# The Contribution of Spectroscopic Measurements in Characterizing Variability in SOC and Scalability to Temporal Monitoring Regimes

Elaine Viglione, Alison Grantham, Rita Seidel, and Christi Gabriel

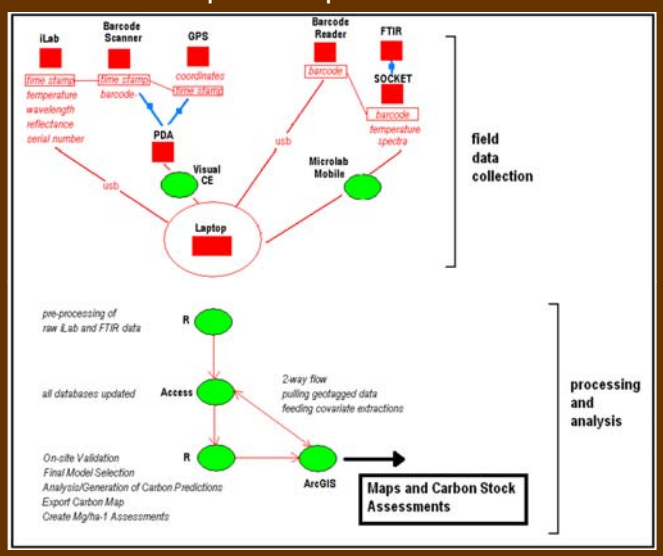
## Introduction

The objective of the following analysis is to investigate the effectiveness of portable and handheld instruments in modeling and measuring carbon variability in a previously unsampled field setting. Monitoring soil carbon quantity, temporal change, and spatial distribution in various farming practices is important for identifying practices that enhance carbon sequestration. In order to do this, we need to understand the soil carbon variability, particularly when designing studies to detect soil carbon change. Soil carbon variability is different depending on site and practice; therefore rapid and effective methods are needed to make a variability assessment early in the investigation of soil carbon at a new location.

## Introduction to the Mobile Field Laboratory

**The Mobile Field Laboratory (MFL)** is a suite of technologies designed to map carbon concentration predictions live in the field from fresh soil samples. It includes a handheld visible spectrophotometer, a portable mid-infrared spectrometer, a rugged laptop-operated Geographic Information System (GIS), an associated Global Positioning System (GPS), and a completely integrated database that includes handheld field computers with data entry forms. The MFL uses the concepts for nondestructive soil sampling that have growing momentum in the research community. For example see Viscarra Rossel et al., 2006, for a discussion of using multiple spectroscopic instruments for measuring soil carbon to take advantage of the rapid and inexpensive potential of in-field measurement.

**Workflow:** The schematic at the right shows the key hardware and software components, bluetooth and USB connections, and subtasks that contribute to the MFL work flow.




# Study Site

## THE RODALE INSTITUTE FARMING SYSTEMS TRIAL (FST)

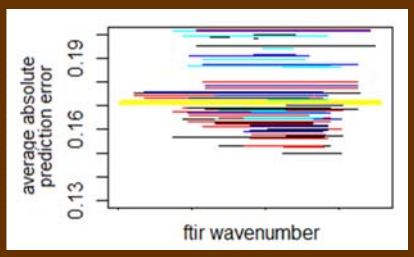
In 1981, Rodale Institute established 8 replications of 3 cropping systems over 12 acres of a complex soil landscape in southeastern PA. The soil ranges from fine-loamy mixed superactive mesic Oxyaquic Fragiudalfs (Alfisol) to loamy-skeletal mixed active mesic Typic Dystrudepts (Inceptisol). Each replication is subdivided into 3 entry points, which allows comparison between multiple points in the cropping rotation within a single year.

The model selection portion of this study was conducted on the first four reps of this trial, located mainly in the upper portion of the map at the left.

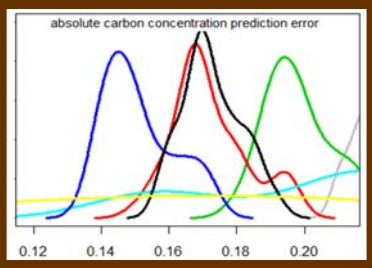
This variability study focused on 4 of the 72 replication/cropping system/entry point combinations. This subset of plots were all in the same farming system and rotation. The variability study plots are highlighted in yellow at the left.

