USDA Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

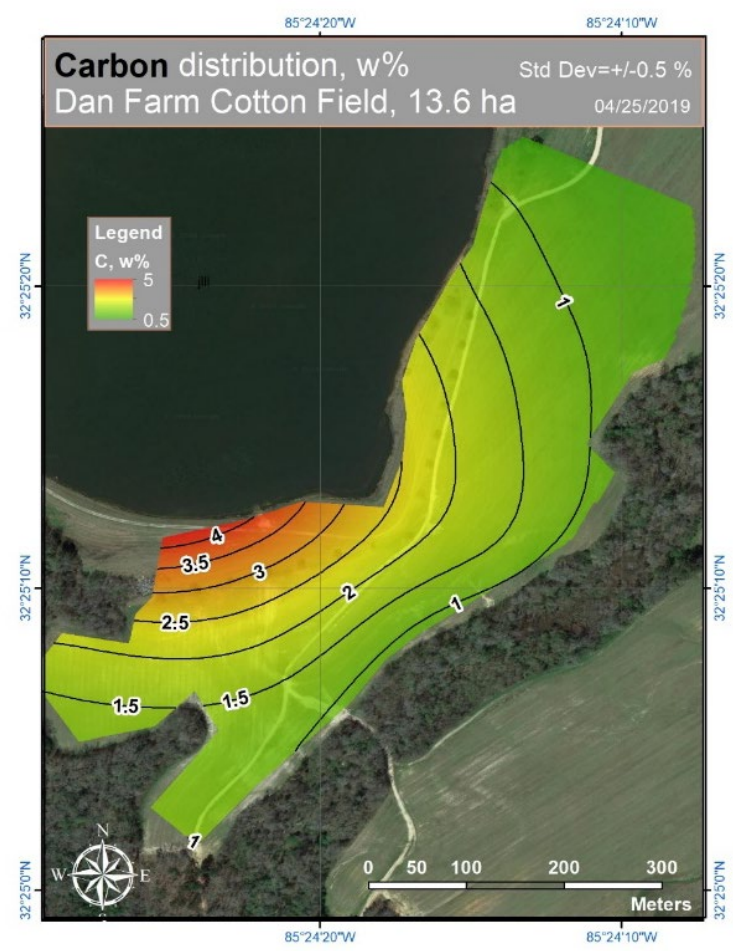
Soil Mapping for Carbon Sequestration and Regenerative Agriculture Using Gamma Analysis Technology

