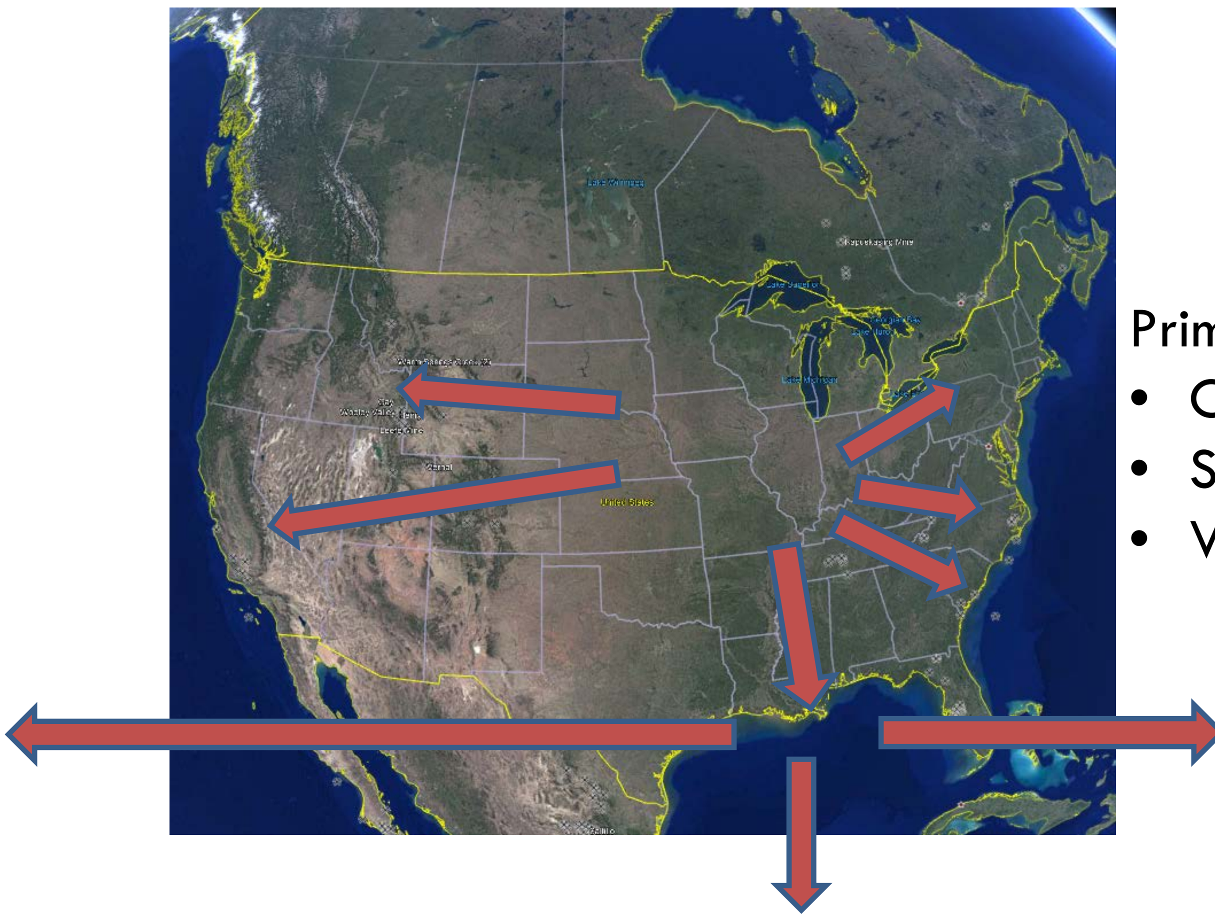
- Erosion and leaching
- Removal of harvested crop

Anthropogenic Divergence-Convergence

Patterns of nutrient flows change over time



Transfer of Nutrients and Carbon National-Global Scale



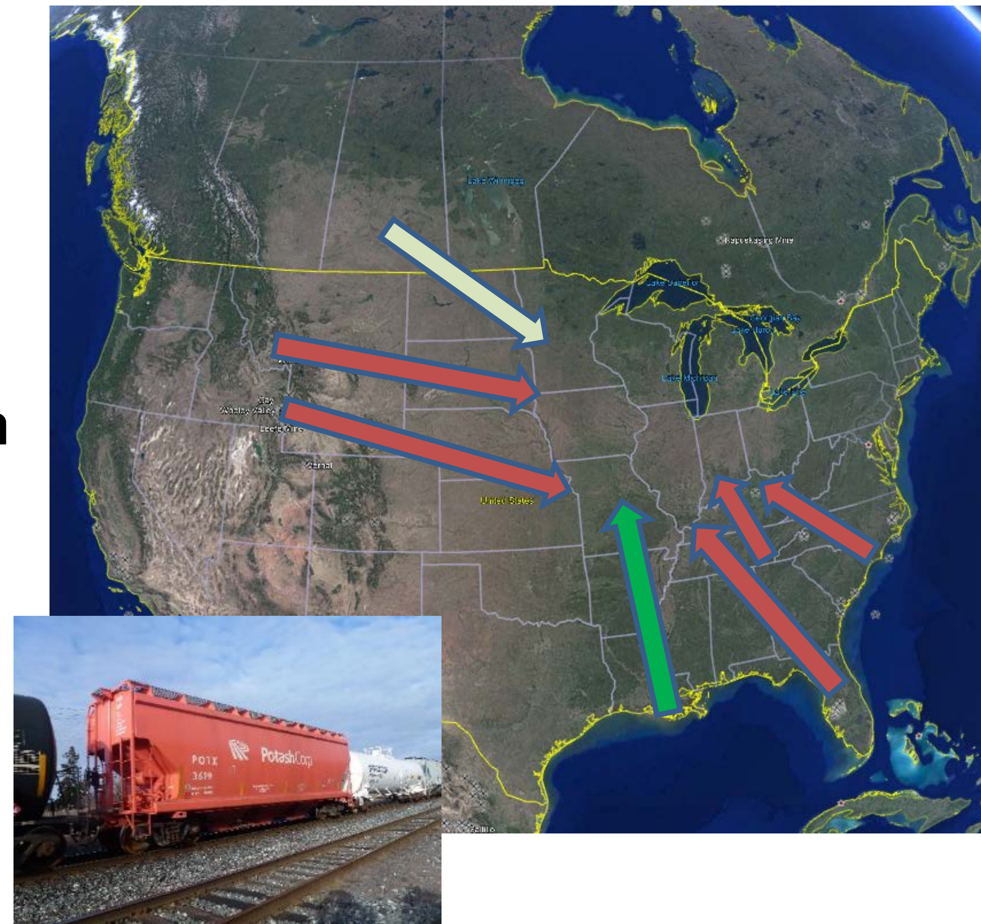
Primary transfers:

- Corn
- Soybean
- Wheat

Geochemical Reallocation Fertilizer

- Mineral deficits are supplemented with fertilizers from concentrated deposits
- Nitrogen reallocated from fossil fuel resources
- **No carbon return**

