# Can field-based spectroscopic sensors measure soil carbon in a regulated carbon trading program?

**Eric D. Lund**

Veris Technologies, Inc., Salina KS USA, www.veristech.com

**Abstract**
Measuring changes in soil carbon is a daunting task, as soil carbon levels can vary significantly at short distances. Uncertainty about soil carbon measurements is affecting agriculture's consideration as an offset provider under a regulated greenhouse gas program, such as cap-and-trade. Purchasers of carbon offsets must be assured that carbon changes are real, and not just an artifact of sampling locations. To complicate matters further, measurements must include the soil profile, making this a three-dimensional effort. Veris Technologies has developed a system that employs a suite of sensors, including near-infrared spectroscopy, to measure carbon throughout the soil profile. The system was deployed on a set of nine fields in Kansas USA, with the objective of establishing a baseline soil carbon inventory. Lab-analyzed soil samples were used to calibrate and cross-validate the field sensors, and confidence intervals from sensors and lab were compared.

**Key Words**
near-infrared, spatial variability, cap-and-trade, spectrometer, soil electrical conductivity

**Introduction**
Since 1850, soils have lost an estimated 78 Gt of carbon, primarily due to cultivation (Lal 2009). This loss of soil carbon represents a significant portion of greenhouse gas emissions, and has resulted in the degradation of agricultural soil quality worldwide. Using practices that restore carbon, such as no-till farming, carbon can be sequestered in the soil. Carbon sequestration has the potential to offset fossil fuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions (Lal 2004).

Under a carbon trading system, farmers and landowners would be paid for adopting carbon-sequestration techniques, provided their increases in carbon can be measured, monitored and verified. Accounting for soil carbon changes is difficult, because carbon increases due to farming practice changes are very small, and carbon varies widely within a field, even within a few meters. What causes soil carbon spatial variability? In addition to the macro factors such as soil formation, soil type, and historical land use, there are many micro-scale influences: crop residues are distributed unevenly from combine harvesters, heavy rains remove and deposit piles of residue sporadically, animals defecate and die in random locations, and many other factors add variations.

In order to verify that carbon has been sequestered, a baseline must be established at the beginning of the project, along with subsequent measuring to verify the carbon change. The amount of carbon that is accredited will be based on the confidence, likely at the 90% level, of those measurements (Willey and Chameides 2007). The confidence interval is determined by the number of samples and the variability of the carbon. If the standard deviation is large, additional samples are required to reduce the confidence interval. If the sampling rate is insufficient, the carbon payment discount due to the uncertainty will be large. If an adequate number of samples are collected, the cost of conventional soil sampling and lab-analysis could be excessive. An alternative that generates large numbers of carbon analyses at a very low cost per sample must be considered. Near-infrared reflectance (NIR) spectroscopy has been shown to correlate well with soil carbon (Sudduth and Hummel 1993; Reeves *et al.* 1999; Shepherd and Walsh 2002). NIR spectroscopy and other proximal field sensors were tested in a soil carbon project on a set of nine fields in northeast Kansas. The objective for this project was to establish baseline soil carbon measurements on land that is currently under contract to produce greenhouse gas reduction and offsets. These measurements were intended to provide quality assurance of the initial carbon levels for the greenhouse gas offsets that will be produced on these lands, and to generate information about costs of carbon quantification.

**Materials and Methods**
A commercially available system from Veris Technologies that maps the surface and the soil profile to a depth of one meter was used on this project. The system is comprised of two modules: an on-the-go shank for collecting measurements at a discrete depth as it maps transects across a field (Figure 1), and a probe for collecting measurements of the soil profile to a depth of one meter (Figure 2). Both modules collect visible

and NIR measurements (400-2200nm) through a sapphire window pressed directly against the soil, at a rate of 20 spectra per second with an eight nm resolution.