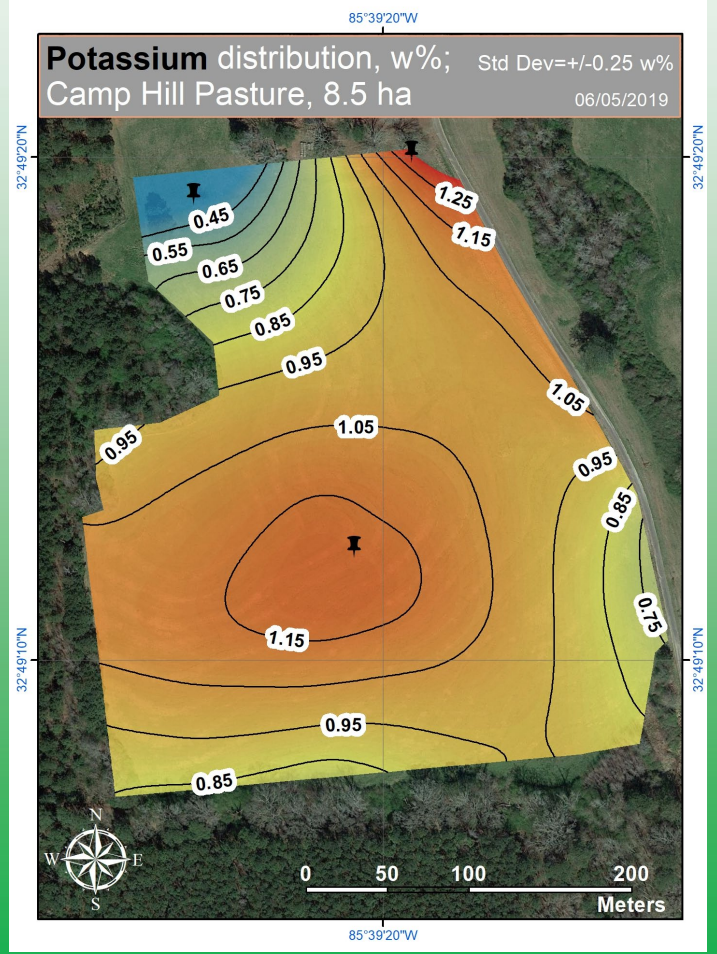
H. Allen Torbert

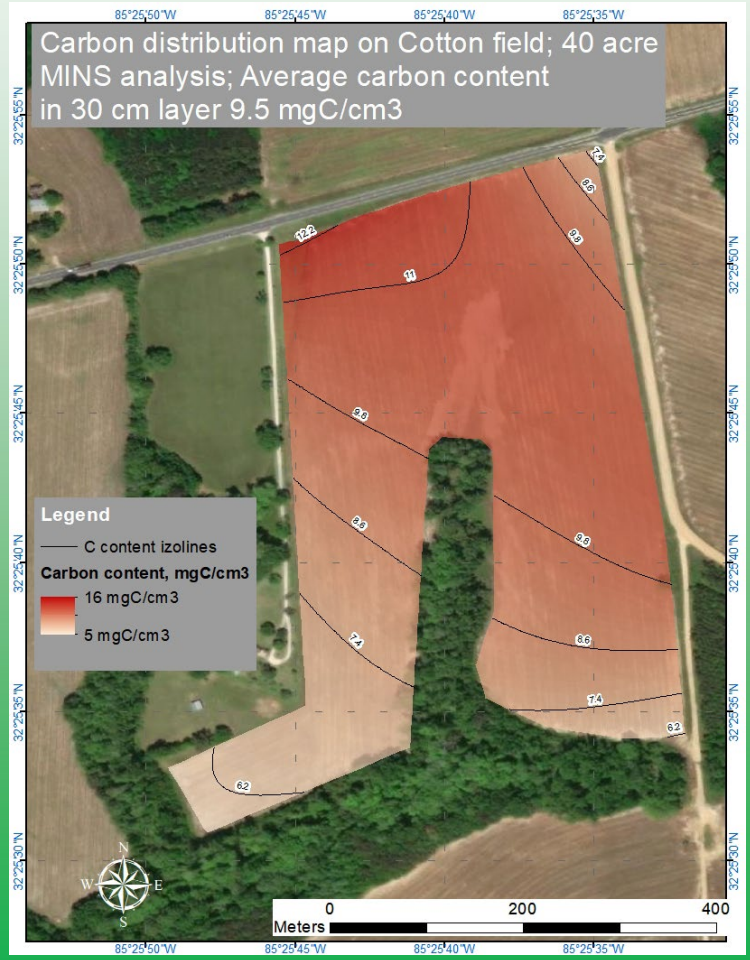
ISTRO 09/23/24

USDA-ARS National Soil Dynamics Laboratory Auburn, Alabama

Mobile Inelastic Neutron Scattering (MINS) Soil Scanning system "*In Situ*" Soil Analysis







NSDL Science Team

Dr. Allen Torbert
Dr. Galina Yakubova
Dr. Aleksandr Kavetskiy
Dr. Stephen Prior

History

2003 -US DOE Brookhaven National Laboratory

Dr. Lucian Wielopolski

- First proceedings article – 2003
- Proof of Concept Experiments – 2005
- First journal article – 2008
- Soil Scanning possible – 2019

