On Site Applications of New Technologies for Soil Carbon Measurements

RC Izaurralde,[a] MH Ebinger,[b] JB Reeves,[c] CW Rice,[d] L Wielopolski,[e] BA Francis,[c]
RD Harris,[b] S Mitra,[e] AM Thomson,[a] JD Etchevers,[f] KD Sayre,[g] and A Rappaport[a]

[a]Pacific Northwest National Laboratory; [b]Los Alamos National Laboratory, [c]United States Department of Agriculture (USDA – ARS); [d]Kansas State University, [e]Brookhaven National Laboratory, [f]Colegio de Postgraduados, Mexico, and [g]CIMMYT

ACKNOWLEDGMENTS

Contact: cesar.izaurralde@pnl.gov

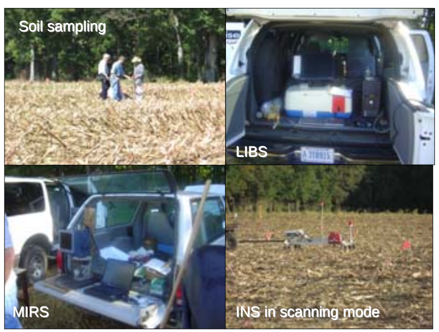
INTRODUCTION

- Changes in soil carbon (C) stocks can be measured directly using soil sampling protocols or estimated indirectly through eddy covariance methods, stratified accounting procedures, or simulation models. The standard protocol for measuring soil C changes involves soil sampling at the field scale, sample preparation for analysis, measurement of soil C concentration by dry combustion (Dry Comb.), and calculation of results on a soil mass basis. Although this procedure produces excellent results, there is a need to develop fast and accurate procedures to measure soil C changes at the field scale.
- Three technologies have emerged with potential for *in situ* measurements of soil C: a) laser-induced breakdown spectroscopy (LIBS), b) inelastic neutron scattering (INS), and c) diffuse reflectance IR spectroscopy in the near-infrared (NIRS, 400-2500 nm) and mid-infrared (MIRS, 2500-25,000 nm) ranges.
- With the support of the U.S. Agency for International Development (USAID) we conducted two tests to evaluate the performance of four technologies (Dry Comb., LIBS, INS, and MIRS) to measure soil C under field conditions. The first test was conducted in the U.S. in a field property of USDA in Beltsville, MD. The second test was conducted on a long-term experiment at CIMMYT, Mexico.

INSTRUMENT DESCRIPTION

- The LIBS technology is based on atomic emission spectroscopy and presented in portable form. In a LIBS measurement, a laser pulse is focused on a (soil) sample, creating high temperatures and electric fields that break all chemical bonds and generating a white-hot plasma. The spectrum generated contains atomic emission peaks at wavelengths characteristic of the sample's constituent elements thereby facilitating their identification.
- The INS is a non-invasive technique that consists in directing 14 MeV fast neutrons produced by a neutron generator into a sample, where they interact with the nuclei of atoms of certain elements, including ^{12}C. The collision of fast neutrons with C atoms releases energy as γ ray photons with a specific energy (4.4 MeV for a ^{12}C nucleus). A stationary and a scanning version of the INS were tested in this study. The interrogated soil mass is > 200 kg.
- Unlike the LIBS and INS technologies, the MIRS probes the bond identities of a sample's molecules, offering the possibility of directly distinguishing inorganic from organic C, thus eliminating the need for acid pretreatment to remove inorganic C. Yet for the same reason, quantifying soil C must be done indirectly, by recourse of advanced data-fitting routines that require libraries of soil spectra vs. soil C data.