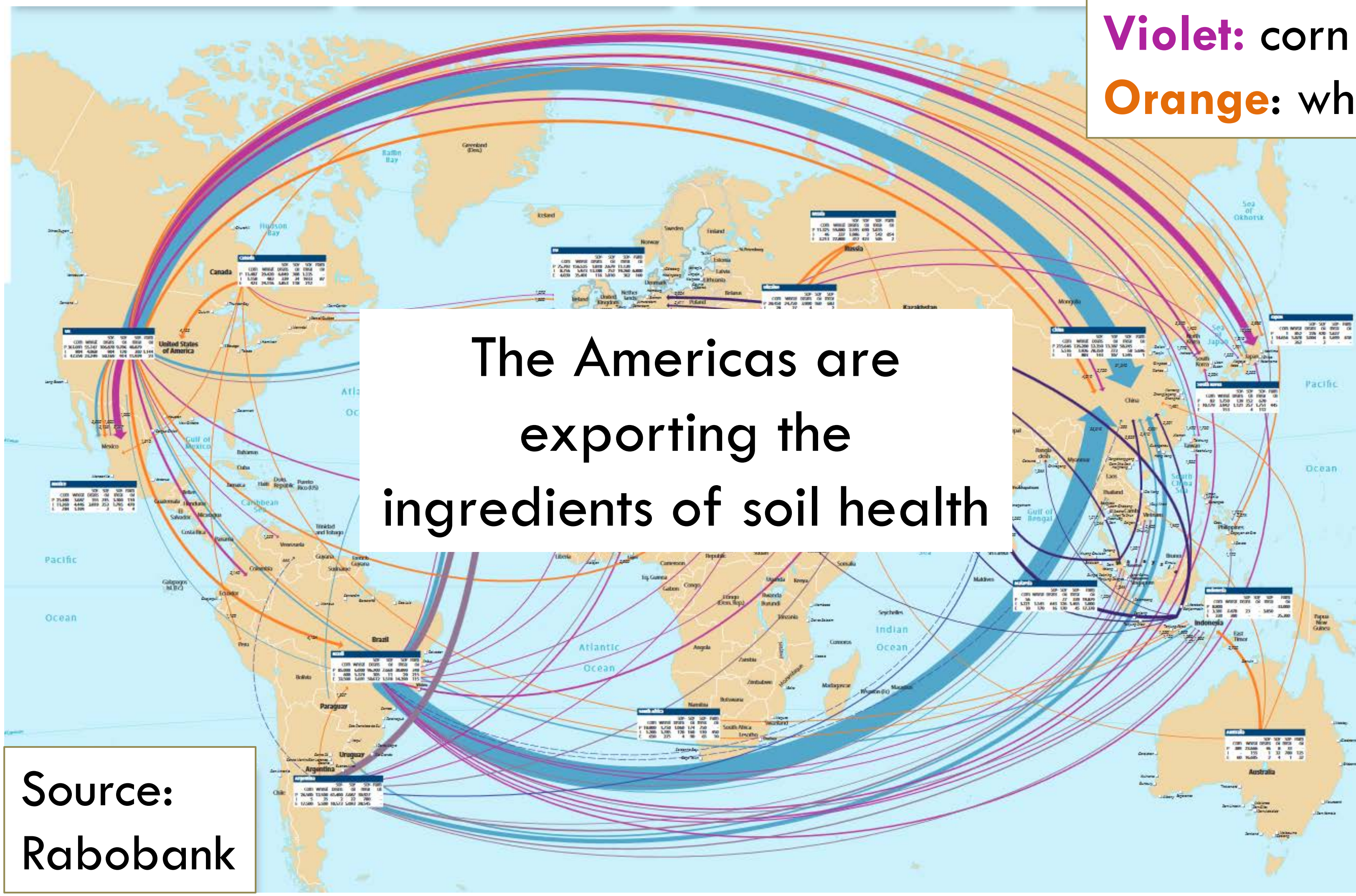
  (no bio!)



Global Agricultural Flows

Grain and Oilseed

Blue: soybean
Violet: corn
Orange: wheat



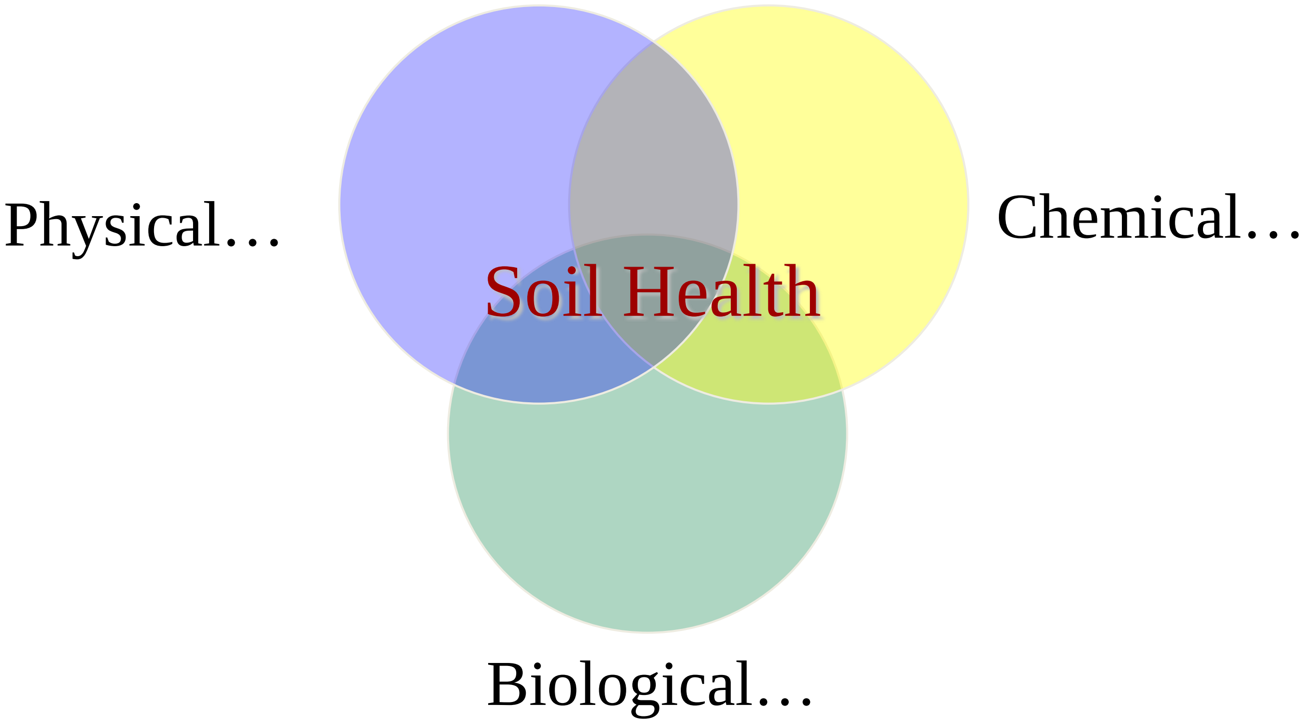
The Americas are exporting the ingredients of soil health

