Economics of Soil Health: Existing Research

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ok/soils/health/?cid=stelprdb1260243

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Qualifying Statement

"Thoughts and opinions presented today are those of the author and do not represent those of USDA or the Natural Resources Conservation Service."

Outline

- Objectives
- Definition of Soil Health
- Indicator/Index Research and Results
- Economics of Soil Health
- Conclusions

Objectives

- Find economic articles that establish a causal relationship or strong association between healthier soil ecosystems and
  - Crop yields,
  - Crop yield variability,
  - Profitability,
  - Variability of profitability.
- Summarize results.

Definition of Soil Health (NRCS)

- ***"… the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans"*** (NRCS, 2014).
- **Text supporting the definition:**
  - Almost always includes discussions about improving a soil's physical, biological and chemical properties.
  - Refers to on-farm benefits and off-farm benefits (ecosystem services).
  - "Managing soil ….should be an integral part of ag. decision making."

Model and First Set of Queries

$\boldsymbol{f}(\boldsymbol{y}, \boldsymbol{z}) = \boldsymbol{g}(\boldsymbol{x}, \boldsymbol{s})$

Where: y is a vector of annually produced crop outputs

z is a vector of annually produced ecosystem services

x is a vector of crop inputs and uncontrolled environment inputs (e.g., rainfall, degree days.)

s is an SH index composed of indicators ($\boldsymbol{s} = z(s_1, s_2, s_3 \ldots . s_n)$)

(Jaenicke and Lengnick, 1999)

- **Far fewer articles with economics and soil health/quality in the title than I expected.**

Indicator/Index Research

Shifted gears – Redirected my effort to the soil science literature.

Large number of studies

- *Identifying possible indicators/index,*
- *Describing measurement methodologies, and*
- *Comparing changes in indicator/index values between a base and alternatives (e.g., tillage systems, cover crops).*

Indicator/Index Research (cont.)

Positives

- Identification of many useable indicators and a few indices.
- Development of soil health management guidelines and supporting outreach materials (e.g., NRCS Indicators, Cornell Soil Health Report).

Example Framework:

Cornell Soil Health Assessment

- Advanced work from '90s and early 2000's by many soil scientists
- Publically available since 2006, revised 2014 with new indicators
- Measures 16 indicators
  - Representing agronomically important bio/phys soil processes
  - Includes std nutrient test
  - Standardized methods and minimum data set
  - Focus on individual indicators is key
- Identifies soil constraints
- Guide for management decisions
  - Report now includes explicit written interpretations and management suggestions table
  - Soil Health Management Planning Framework

Cornell Soil Health Assessment

Joe Vegland
123 Main St.
Anytown, NY, 12345

Agricultural Service Provider:
Smith, George
Jim's Consulting
George@jimsconsulting.com

Sample ID: A_123
Field/Treatment: Field
Tillage: No Till
Crops Crown: MIX, MIX, MIX
Date Sampled: 5/31/2014
Given Soil Type: Anytown
Given Soil Texture: Silt Loam
Coordinates: 42.44790 °N; 76.47570 °W

Measured Soil Textural Class: Silt Loam   Sand: 5%   Silt: 70%   Clay: 25%

Test Report

	Indicator	Value	Rating	Constraint
Physical	Available Water Capacity	0.13	28	Water Retention and Availability
Physical	Surface Hardness	148	62	
Physical	Subsurface Hardness	425	8	Subsurface Pan/Deep Compaction, Deep Rooting, Water and Nutrient Access
Physical	Aggregate Stability	22.5	26	Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff
Biological	Organic Matter	3.2	42	
Biological	ACE Soil Protein Index	6.5	35	
Biological	Root Pathogen Pressure	5.5	44	
Biological	Respiration	1.17	15	Soil Microbial Abundance and Activity
Biological	Active Carbon	391	12	Energy Source for Soil Biota
Chemical	pH	6.0	71	
Chemical	Phosphorus	9.3	100	
Chemical	Potassium	264.7	100	
Chemical	Minor Elements Mg: 419 Fe: 1.1 Mn: 12.9 Zn: 1.9		100	
	Overall Quality Score		49	Low

soilhealth.cals.cornell.edu

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

Indicator/Index Research (cont.)

