A one step simplified indicator for rating soil quality

Obade Vincent de Paul and Rattan Lal

The Ohio State University

INTRODUCTION

Soil quality is defined by its chemical, physical and biological characteristics (Figure 1), and is influenced by site-specific land use and management practices (Doran and Zeiss 2000; Lal, 2009; NRCS 2012; Stavi et al., 2011). The change in soil quality has significant effects on basic processes including biogeochemical cycling, and thus global warming, soil erodibility, and biodiversity. Despite the significance of soil quality as a critical environmental variable, our knowledge of soil quality dynamics remains vestigial. Predicting the effects of soil quality changes is particularly limited by (i) uncertainty at variable scales, (ii) generalization, (iii) data quality issues, and (iv) incorrect algorithms and assumptions (Bouma and McBratney, 2013; Lal, 2009).

Soil quality indicators (SQI) may be qualitative, quantitative or both. SQI's may: (i) rate the soil under management relative to soil under some control (e.g., soil under natural vegetation), (ii) relate SOC (a proxy of soil quality) to the combination of the remaining measured soil physicochemical and biologic properties, or (iii) be based on the capability of the specified soil to perform specific functions (e.g., agronomic yields). This study demonstrates a simplified approach for developing a SQI. Precise information on soil quality is critical for developing sustainable agro-ecosystems that can ensure sufficiency in food, water and energy to humanity.

Definition
- soil physical, chemical and biologic components and interaction between these.
- soil capacity to continuously support ecosystem functions.

Problems
- uncertainty at multiple scales (e.g., time)
- soil spatial heterogeneity (e.g., depth)
- abstraction (soil generalization)
- data quality, sample size and design
- model limitations (incorrect algorithms) and assumptions

Soil Quality Index (SQI)

SQI Requirements
(i) simple, (ii) measurable, (iii) sensitive at all scales, (iv) applicable widely, and (v) validated from easily obtainable data sets.

Model and Parameters
qualitative: munsell color chart, visual
quantitative: math & statistical
parameters SOC, ρ_b, available water capacity, electrical conductivity, soil nitrates, pH, yield

Figure 1. soil quality index (SQI) intricacies.

MATERIALS AND METHODS

- Soil sampled between April and May, 2012, at depths (i.e., 0-10, 10-20, 20-40, 40-60 cm) within Ohio, USA (Table 1).
- Management: NT with/without manure (M), cover crops (cc), natural vegetation (NV), and conventional tillage (CT).
- CT fields at Miami, Seneca, and Preble chisel plowed to 20 cm depth, Auglaize site was disked.

Table 1.
Sampling locations, crop sequence, management practices in Ohio. Soil type description follows the *USDA soil classification system*.

Site	Coordinates	Soil type	Crop sequence	Management
Miami	40° 10' 12" N, 84 °07' 41.7" W	CrA	csc	NV, NT, NTcc, CT
Seneca (1)	41° 00' 25" N, 85 °16' 21" W	kbA	ccs	NV, NTccm, NTcc, CT
Seneca (2)	41° 12' 43" N, 82 °54' 39" W	GWA	csc	NV, NTcc, CT
Preble	39° 46' 09" N, 84 °36' 52" W & 39° 41' 45" N, 84 °40' 36" W	CtA	ch	NV, NT, CT
Auglaize	40° 27' 34.5" N, 84 °26' 14.8" W	P_w	c	NV, NT, CT

CrA (Crosby silt loam)
kbA(Kibbie fine sandy loam)
GWA (Glynwood silt loam)
CtA (Crosby Celina silt loams)
P_w (Pewamo silty clay loam)
cc: cover crop
m: manure

CT: Conventional Tillage
NT: No Till
NV: Natural Vegetation (e.g., forest)
c: corn
s: soybean
h: hay

- **SQI** computed using ***soil organic carbon (SOC) concentration*** as the dependent variable, and the soil bulk density (ρ_b), available water capacity (AWC), total nitrogen, pH, electrical conductivity (EC), management, sites and depth as the independent variables.
- SQI modeled by **(i) stepwise regression**, and **(ii) stepwise regression with Principal Component Analyses (PCA)**, and computed in SAS 9.2 using proc princomp and proc reg (@ $p< 0.05$).
- R^2 indicates model accuracy i.e., a low R^2 indicated a poor fit, and vice versa.

RESULTS & DISCUSSION

- Table 2 lists the mean values and variability of the soil properties. Interpreting mean soil property values may be challenging, however the values may provide an indication of the soil health status (e.g., high soil ρ_b indicates compaction which affects plant root survival and nutrient uptake).
- Large variability in total N, EC and SOC, could partially explain the difficulty in soil quality prediction from these parameters.