Source: Rabobank

Soil Health Assessment

"What's Measured Gets Done"

Conceptual View of Soil Health



- <u>Functions</u> are supported by <u>processes</u>……
- <u>Processes</u> are affected by <u>state variables</u>……
- <u>Indicators</u> can represent relevant <u>state variables</u>

Comprehensive Assessment of Soil Health

- **Available since 2006**
- **Builds on Soil Management Assessment Framework** (Andrews et al., 2004)
- **Measures 16 indicators**
- **Identifies soil constraints**
- **Guides management decisions**

Comprehensive Assessment of Soil Health

From the Cornell Soil Health Laboratory, Department of Soil and Crop Sciences, School of Integrative Plant Science, Cornell University, Ithaca, NY 14853. http://soilhealth.cals.cornell.edu

Grower:
Bob Schindelbeck
306 Tower Rd.
Ithaca, NY 14853

Agricultural Service Provider:
Mr. Bob Consulting
rrs3@cornell.edu

Sample ID:	LL4
Field ID:	AUR E Zone Till -WITH Cover Crop
Date Sampled:	05/14/2015
Given Soil Type:	Lima silt loam
Crops Grown:	COG/COG/COG

Measured Soil Textural Class: **loam**
Sand: **38%** - Silt: **44%** - Clay: **18%**

Group	Indicator	Value	Rating	Constraints
physical	Available Water Capacity	0.22	82	
physical	Surface Hardness	248	16	Rooting, Water Transmission
physical	Subsurface Hardness	360	29	
physical	Aggregate Stability	39.7	49	
biological	Organic Matter	3.1	54	
biological	ACE Soil Protein Index	4.6	21	
biological	Soil Respiration	0.6	52	
biological	Active Carbon	619	73	
chemical	Soil pH	7.0	100	
chemical	Extractable Phosphorus	9.6	100	
chemical	Extractable Potassium	91.2	100	
chemical	Minor Elements Mg: 376.0 / Fe: 0.5 / Mn: 9.2 / Zn: 0.5		100	

Overall Quality Score: **65** / Excellent

Selection of CASH Indicators

- Relevance to important soil processes
- Consistency and reproducibility
- Ease of sampling
- Low cost

CASH Indicators

Chemical

Standard soil test plus options:

- **Extractable P, K, and micronutrients**: Plant nutrient availability
- **pH**: Influences chemical and biological reactions and availability of nutrients
- **Soluble Salts**: Salt problems
- **Heavy Metals** : Contamination and toxicity

CASH Indicators

Physical

- **Aggregate Stability** by simulated rainfall: Resistance to dispersal. Influences water infiltration/runoff, erosion, aeration, germination, rooting
- **Available Water Capacity:** plant available water storage capacity, drought resistance
- **Penetration resistance (2 depths):** soil compaction, rooting, germination, drought resistance

CASH Indicators

Biological

- **Organic Matter:** Energy and nutrient storage, C sequestration
- **Active C (POXC):** easily available carbon, microbial food source
- **Soil Proteins:** N containing life building blocks, N release
- **Respiration:** Microbial abundance and activity
- **Root Disease Bioassay:** soil-borne disease pressure

Soil Health Assessment Report
10 pages

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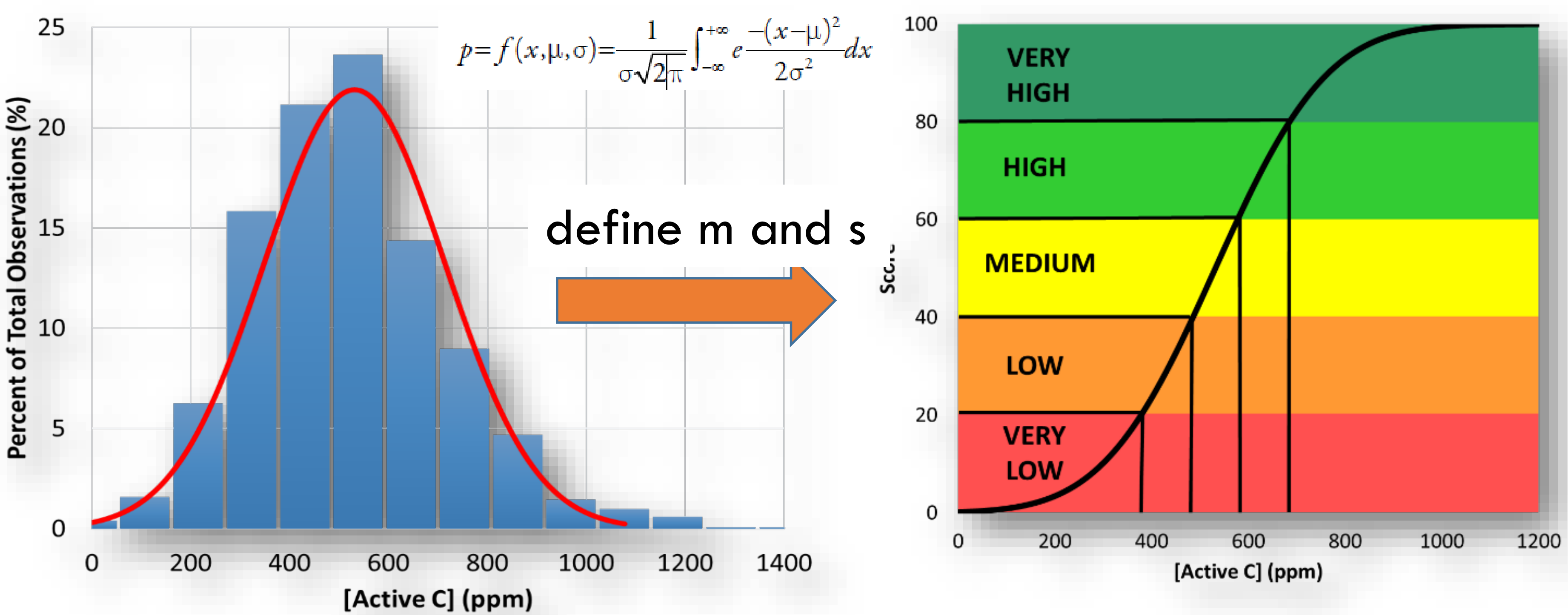
Generalized Scoring Function

Normative Evaluation Using Fuzzy Logic:

Cumulative Normal Distribution Function

$$p = f(x, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{+\infty} e^{\frac{-(x-\mu)^2}{2\sigma^2}} dx$$