Views of field setup and work in the Beltsville experiment

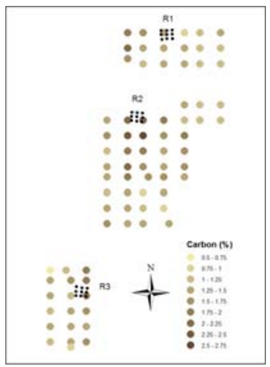


FIELD TESTS

- Beltsville Test: Conducted on a 25-ha field known as OPE3 (Optimizing Production Inputs for Economic and Environmental Enhancement) on 2-3 October 2006. Three 30 m x 30 m plots containing 9 sampling points were sampled at three depth intervals (0-5, 5-15, 15-30 cm). The samples were processed in the field for LIBS and MIRS analysis. The INS instrument estimated soil C density via soil scanning. All samples were analyzed for C content at Kansas State University by dry combustion and the results reported as soil C density using soil bulk density values determined by the soil core method. The Dry Comb. Team provided selected C values to the other teams for calibration and then collected the C estimates for Plot No. 3 from the other teams for comparison.
- Mexico Test: Conducted at CIMMYT during 30 April – 3 May 2007 on a 17-year old crop rotation, tillage, residue study. The treatments sampled consisted of maize (*Zea mays* L., m) and wheat (*Triticum aestivum* L., w) grown in monoculture (M) or in rotation (R), with conventional (CT) or no tillage (ZT) methods, and with (+) or without (-) crop residue removal after harvest. Each treatment is replicated twice. A composite soil sample made of 12 subsamples per soil depth (0-5, 5-10, and 10-20 cm) was taken from each of the 22 x 7.5 m plots. The soil samples were processed and analyzed as in the Beltsville test. This test did not include the INS instrument.

Left: Map of OPE3 (Beltsville, MD) showing C levels from a previous study (colored dots) and the sampling grid used for this study (R1, R2, and R3).

Right: General and detailed views of CIMMYT plots.



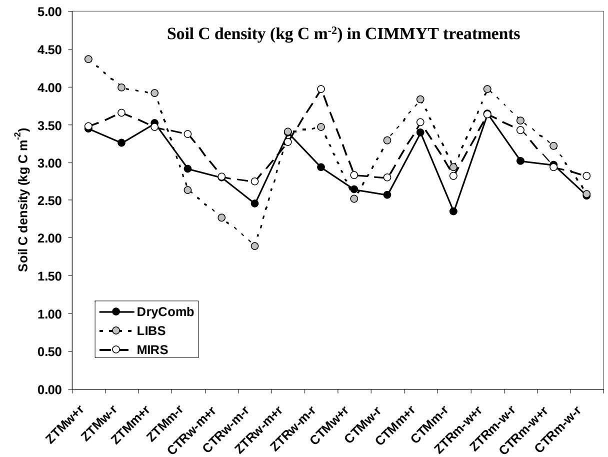
RESULTS

Mean soil C density to a depth of 30 cm of Plot No. 3 of OPE3 field as determined by dry combustion and three advanced technologies.

	Dry Comb.	MIRS	LIBS	INS
	g C cm^{-2}			
Mean	0.407	0.432	0.327	0.257
Std. Dev.	0.055	0.061	0.081	0.052
N	9	9	9	Scanning

Summary statistics for the methods used to estimate soil C density (kg C m^{-2}) in the CIMMYT experiment.

Statistics	Dry Comb.	LIBS	MIRS
	kg C m^{-2}		
Mean	1.306	1.440	1.413
Maximum	2.315	2.300	1.791
Minimum	0.814	0.600	1.166
Std. Dev.	0.301	0.393	0.134
Range	1.500	1.700	0.625
N	112	112	112



SUMMARY

- This study compared for the first time the side-by-side performance of three advanced technologies to measure soil C under field conditions: LIBS, INS, and MIRS.
- The LIBS and MIRS results compare directly with those obtained by Dry Comb. These methods require soil sampling and need soil bulk density information to convert soil C concentrations to soil C density.
- The INS instrument interrogates large volumes of soil to generate mean soil C values for the site measured or field scanned. The INS measurements require calibration with mean values obtained from soil sampling measurements. Comparison between INS and discrete soil sampling measurements requires further study.
- The results obtained indicate acceptable performances of the advanced instruments but they also show the need for improvement in terms of calibration.
- The three instruments demonstrated their portability and their capacity to perform under field conditions.
- Import / export issues to developing countries should be examined in order to facilitate the transport of these instruments across international borders.