Complicating Factors

- **NRCS review of physical & chemical properties:**
  - ***"No consistent evidence showed that <u>rotation practices</u> alone affect the physical properties of soils, at least in the short term. In the long term, the production of organic matter may affect some physical soil properties, such as aggregate stability. The effects, if any, vary according to the crop and type of rotation (NRCS, 2014b, p. 2)."***
  - **<u>Tillage practices</u> such as no-till do not appear to have immediate impacts on a soil's physical and chemical properties.**
  - **Commonly stated benefits of <u>cover crops</u> can be offset in arid regions.**

Conclusions - (Abbott and Murphy 2007)

- ***"The current inability to predict the outcome of a change in agricultural management on soil biological processes, with a subsequent understanding of what this means in terms of production or the environment, is a major constraint to the successful design of farming systems that harness the biological potential of soil (Abbott & Murphy, 2007, p. 2)."***
- **Scientists are working on identifying indicator variables and ways to measure and compare the variables by management activity.**

SH Indices – Results

Bastida et al. (2008): A universal, useful soil health formula has yet to be identified for the following reasons:

- Different methodologies with different standardizations.
- Soil heterogeneity.
- Soil and climate and vegetation interactions.
- Different understandings of the soil functions being investigated and applicable variables.

Economics of Soil Health (SH)

- **Even with mixed results, what economically related examples are in the literature?**
- **Most of the work is plot and practice-based (tillage systems and cover crops).**
- **Research groupings:**
  - Yields/profits (partial budgets) and some SH indicators compared.
  - Yields/profits compared and SH benefits assumed, or
  - Yields/profits compared, additional economic(?) analyses employed, and SH benefits assumed.

Yields/Profits and Soil Indicators

Two Example Articles:

- Karlen, D. L., Kovar, J. L., Cambardella, C. A., & Colvin, T. S. (2013). Thirty-year tillage effects on crop yield and soil fertility indicators. *Soil & Tillage Research, 130*, 24-41.

- Karlen, D. L., Cambardella, C. A., Kovar, J. L., & Colvin, T. S. (2013). Soil quality response to long-term tillage and crop rotation practices. *Soil & Tillage Research, 133*, 54-64.

30-Year Tillage-Fertility Study

- ISU – Boone County Univ. farm.
- Experimental design with replications.
- Corn/soybean and cont. corn.
- 5 tillage systems: moldboard, chisel, disk, ridge-till, and no-till.
- 13 soil indicators.
- Yields.
- Net returns (crop budgets).

30-Year Tillage-Fertility Study: (cont.)

- **Crop yields are not agronomically different across tillage systems and years (entire sample).**
- **Ridge-till and no-till yields are lower during 2003 to 2006 – Stratification of P and K.**
- **Net returns for no-till higher than the other systems (machinery expenses).**
- **Significant differences noted for P, K, and pH. Differences are small and not agronomically important.**

30-Year Tillage-Fertility Study: (cont.)

Second study focused on indicators and use of the Soil Management Assessment Framework

Physical - Water-stable macroaggregation (WSA) Physical - Bulk density (BD)	• SMAF values confirmed differences due to soil type. • Some indicator values – PMN, pH, Bray P, and BD – were functioning at their full potential across tillage systems and rotations. Others at less than full potential. • SQI values for no-till among the lowest across rotation, tillage, and soil depth.
Chemical - Electrical conductivity (EC) Chemical - pH Chemical - Extractable K (Ex-K) Chemical – Extractable P using Bray P1 reagent (Bray-P)	
Biological - Total organic carbon (TOC) Biological - Microbial biomass carbon (MBC) Biological – Potentially mineralizable N (PMN)	

30-Year Tillage-Fertility Study: (cont.)