After Andrews et al., 2002

Soil Health Management Planning

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Management Suggestions for Physical and Biological Constraints		
Constraint	**Short Term Management Suggestions**	**Long Term Management Suggestions**
Availabe Water Capacity Low	• Add stable organic materials, mulch • Add compost or biochar • Incorporate high biomass cover crop	• Reduce tillage • Rotate with sod crops • Incorporate high biomass cover crop
Surface Hardness High	• Perform some mechanical soil loosening (strip till, aerators, broadfork, spader) • Use shallow-rooted cover crops • Use a living mulch or interseed cover crop	• Shallow-rooted cover/rotation crops • Avoid traffic on wet soils, monitor • Avoid excessive traffic/tillage/loads • Use controlled traffic patterns/lanes
Subsurface Hardness High	• Use targeted deep tillage (subsoiler, yeomans plow, chisel plow, spader.) • Plant deep rooted cover crops/radish	• Avoid plows/disks that create pans • Avoid heavy loads • Reduce traffic when subsoil is wet
Aggregate Stability Low	• Incorporate fresh organic materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch	• Reduce tillage • Use a surface mulch • Rotate with sod crops and mycorrhizal hosts
Organic Matter Low	• Add stable organic materials, mulch • Add compost and biochar • Incorporate high biomass cover crop	• Reduce tillage/mechanical cultivation • Rotate with sod crop • Incorporate high biomass cover crop
Soil Protein Index Low	• Add N-rich organic matter (low C:N source like manure, high N well-finished compost) • Incorporate young, green, cover crop biomass • Plant legumes and grass-legume mixtures • Inoculate legume seed with Rhizobia & check for nodulation	• Reduce tillage • Rotate with forage legume sod crop • Cover crop and add fresh manure • Keep pH at 6.2-6.5 (helps N fixation) • Monitor C:N ratio of inputs
Root Pathogen Pressure High	• Use disease-suppressive cover crops • Plant on ridges/raised beds • Monitor irrigation • Biofumigate	• Use disease-suppressive cover crops • Increase diversity of crop rotation • Sterilize seed and equipment • Improve drainage/monitor irrigation
Respiration Low	• Maintain plant cover throughout season • Add fresh organic materials • Add manure, green manure • Consider reducing biocide usage	• Reduce tillage/mechanical cultivation • Increase rotational diversity • Maintain plant cover throughout season • Cover crop with symbiotic host plants
Active Carbon Low	• Add fresh organic materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch	• Reduce tillage/mechanical cultivation • Rotate with sod crop • Cover crop whenever possible

Constrained and Suboptimal indicators are flagged in report management table

Enhancing Soil Health Testing

Best Subsets Analysis

Which indicator subsets are most predictive of overall SH?

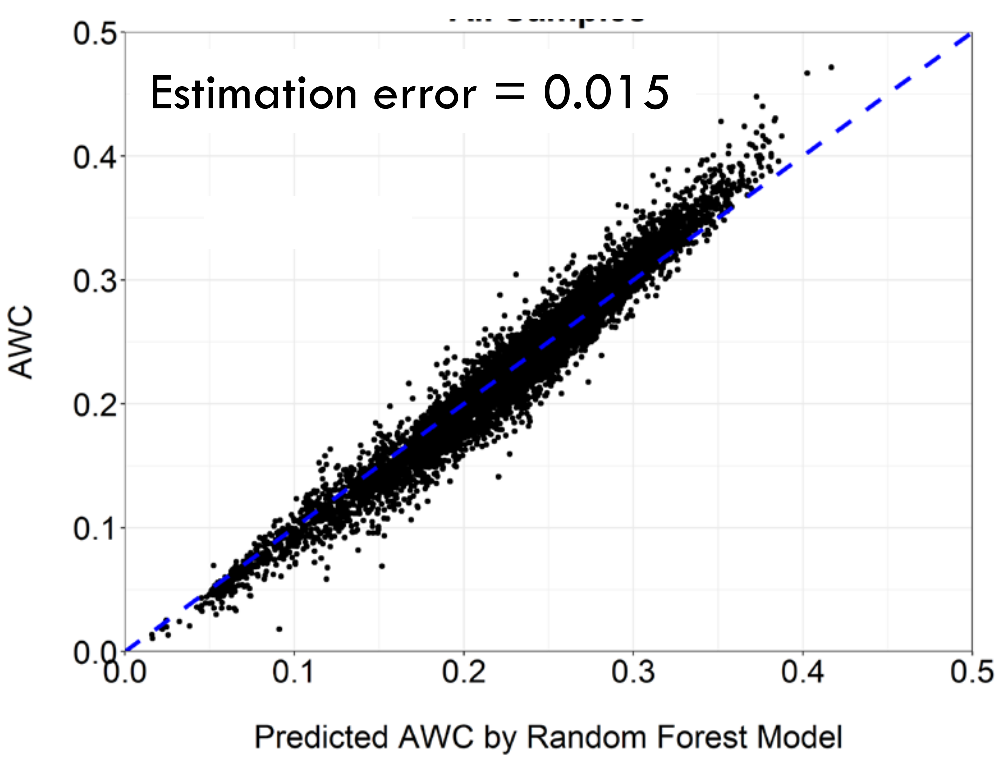
n=8074

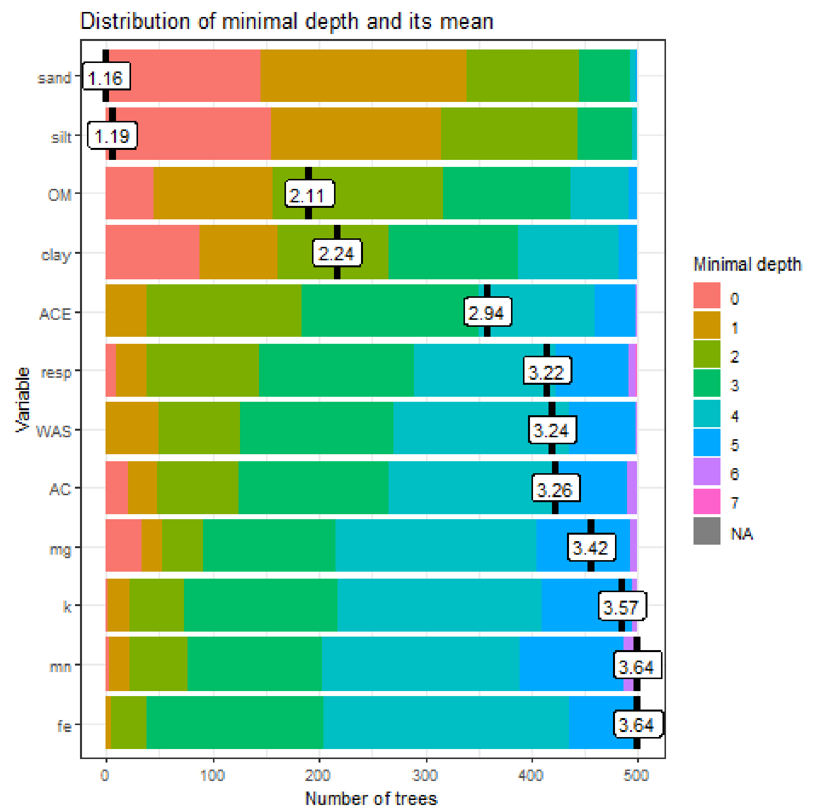
Subset size	SH Indicators	R^2_{adj}
1	ActC	0.60
2	ActC + OM	0.68
3	ActC + OM + Resp	0.73
4	ActC + Resp + WAS + AWC	0.73

Amsili et al. (in prep.)

