Prototype Development of a New Soil Index Using the Econometric Method: Data Envelopment Analysis

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History of Soil Concepts & Quantitative Aspects

Dates	Major Concepts	Selected Major Authors
1977	Soil Quality	Warkentin and Fletcher, 1977 SSSA*, 1987
1990s	Soil Health Soil Health Index Soil Quality In/Ix	Larson and Pierce, 1991 Doran and Parkin, 1994 Karlen et al. 1997 Andrews et al. 2002…etc
2010s	Soil Security	Brauch and Spring. 2011 Bouma and McBratney. 2013 Koch et al. 2013 McBratney et al. 2014 Grunwald et al. 2016

*SSSA: Soil Science Society of America

- ✓ Integral soil concepts (quality, health, security) have been quantified with indication system.
- ✓ However, most of the published soil indicator/index systems do not meet axiomatic indication criteria (listed below)

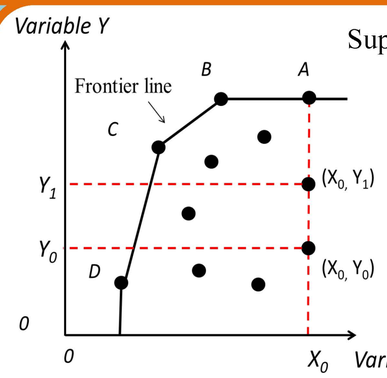
Popular Methods for Environmental Index Development

- ✓ Ordination techniques and related methods (e.g., principal component analysis, correspondence analysis, factor analysis) have been used often to develop soil and environmental indices.
- ✓ However, those indices require local calibration, which does not meet the axiomatic criteria for a scientifically ideal index.
  - ➢ Transitivity: The index is consistent in space.
  - ➢ Time-reversibility: The index is consistent in time.
  - ➢ Dimensionality: The index is robust in having variables with different units.
- ✓ The Data Envelopment Analysis (DEA) can meet these criteria.

Objectives

To construct a prototype Data Envelopment Analysis (DEA) to assess soil functions quantitatively. Specifically, we developed the Soil Carbon Sequestration (SCseq) Capability indicator/index (SCI) in Florida.

Theory of DEA method



Supposed…variable x: nutrition loading
variable y: crop yield

The calculation flow:

1. Calculate the frontier line
2. Calculate the minimum distance from each point to the line

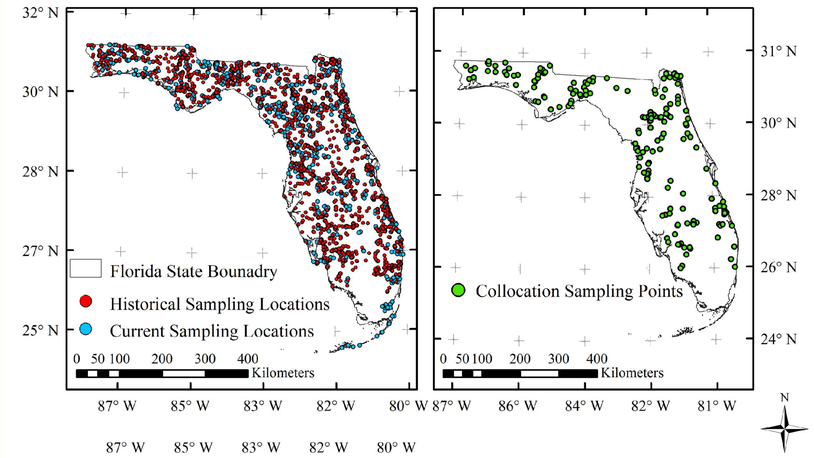
A and B: Most productive
C: More productive than D

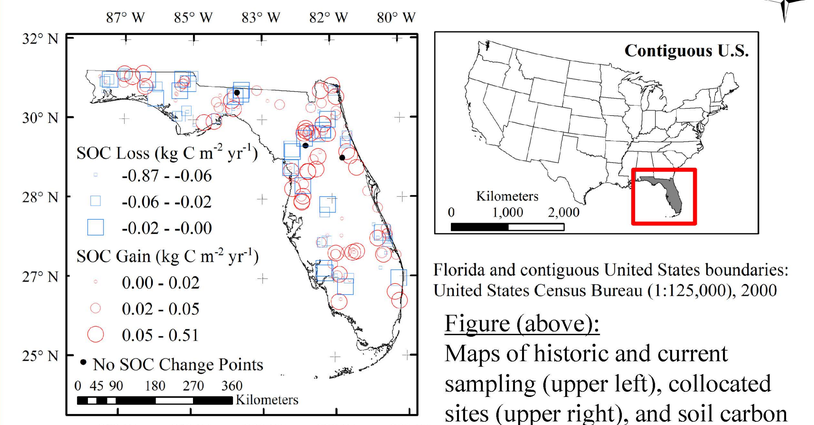
Fig. Illustration of the DEA concept in case of two inputs.