Corn	Net Returns/ha	SQI (Loam)	SQI (Clay Loam)
Moldboard	$560	0.89	0.93
Chisel	$590	0.82	0.83
Spring Disk	$612	0.90	0.89
Ridge-Till	$571	0.91	0.89
No-Till	$620	0.74	0.72

(Note: Probably should focus on individual indictors)

Soybeans	Net Returns/ha	SQI (Loam)	SQI (Clay Loam)
Moldboard	$446	0.84	0.89
Chisel	$481	0.82	0.85
Spring Disk	$437	0.83	0.87
Ridge-Till	$471	0.83	0.90
No-Till	$483	0.74	0.65

SQIs calculations are for the 0 to 5 cm range. SQI values for no-till among the lowest in the 5 to 15 cm range.

Partial Budget: Organic Wheat/Fallow vs. Organic Wheat/Pea Cover Crop

Example: Yields/Profits ; Assumed SH benefits

EQIP – Laramie County, WY – 2009 to 2013 – 45 tracts

Base System:

- Organic wheat/fallow.
- Conventional tillage
- ~32 bu/ac of organic wheat every other year.

Conservation System

- Organic wheat/Austrian Pea cover crop.
- No-till planting into wheat stubble 70#/ac by Sept 30.
- Tillage of cover crop in May (existing practice)
- (Note: Strip Cropping-585 is also an existing practice in this area)

Adapted from Aaron Waller's (NRCS) work.

Example: Yields/Profits ;Assumed SH benefits

Partial Budget: Organic Wheat/Fallow vs. Organic Wheat/Pea Cover Crop (cont.)

Increased Revenue	**Increased Cost**
• Organic wheat yield increase • 6 bu/ac * $14.18/bu = **$88.80/ac** Other • Increased soil cover during high wind period • Less risk of low protein dockage in organic wheat • Less risk of low yield in drought years • Carryover nitrogen in subsequent years • EQIP Payment for Cover Crop (organic)=$61.40	• 70#/ac peas + inoculant * $0.55/lb = $38.50/ac • No-till drill = $15.31/ac • Spring cultivation = $0 (existing practice) Total Increased Cost = **$53.81/ac** Other • Potential negative: fallow soil moisture impact if peas are allowed to mature past May.
Net Benefits without EQIP payment = **$34.99**	

Irrigated Continuous Corn and Cover Crops - Mediterranean

Goal: Assess economic and environmental impacts of cover crops in an irrigated, continuous corn system.

Production Systems:

- Continuous corn with and without cover crops.
- Yields, CC biomass, and nitrate concentrations

Monte-Carlo Simulations to Assess Profitability:

- LN – Cover crop residue not sold; no change in N rate.
- LF – Cover crop residue not sold; cover crop N credit.
- SN – Cover crop residue sold; no change in N rate.

(Gabriel, Garrido and Quemada 2013)

Irrigated Continuous Corn and Cover Crops – Mediterranean (cont.)

- **Standard Comparison Analysis**
  - Corn yields were not correlated with cover crop biomass.
  - Cover crop reduced profitability.
- **Monte-Carlo Analysis:**
  - Cover crops increase corn yields, but not necessarily profits.
  - If cover crop biomass is sold, profits increase while nitrate leaching decreases.

Example: Meta-analysis – Winter Cover Crops and Corn Yields

- "**Meta-analysis**: A study of studies.
- **36 peer reviewed studies** (Miguez and Bollero 2000).
- **Cover crops**: legume, grass, biculture.
- **Dep. variable**: $\ln(\text{Yield}_{WCC}/\text{Yield}_{NC})$.
- **Independent variables**: Cover crop (categorical); study; fertilization rate; cover crop x fertilization rate; region; and within study and other random effects.

Example: Meta-analysis Results – Winter Cover Crops and Corn Yields (cont.)

Further research needed on the roles tillage, seeding rates, kill date, etc.

- **Corn yields following biculture WCC:**
  - 21.5% higher than corn following no cover crop.
  - High variance; small number of observations.
- **Corn yields following grass WCC:**
  - No different than corn yields without a WCC.
- **Corn yields following a legume WCC:**
  - 24 percent higher than corn without a cover crop and no N applied.
  - No difference at high N rates.

Conclusions to Date

- **Soil health is an intuitive, appealing concept.**
- **Indicator/index and economic research results are mixed.**
- **This workshop is a step forward.**
- **More interdisciplinary research and education are needed to solve this problem.**

Thanks!

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