Simplifying Measurements

Predicting Available Water Capacity Using Random Forest Approach



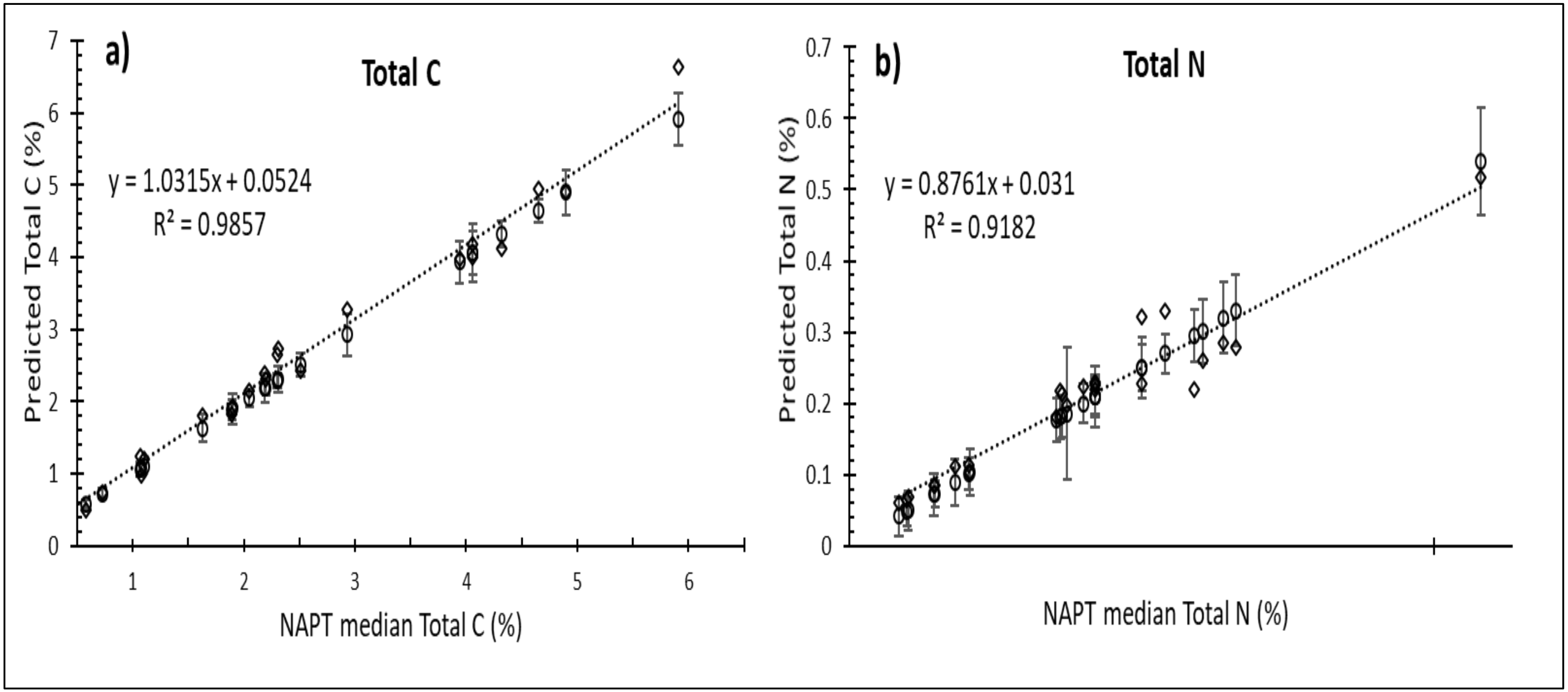


Amsili et al. (in prep.)

Simplifying Measurements

Mid-Infrared Reflectance Spectroscopy

(Sherpa, 2019)