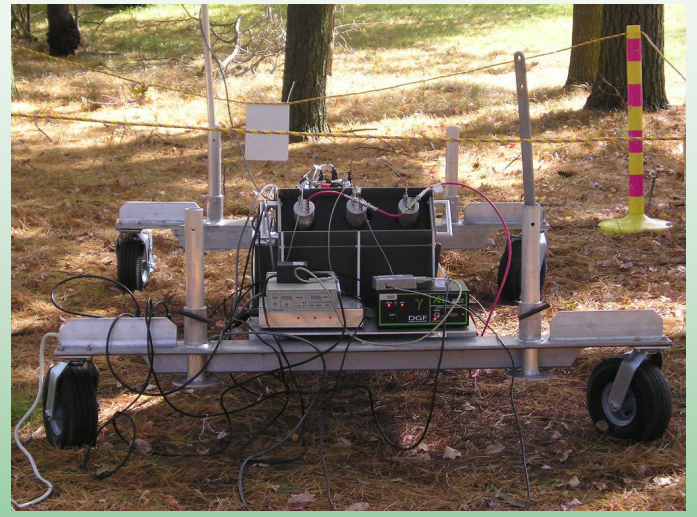
Wielopolski, L, G. Hendrey, K. Johnsen, S. Mitra, S.A. Prior, H.H. Rogers, and H.A. Torbert. 2008. Non-destructive system for analyzing carbon in the soil. Soil Sci. Soc. Amer. J. 72:1269-1277.

Kavetskiy, A., G. Yakubova, N. Sargsyan, C. Wikle, S.A. Prior, H.A. Torbert, and B.A. Chin. 2019. Scanning mode application of neutron-gamma analysis for soil carbon mapping. Pedosphere 29:334-343. DOI:10.1016/S1002-0160(19)60806-4.