Table 2.
Mean of soil properties from 0-10, 10-20, 20-40 & 40-60 cm soil layers under different management within Ohio. *n = 214

Soil Property	*Mean	Standard Deviation
ρ_b (Mg m^{-3})	1.48	0.17
Porosity	0.44	0.07
AWC (cm^3 of water cm^{-3} of soil)	0.16	0.05
Total N (Mg ha^{-1})	3.75	1.74
pH	6.67	0.60
EC (µS cm^{-1})	478.81	269.24
SOC (Mg ha^{-1})	38.47	18.77

Key
AWC: Available Water Capacity
EC: Electrical Conductivity
Total N: Total Nitrogen concentration
SOC: Soil Organic Carbon concentration
ρ_b Soil bulk density (Mg m^{-3})

Table 3 is the correlation analyses for soil property variability with management and site whereby:
- SOC was negatively correlated with AWC, management and ρ_b, but positively with soil depth.
- Site positively but weakly determined AWC (r of 0.21), and negatively with pH (-0.16)
- EC and SOC varied negatively with ρ_b.
- Total N and SOC were highly correlated (i.e., 0.97).

Table 3.
Correlation matrix for the soil properties measured

	Management	Site	Soil depth	ρ_b	Porosity	AWC	Total N	pH	EC	SOC
Management	1.00									
Site	-0.26	1.00								
Soil depth	0	0	1.00							
ρ_b	0.34	0.07	0.37	1.00						
Porosity	-0.35	-0.05	-0.38	-1.00	1.00					
AWC	-0.28	0.21	-0.20	-0.40	0.41	1.00				
Total N	-0.24	0.07	0.40	-0.20	0.19	-0.26	1.00			
pH	0.34	-0.16	-0.11	-0.14	0.13	-0.21	0.25	1.00		
EC	0.19	0.01	-0.42	-0.50	0.50	-0.07	0.19	0.49	1.00	
SOC	-0.26	0.02	0.40	-0.24	0.23	-0.25	0.97	0.21	0.19	1.00

Models (i) and (ii)

SQI = 4.22 + 10.52 × Total N **R^2=0.95** **(i) Stepwise regression**

SQI = 38.47 + 10.14 × Prin 2 + 5.07 × Prin 1 + 6.33 × Prin 7 – 2.24 × Prin 3 + 13.25 × Prin 9 + 1.28 × Prin 6 – 1.09 × Prin 8 – 0.30 × Prin 4 – 0.29 × Prin 5
R^2 = 1 **(ii) Stepwise regression + PCA**

Prin. are the respective Principal Component (PC)

- Based on R^2, **the stepwise plus PCA (i.e., ii)** had a better fit therefore good for assessing interactive factors influencing soil quality.
- For practical comparative purposes across sites, a high soil quality is reflected by larger SQI value computed from soil properties.
- Limitation include uncertainty in interpolation across regions where data not collected. i.e., model NOT generic.

CONCLUSION

- Study found that the stepwise regression provides a simplified SQI model (i.e., SQI directly related to only total N). However, combining the stepwise regression with a PCA provides a weighted approach that integrates all the soil property variables, and has relatively higher R^2, therefore is more accurate.
- A blend of stepwise and PCA though complex, may be critical for assessing SQI under varying soil management, ρ_b, EC, pH, soil depth, porosity, AWC, total N, and soil texture because of greater model accuracy than using only the simple regression.
- Future research will design a normalization and validation protocol for the model.

REFERENCES

Bouma, J. & McBratney, A.: 2013, 'Framing soils as an actor when dealing with wicked environmental problems', Geoderma 200-201, 130-139.
Doran, J. W. & Zeiss, M. R.: 2000, 'Soil health and sustainability: managing the biotic component of soil quality', Applied Soil Ecology 15, 3-11.
Lal, R.: 2009, 'Challenges and opportunities in soil organic matter research', European Journal of Soil Science 60, 158-169.
NRCS: 2012, 'Soil quality concept', Natural Resources Conservation Service (NRCS).
Stavi, I., Lal, R. & Owens, L. B.: 2011, 'Effects of cattle grazing during the dormant season on soil surface hydrology and physical quality in a moist temperate region', Ecohydrology 4, 106-114.

This research is part of a regional collaborative project supported by the USDA-NIFA, Award No. 2011-68002-30190 "Cropping Systems Coordinated Agricultural Project (CAP): Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems"
sustainablecorn.org

SUSTAINABLE CORN.ORG
CROPS, CLIMATE, CULTURE AND CHANGE

United States Department of Agriculture
National Institute of Food and Agriculture