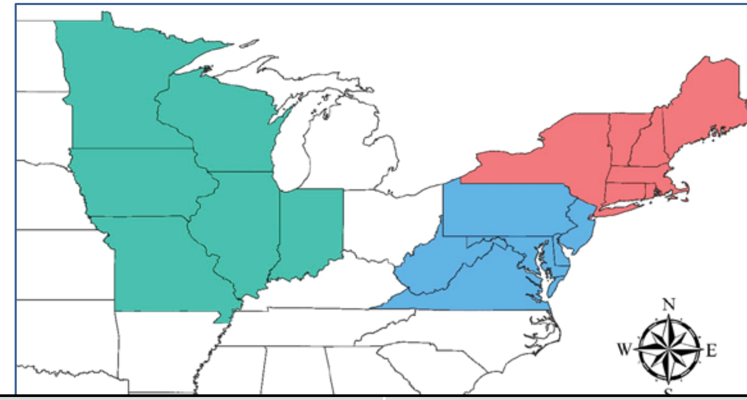


Soil Health Research Results

using CASH Approach

Regional Soil Health Differences

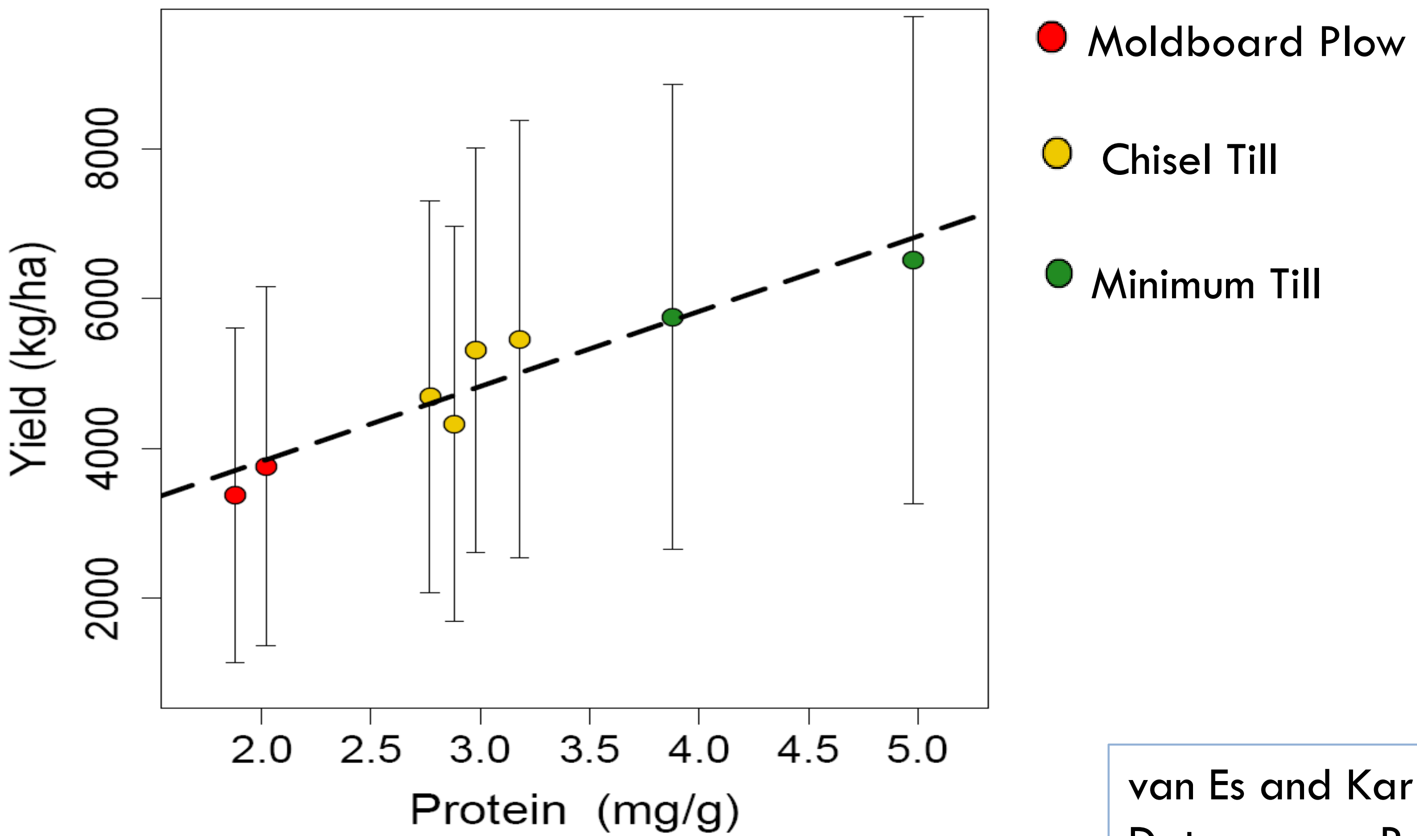
Fine et al., 2017
(data for medium-textured soils)



	Northeast	Mid-Atlantic	Midwest
Ag Stability (%)	48.8 a	42.7 b	25.2 c
Avail Water Cap (g/g)	0.19 c	0.22 b	0.23 a
PenResist-15 (kPa)	1050 a	1346 b	1264 b
PenResist-45 (kPa)	2037	2005	2053
OrgMatter (%)	3.99 a	4.12 a	3.04 b
ActC (mg/kg)	549 a	564 a	475 c
Protein (mg/g)	8.8 b	10.0 a	4.9 c
Respiration (mg CO2/g)	0.70 b	0.86 a	0.47 c

Long-Term Tillage Studies - North Carolina

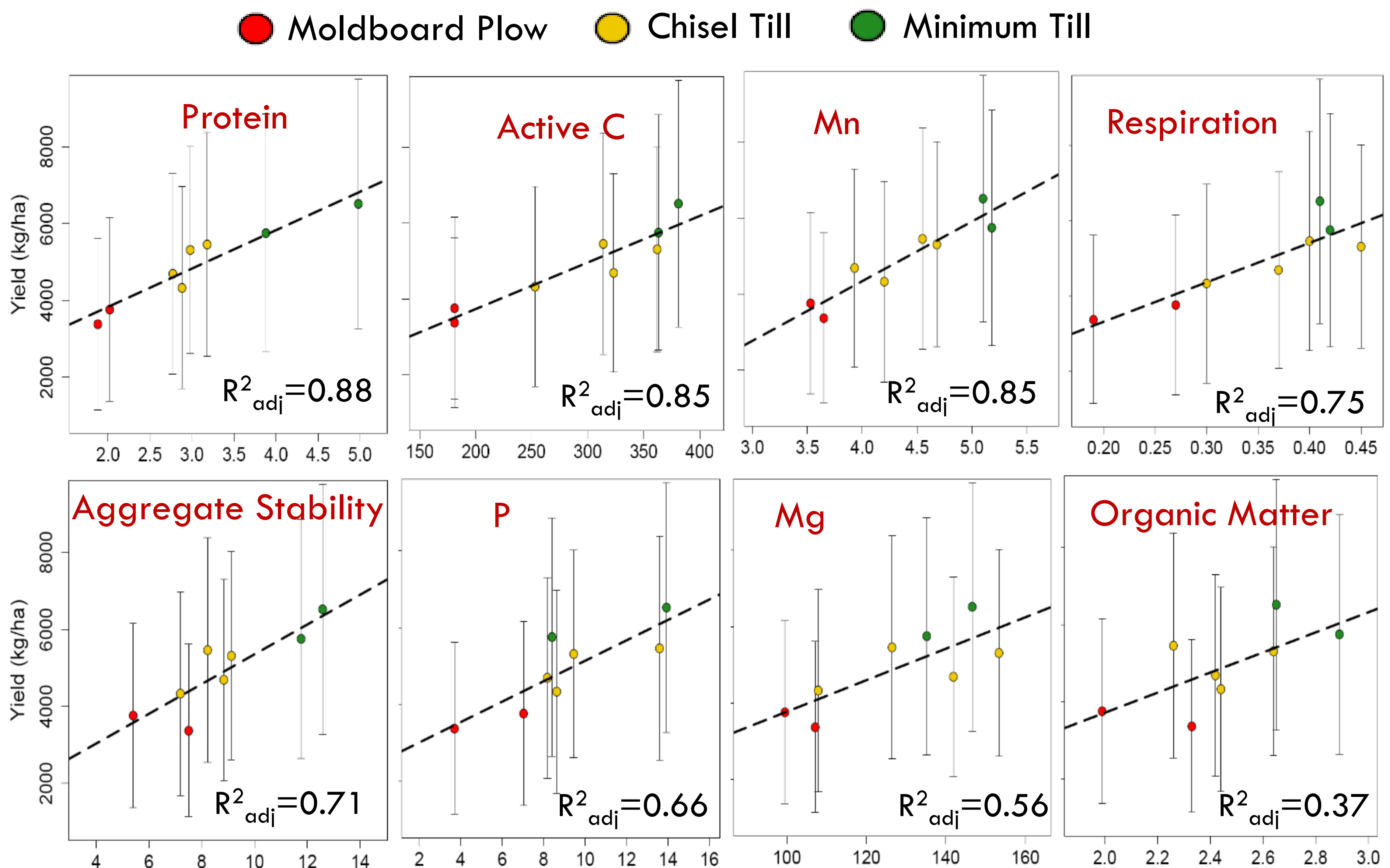
Maize Yield is related to Soil Health (soil protein)