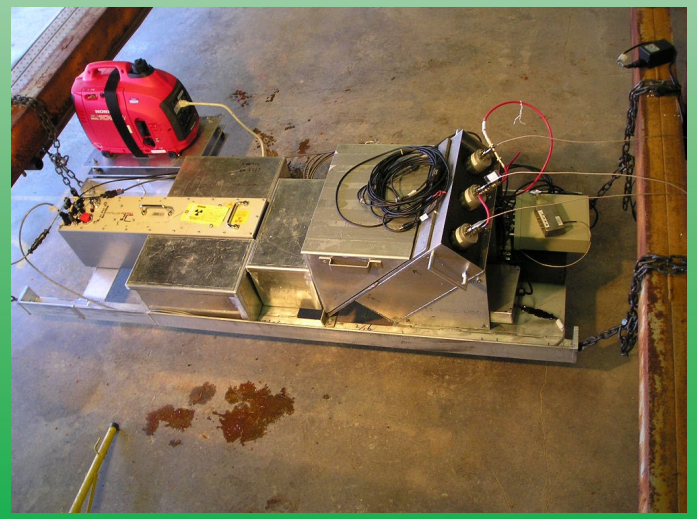
History

2005 -US DOE Brookhaven National Laboratory

Long Island, NY

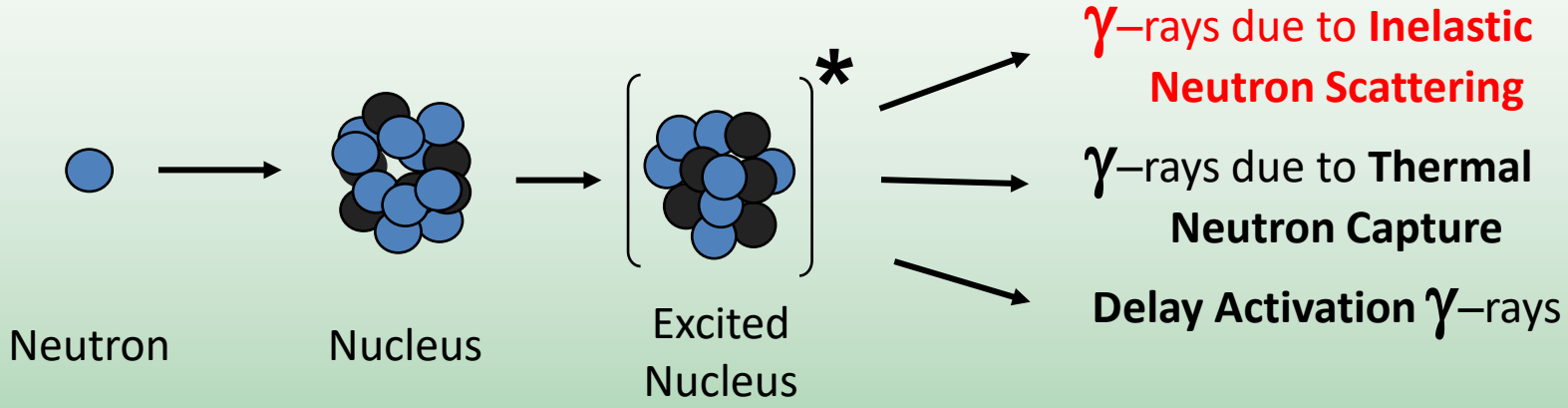


Auburn, AL



General Principal of the INS method

Neutron interaction with an atomic nucleus



Each kind of nucleus and process produces gamma-rays of a particular energy

Main soil elements are Si, O, Al, H, **C**, Na, N, K, Ca, Fe

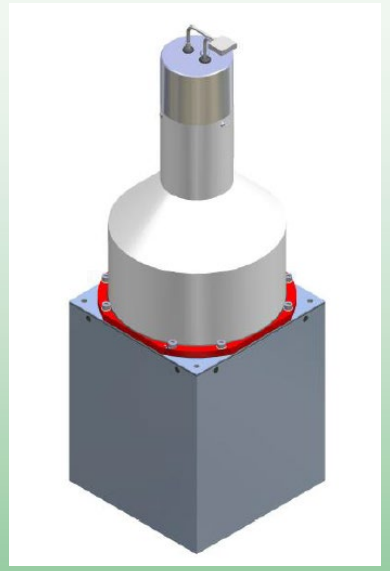
Soil Carbon Measurement is based on 14 MeV inelastic neutron scattering from carbon nuclei and measurement of the carbon 4.44 MeV characteristic γ radiation.

Main Components and Instruments for MINS System

MP320 Neutron Generator (DT)