**Figure 1. (left) Veris shank-based spectrophotometer for near-surface mapping.**

**Figure 2. (right) Veris probe-based spectrophotometer for profile measurements.**

Auxiliary Veris sensors are deployed on the system, including soil electrical conductivity (EC), and probe insertion force. Soil EC measurements relate to soil texture, Vis-NIR spectra relate to soil carbon and moisture, and force is used along with the other sensors to estimate soil bulk density. This suite of sensors measures soil properties that affect existing carbon levels and future sequestration rates. Standard chemometrics procedures were used for developing soil-spectra calibrations, including principal components analysis (PCA) and partial least-squares regression (PLS). A proprietary sample selection technique was used to collect calibration/validation soil samples (Christy 2008).

Each field was mapped with the sensor shank implement on 20 m transects, averaging 40-50 data points per ha. From these maps and data, calibration/validation sites were selected using a combination of visual and geo-statistical criteria. At each calibration/validation site, the sensor probe was inserted to a depth of 60 cm. Soil samples from the calibration/validation sites were collected using the hydraulic probe (0-60 cm) and hand probe (0-15 cm). 229 soil samples were analyzed at Kansas State University Soil Testing Lab for carbon and nitrogen with a LECO CN2000 using a dry combustion method. Soil moisture and bulk density were measured in Veris Technologies' lab. Fields were probed with the sensor probe on an average one ha grid—resulting in nearly 500 additional insertions. After calibration with lab-analyzed samples, detailed estimates of carbon were generated, cross-validated calibrations are applied to the spectra, and maps were created (Figure 3).

Using sensor samples, the confidence interval is .29 Mg C/ha. A soil carbon multiplication factor of 1.1 for adoption of no-till farming has been proposed by the Intergovernmental Panel on Climate Change (Houghton *et al.* 1996). Depending on how the confidence interval will be applied by carbon aggregators and verifiers, that would mean more than 90% of a 10% increase in carbon would be verifiable. Alternatively, using 229 conventional soil samples resulted in a confidence interval of .77, nearly three times larger. Collection and lab-analysis of 2523 samples using conventional methods would have been significantly more expensive. An estimate of soil carbon in each field is shown in Table 2.

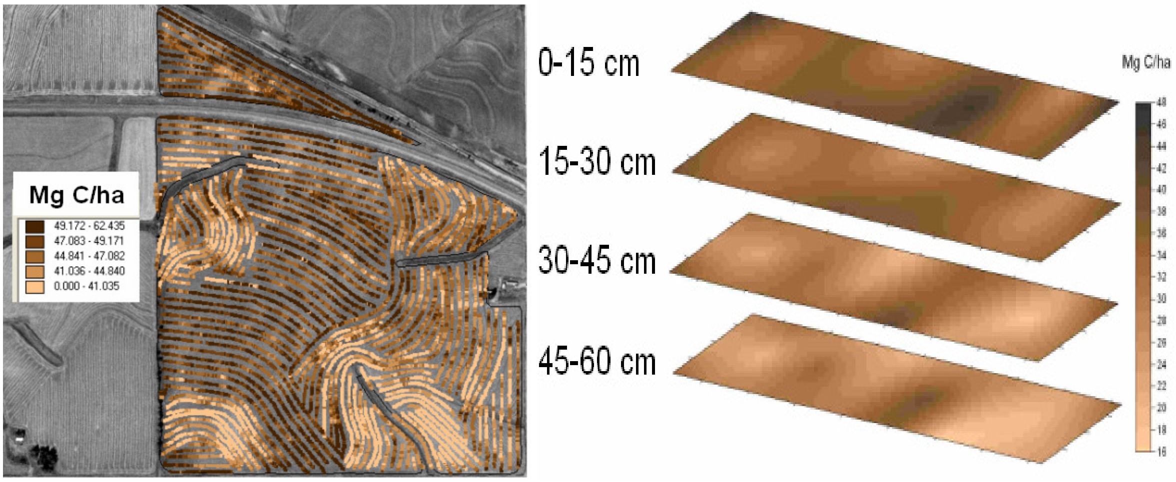

**Figure 3. Detailed sensor-based carbon estimates of near-surface (left) and soil profile (right).**

## Results

The soil sensor calibrations for carbon were highly correlated with lab-analyzed C. Ratio of performance to deviation (RPD) values ranged from 1.94 to 3.74 with an overall RPD of 2.19 (Table 1).