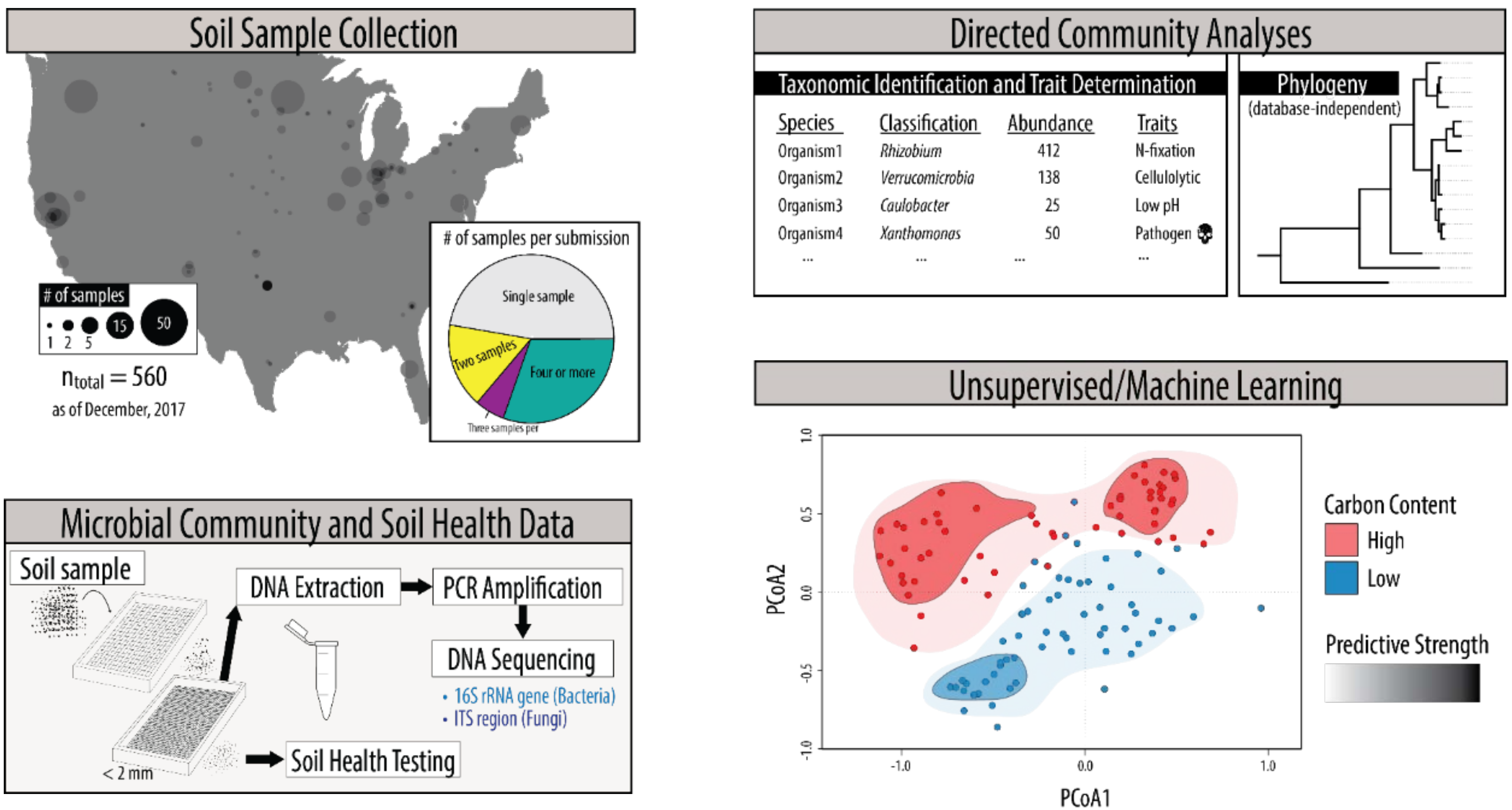
van Es and Karlen, 2019.
Data source: Roper et al., 2017

Soil Health Indicators and Yields – Corn

(ranked; significant at α=0.05; van Es and Karlen, 2019)

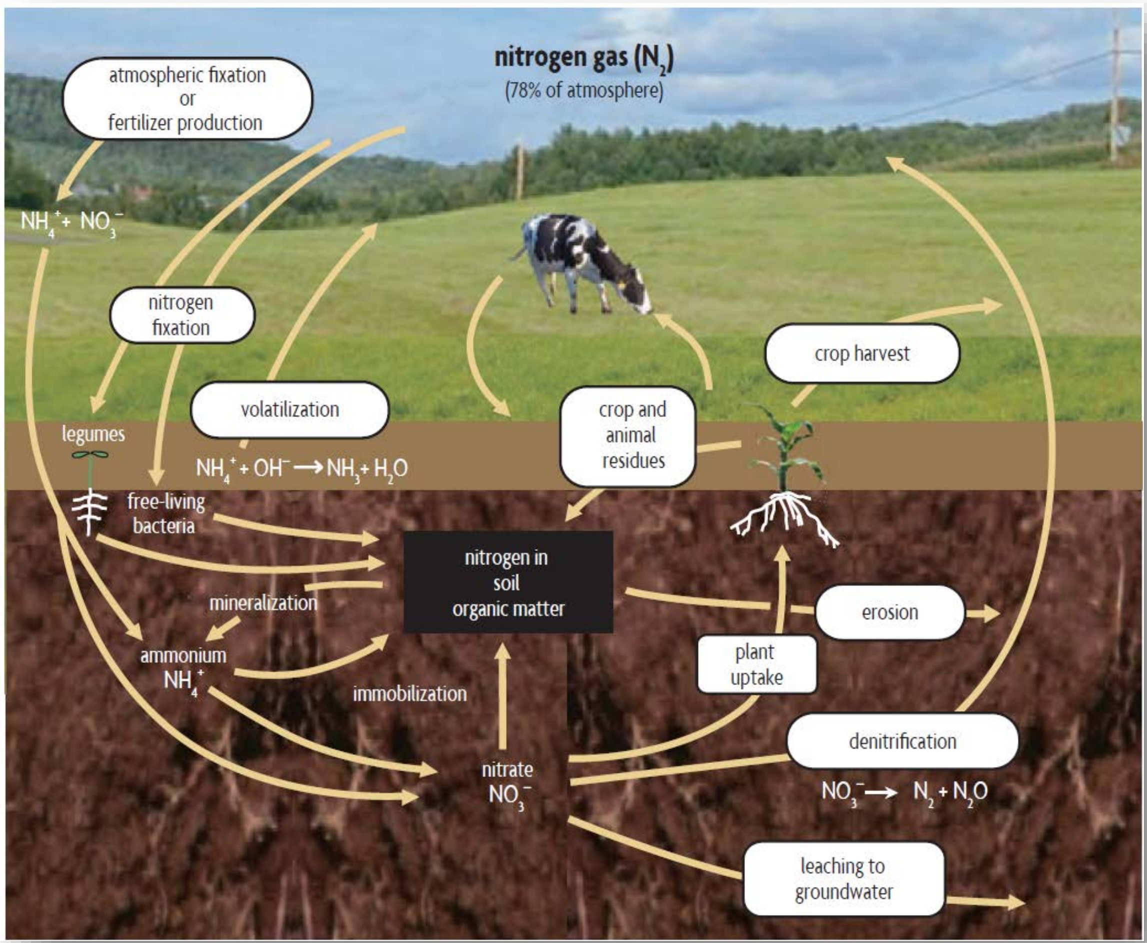


Microbial Community Analysis: Next Step?