Dimensions: 28 cm x 46 cm x 15 cm
Weight: 12 kg

NaI Gamma Detector



Crystal dimensions:
14 cm x 14 cm x 15 cm
Weight: 16 kg

Gamma Spectroscopy Electronics
XIA Vega Board

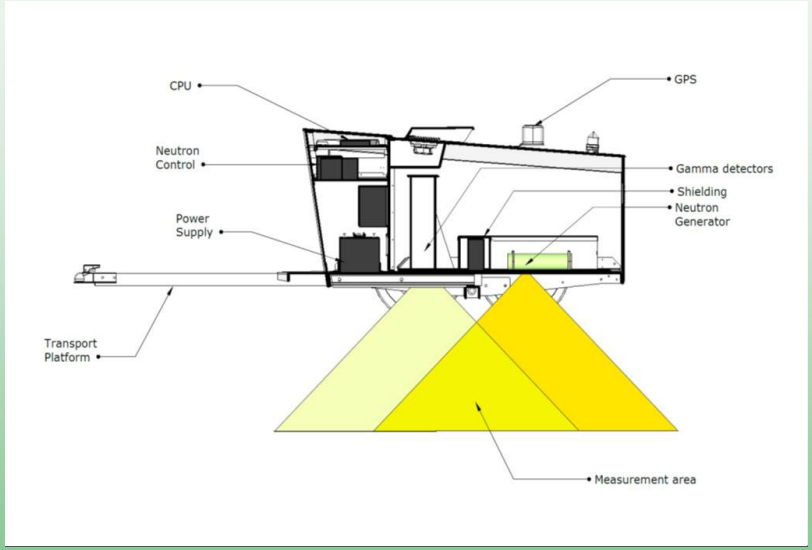
Neutron Detector

GPS

All equipment is commercially available

MINS System for Soil C Analysis in Agricultural Fields

Field System Geometry and System Design with GPS



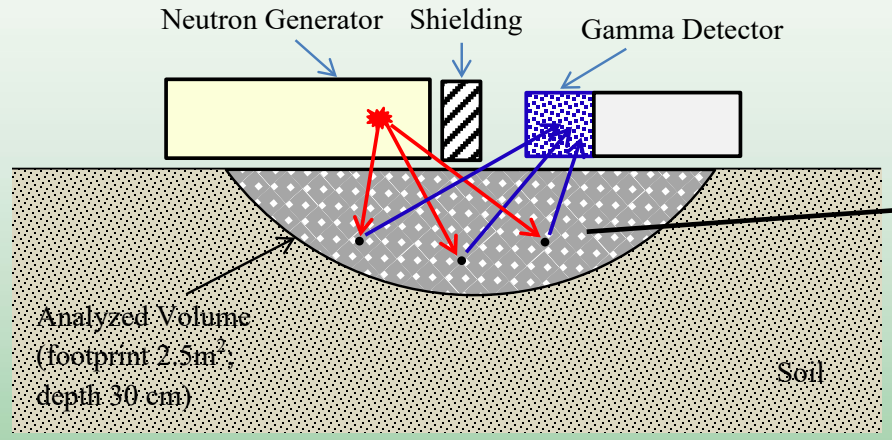
Scanning, data acquisition, and processing are operated by specially developed software

Scanning productivity: ~640 acres/day

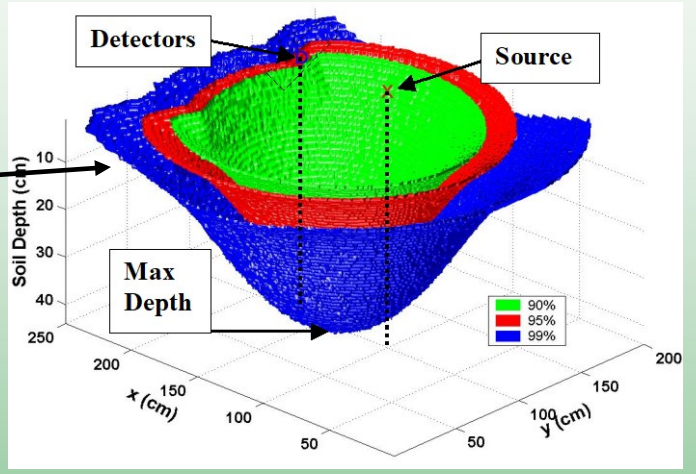
MINS system has been demonstrated to work reliably under field conditions

General Geometry of Neutron Stimulated Gamma Spectroscopy for Soil C Analysis

Measurement Geometry



Analyzed Soil Volume (MC simulation)



Signal acquired:

90%(green),
95% (red),
99% (blue)

Doron, O., 2007. Simulation of an INS Soil Analysis System, Dissertation Thesis,\The University of Texas at Austin

Main System Components:

Neutron Source – D-T Neutron Generator MP320, 10^7 n/s

Gamma Detector – large volume (several dm^3) inorganic scintillator NaI(Tl), $LaBr_3$(Ce), BGO

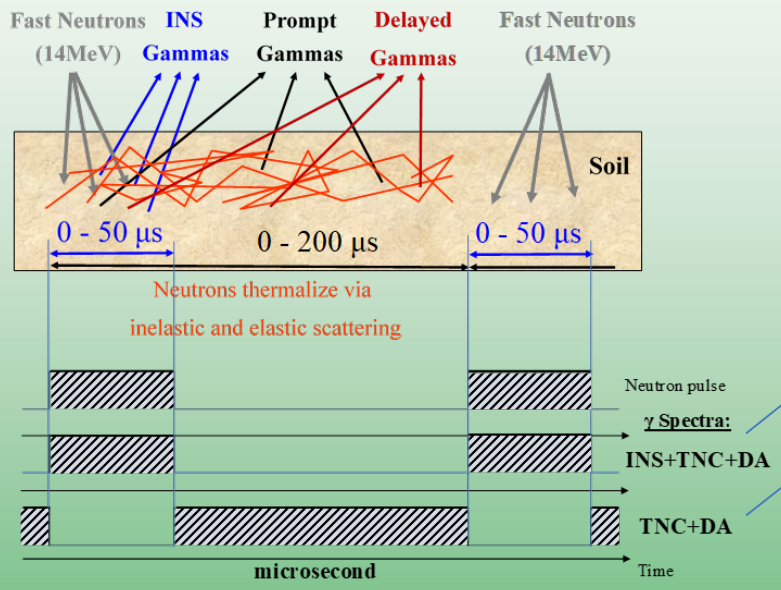
Analyzed Soil Volume: footprint 2.5 m^2
depth 30 cm