**Table 1. Results from Veris sensors and lab analyses for each field.**

| Field # | Ha | $R^2$ | RPD | RMSE-CV | Sensor samples | 90% C. I. Sensors | Lab Samples | 90% C. I. Lab |
|---|---|---|---|---|---|---|---|---|
| #1 | 59.13 | 0.86 | 2.77 | 5.20 | 613 | 0.41 | 26 | 1.68 |
| #2 | 21.06 | 0.93 | 3.74 | 2.94 | 146 | 1.19 | 22 | 1.03 |
| #3 | 48.60 | 0.73 | 1.96 | 6.13 | 253 | 0.61 | 25 | 2.02 |
| #4 | 40.50 | 0.91 | 3.50 | 3.30 | 264 | 0.68 | 23 | 1.13 |
| #5 | 59.54 | 0.72 | 1.94 | 7.25 | 83 | 1.82 | 26 | 2.34 |
| #6 | 91.13 | 0.76 | 2.05 | 9.19 | 459 | 0.74 | 40 | 2.39 |
| #7 | 57.11 | 0.83 | 2.44 | 6.25 | 233 | 1.15 | 26 | 2.02 |
| #8 | 59.13 | 0.76 | 2.07 | 7.93 | 216 | 1.23 | 25 | 2.61 |
| #9 | 51.84 | 0.82 | 2.41 | 6.57 | 256 | 1.17 | 16 | 2.70 |
| TOTAL | 488.03 | 0.79 | 2.19 | 7.11 | 2523 | 0.29 | 229 | 0.77 |

**Table 2. Total baseline soil carbon at four depths in each field.**

| Field # | Ha | Mg C/ha 0-15 cm | Mg C/ha 15-30 cm | Mg C/ha 30-45 cm | Mg C/ha 45-60 cm | Mg C/ha 0-60 cm |
|---|---|---|---|---|---|---|
| #1 | 59.1 | 36.9 | 33.7 | 30.3 | 28.0 | 128.9 |
| #2 | 21.1 | 36.9 | 33.4 | 29.9 | 28.2 | 128.4 |
| #3 | 48.6 | 34.7 | 31.6 | 27.7 | 25.3 | 119.4 |
| #4 | 40.5 | 37.4 | 34.3 | 29.2 | 26.3 | 127.3 |
| #5 | 59.5 | 38.0 | 34.5 | 26.2 | 23.1 | 121.8 |
| #6 | 91.1 | 38.7 | 34.9 | 27.7 | 22.6 | 123.9 |
| #7 | 59.1 | 41.2 | 32.1 | 26.9 | 23.0 | 123.2 |
| #8 | 57.1 | 36.4 | 32.9 | 25.7 | 22.7 | 117.7 |
| #9 | 51.8 | 40.0 | 32.1 | 24.2 | 20.7 | 117.1 |
| Average Mg C/ ha | 488.0 | 37.8 | 33.3 | 27.5 | 24.5 | 123.1 |
| **TOTAL Mg C Project** | | **18,449.8** | **16,234.7** | **13,440.7** | **11,932.4** | **60,057.7** |

## Conclusions

On a several hundred-hectare project, commercially available spectroscopy equipment from Veris Technologies demonstrated an ability to measure profile soil carbon at the field scale, with the confidence needed for regulated carbon trading. Additional research is needed to develop optimal methods of using a combination of lab-analyzed samples and spectroscopic sensors to accurately and affordably measure changes in soil carbon levels.

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