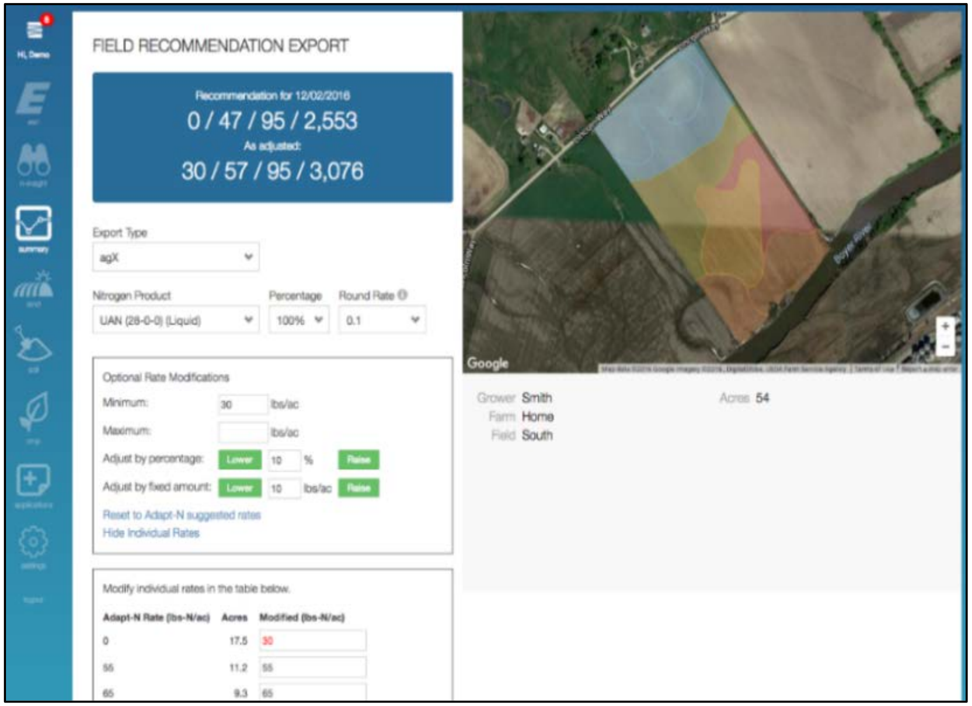
Slide by Roland Wilhelm

Using Soil Health Information to Manage Nitrogen



Adapt-N Integrates Soil Health into N Recommendations

- Soil organic matter
- Rotation effects
- Cover crop effects
- Rooting depth
- Enhanced efficiency products



Summary

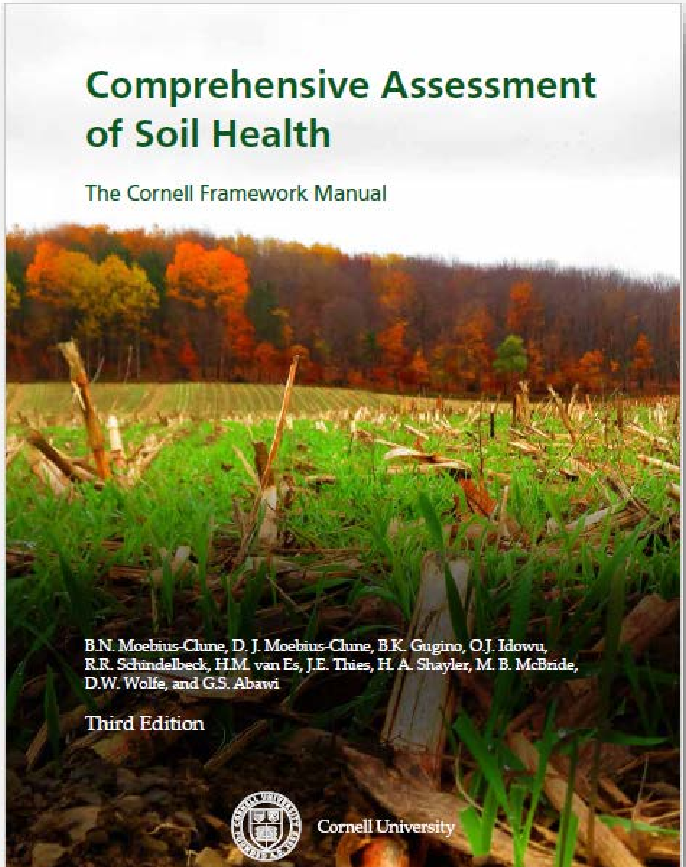
Soil Health

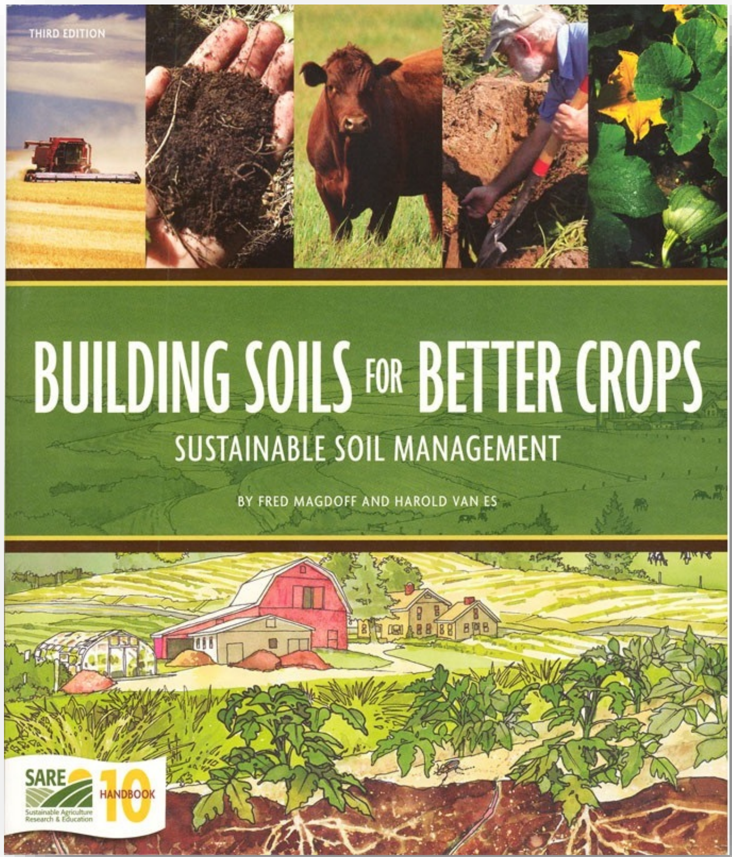
- Natural processes build soil health
- Management and economic forces degrade soil health

Soil Health Assessment

- Process and function focused
- Scoring functions to interpret values
- New insights from experiments
- Biological indicators are important

BOOKS
FREE - ONLINE!





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