Datasets, SCseq in Florida and Work Flow

$$\frac{SOC_{current\ stock} - SOC_{hisotic\ Stock}}{\text{Number of years between the sampling periods}} = SOC\ seq$$

Sampling Period	2008-'09	1965-'96
Sampling Sites	1080 sites	1251 site-specific soil profiles
Sampling Design	Stratified random	Expert knowledge based





Florida and contiguous United States boundaries: United States Census Bureau (1:125,000), 2000

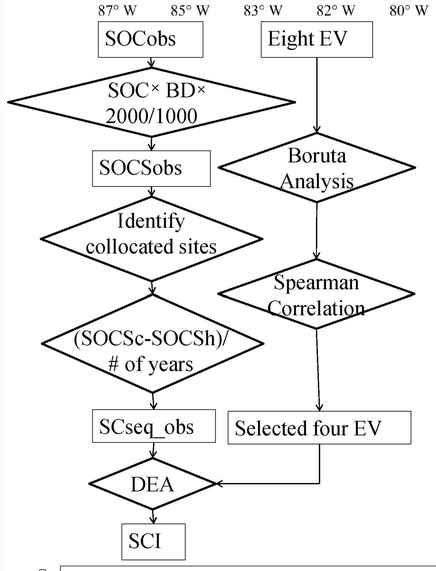
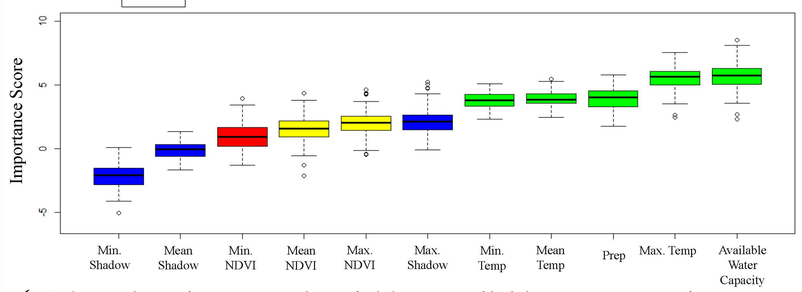


Figure (above):
Maps of historic and current sampling (upper left), collocated sites (upper right), and soil carbon sequestration rate (lower left).

Figure (left):
Schematic workflow for indicator calculation using Data Envelopment Analysis. The selected four environmental variables (EV) include available water capacity (AWC), annual mean temperature and precipitation, and normalized difference vegetation index (NDVI).

Figure (below):
Importance (Z-score) of all-relevant variables to infer on soil carbon sequestration rate (kg C m^{-2} yr^{-1}) identified by the Boruta variable selection method.



- ✓ Selected environmental variables: Available water capacity, annual mean temperature and precipitation, and mean NDVI

Results and Discussions

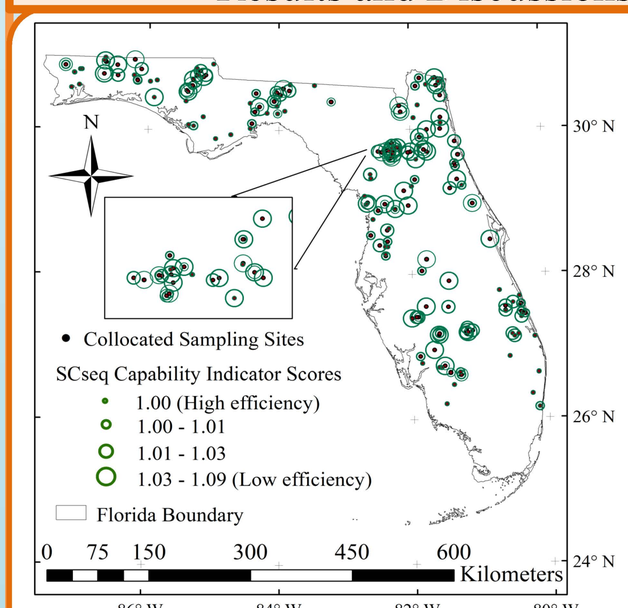
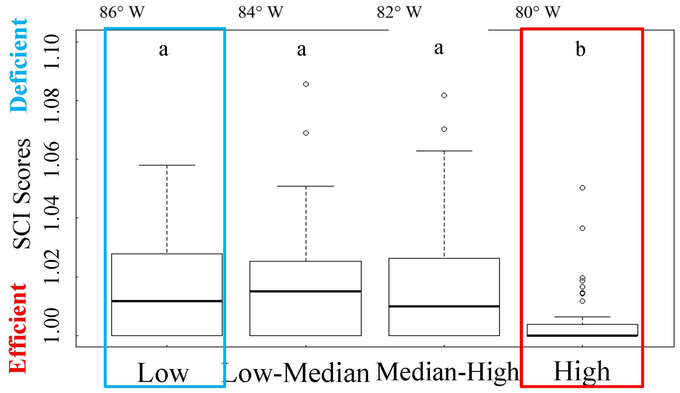


Figure (left): Maps of soil carbon sequestration indicators/indices (SCI) at the collocated sites in the State of Florida.

Figure (below): Soil carbon sequestration indicators/indices (SCI) by available water capacity classes based on quartile classification scheme.



Low: (<1.4 cm)
Low-Median (1.4-1.8cm)
Median-High (1.8-2.3 cm)
High (>2.3 cm)

- ✓ The observed SCI scores (1.00 ~ 1.09) with values close to 1 express high capability for carbon storage.
- ✓ The SCseq capacity is statistically greater in soils with more water capacity than in low water capacity soils.

Conclusions

1) The available water capacity, annual mean temperature and precipitation, and NDVI were selected as important environmental variables to calculate the SCI.
2) The SCI scores allow comparing the spatially-explicit efficiency of carbon accretion as they relate with environmental conditions, such as climate.
3) The SCI scores enable to discern areas with efficient SCseq capability from deficient sites; and thus, guide management.
4) The DEA provides a new indication assessment method for soil science to quantitatively determine soil concepts (quality, health, and security).

Acknowledgements

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