# Methods – Model Selection

We conducted a series of validations based on CN-analyzed soil samples archived from 2009 in FST. All validations used the one-out method, i.e. we removed a single sample at a time, estimated a carbon prediction model from the remaining data, predicted the holdout value's carbon value, and then compared it to the CN carbon value. Wave number combinations from both instruments were allowed to vary as part of this model comparison process. Models with the best prediction metrics were advanced to further analysis until a final model was selected.

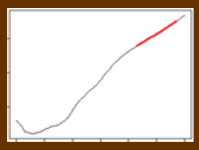



This error metric analysis involves comparing the FTIR prediction results across different models (colors) and wave numbers (horizontal bands).

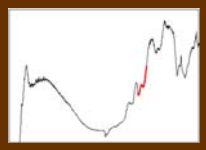



This error metric analysis is comparing Partial Least Squares Regressions (PLSR) involving both single- and dual- instrument data.

The final model selected was a 3-component PLSR, using the red-shaded portions of both spectra below.



visible

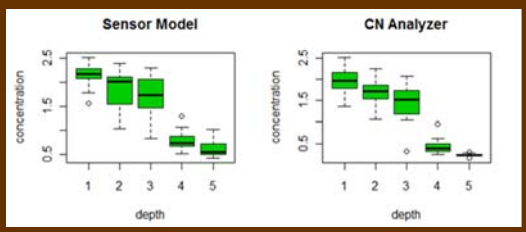


mid-IR

# Methods – Variability Data Collection

SAMPLING METHODS: We pulled 5 soil cores from each of the 4 plots, at 60-foot spacing, with a tractor-mounted Giddings probe, to a depth of 60 cm. We immediately sampled the visible transmittance of each core at 2-cm intervals, via direct contact with a handheld visible spectrophotometer (Microptix iLAB); we then split the cores into depth increments at 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, and 30-60 cm. We milled and sieved to 2-mm, dried at 50 degrees C for 48 hours, compressed into weigh cups, and read the mid-infrared absorbance with FTIR (A2 Technologies' Exoscan).

Finally, we moistened the sample and read the visible transmittance with the same handheld visible spectrophotometer used in the field. In total, we collected data on 4 plots, at 5 locations each, and at 5 depths per location, for a total of 100 samples. For later validation, we had each of these 100 samples analyzed with an EA 1110 CHNS model analyzer.

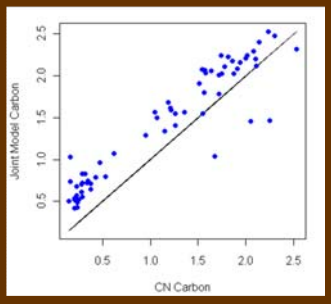



Comparison of modeled carbon predictions vs CN analyzed carbon data for the test plots.

| Depth Increments | |
|---|---|
| 1 | 0-5 cm |
| 2 | 5-10 cm |
| 3 | 10-20 cm |
| 4 | 20-30 cm |
| 5 | 30-60 cm |

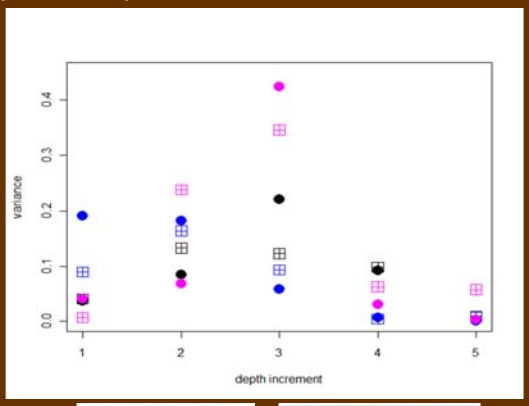
# Results

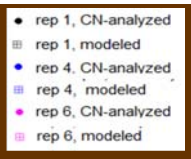
## PREDICTIVE PERFORMANCE




This graphic shows the predictive performance of the 2010 sampling ($r^2$=0.88 and RPD=2.87, with a noticeable positive bias), using the model built on 2009 FST data. The 2010 data will in turn be used for ongoing model validation studies.