Analyzed Soil Mass: ~300 kg

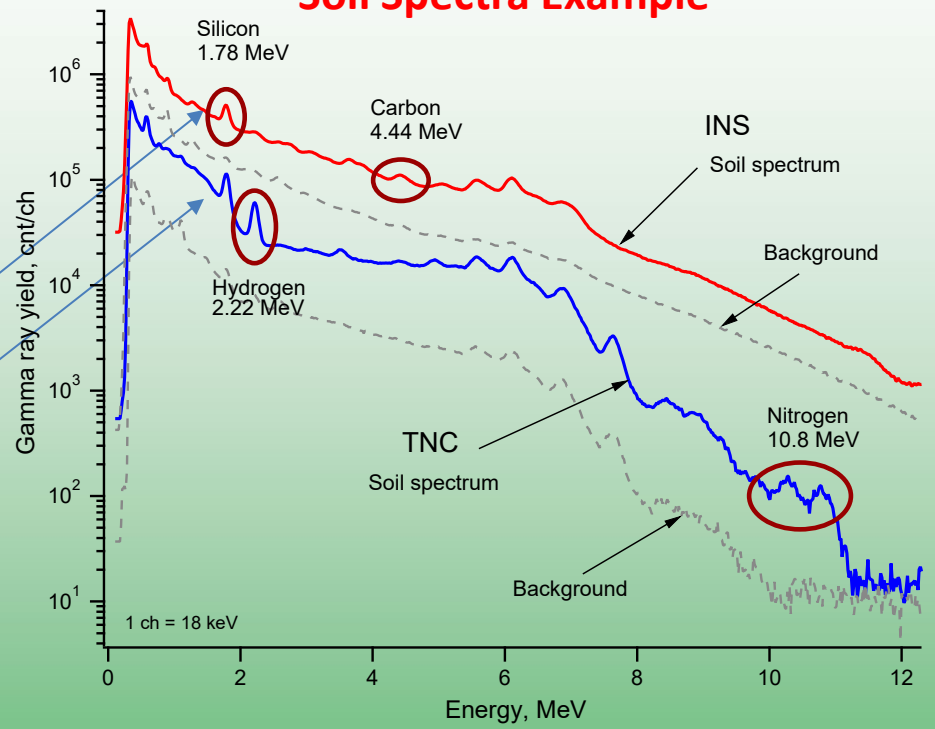
USE PFTNA Technique

Pulsed Fast Thermal Neutron Analysis (PFTNA)

Measurements in **Time Separation Mode**:
in **microsecond range** using split electronics