**VARIABILITY ANALYSIS:** For each of the plots, we analyzed the variance in carbon concentration for the five subplot points at each depth stratum. For example, in plot 431, we computed the variance of all five 10-20 depth increment samples, to arrive at the blue symbols at depth three below. The solid dots represent CN-analyzed carbon variances, the squares represent the carbon variances using the 2009 data model.



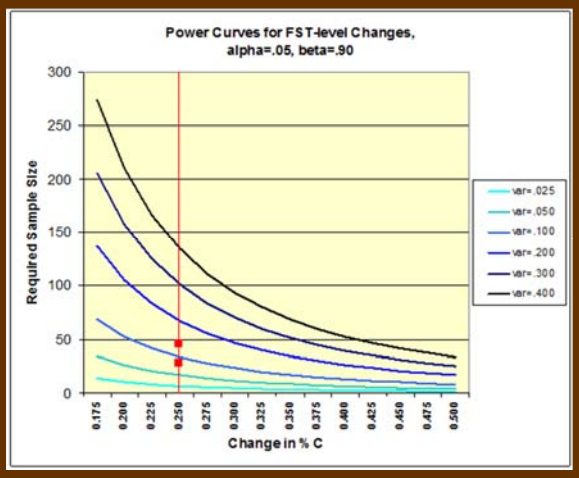

| Depth Increments | |
|---|---|
| 1 | 0-5 cm |
| 2 | 5-10 cm |
| 3 | 10-20 cm |
| 4 | 20-30 cm |
| 5 | 30-60 cm |

| depth | rep1 | rep4 | rep6 |
|---|---|---|---|
| 0-5 | 0.90 | 0.08 | 0.08 |
| 5-10 | 0.78 | 0.68 | 0.43 |
| 10-20 | 0.72 | 0.21 | 0.42 |
| 20-30 | 0.79 | 0.57 | 0.22 |
| 30-60 | 0.50 | 0.06 | 0.04 |

The table lists the p values of a Morgan-Pitman test for equal variances. When comparing the two instruments' carbon measurements, the test fails to reject a hypothesis of equal variances in almost every case at the p=0.05 level.

# Conclusion and an Application

The variability of the MFL-measured carbon shows general comparability to that of carbon measured by traditional methods. It is known that higher variability tends to obscure detection of temporal changes in soil carbon (for example, Ellert et al., 2002). Some knowledge of a new site's carbon variability in advance of baseline sampling would allow more control over the statistical power of a change detection study. The MFL instrumentation affords a way to obtain a variability estimate quickly and with minimal expense. Suppose we have set up a paired t-test for carbon change detection, and would like to detect a 0.25% change in soil carbon, with 90% power, in rep 1 at 5-10 cm. The sample size calculations for the respective methods are shown; both would recommend under 50 samples, with the MFL recommending slightly more. This is more input to the study design than we would otherwise have, and can guide our final sample size determination.




Adapted from Carter and Gregorich, 2007


# Acknowledgements

Funding for this work was provided by the Pennsylvania Department of Environmental Protection Energy Development Authority and the Rodale Institute (RI).

Christine Ziegler (RI), Steven Meckler (Penn State), Tim Smith (RI), Jennifer Tillman (RI), Molly Lohman (RI), Sandra Wayman (RI), Owen Maguire (RI), Dave Matz (RI), Frank Higgins (A2), and Drs. Ephraim Govere and Douglas Archibald (Penn State) contributed to various aspects of the field lab development, sampling activities, data analysis, sample processing, and editing.


# References Cited


Ellert, B.H., Janzen, H.H., Entz, T., 2002, Assessment of a Method to Measure Temporal Change in Soil Carbon Storage, Soil Sci. Soc. Am. J.66:1687–1695.

Viscarra-Rossel, R.A., Walvoort, D.J.J., McBratney, A.B., Janik, L.J., and Skjemstad, J.O., 2006, Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties, Geoderma 131, 59-75.

Carter and Gregorich, 2007, Soil Sampling and Methods of Analysis, Second Edition, CRC Press.