Soil Spectra Example



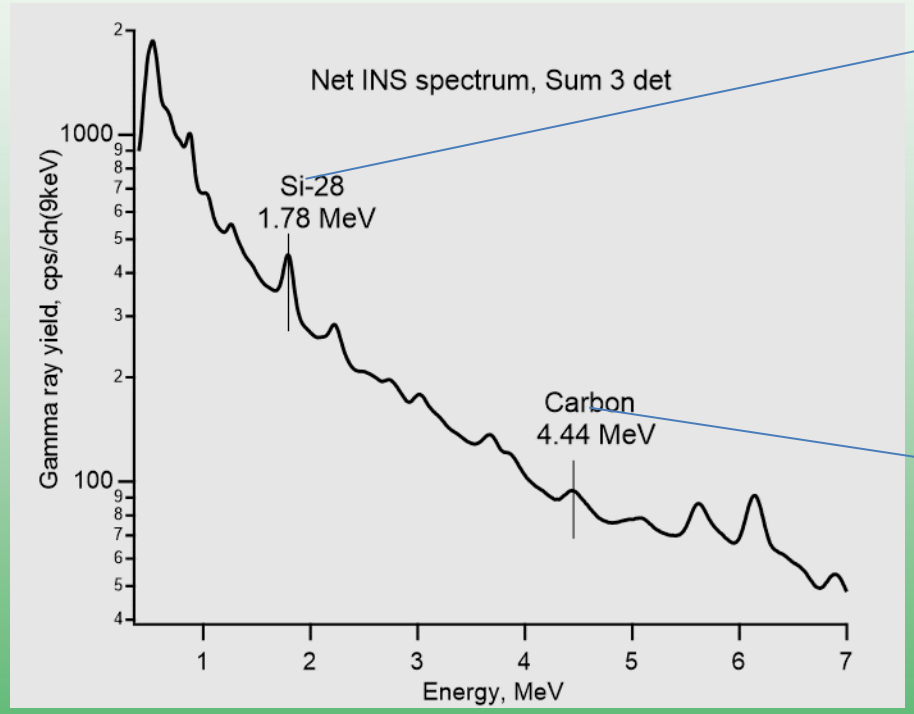
INS spectrum = (INS+TNC+DA) – (TNC+DA) spectra

INS(TNC) spectrum = INS(TNC) spectrum from soil + INS(TNC) System Background spectrum

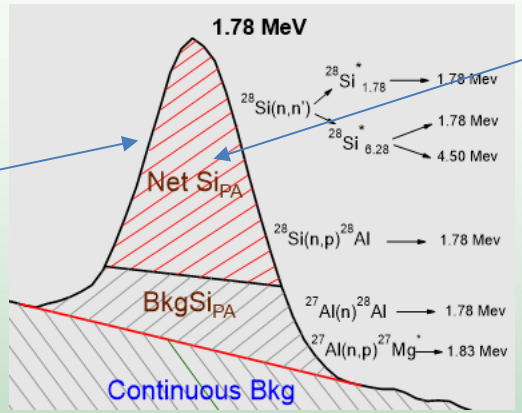
Extracting the gamma response from one specific element is possible

Separation of carbon peak area at 4.44 MeV

net INS spectrum =
(INS+TNC+DA) – (TNC+DA) spectra



"Silicon" peak

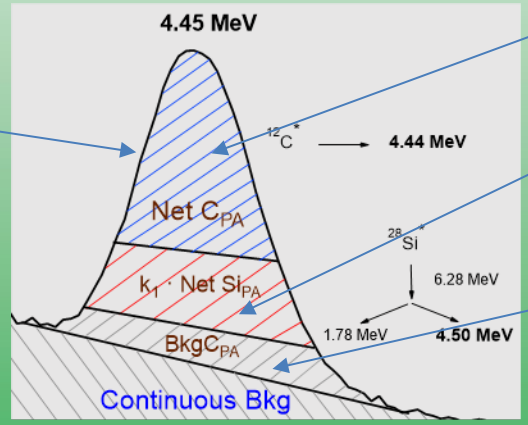


Part of peak
related to Si in soil

Each peak in the spectrum consist of:

- **part related to the element of interest,**
- **part from system background, and**
- **part from overlapping peak(s) of other soil elements**

"Carbon" peak



Part of peak
related to C in soil

Part of peak related to
Si cascade transition

Part of peak related to
C system background

Si cascade transition coefficient, k_1=0.0547
(Herman et al., 2007)

Soil Carbon peak area = (Measured "Carbon" peak area - BKG "Carbon" peak area) -
- k_1 · (Measured "Silicon" peak area - BKG "Silicon" peak area)

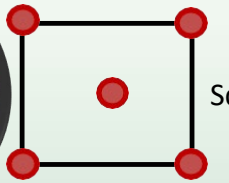
Comparison of MINS and Dry Combustion Analysis

Aerial view of surveyed field showin site divisions

yellow markers are locations of PFTNA measurements and sample collections

Dry combustion analysis processing scheme

Probing scheme



Square side 50 cm

Cutting

Drying

Grinding

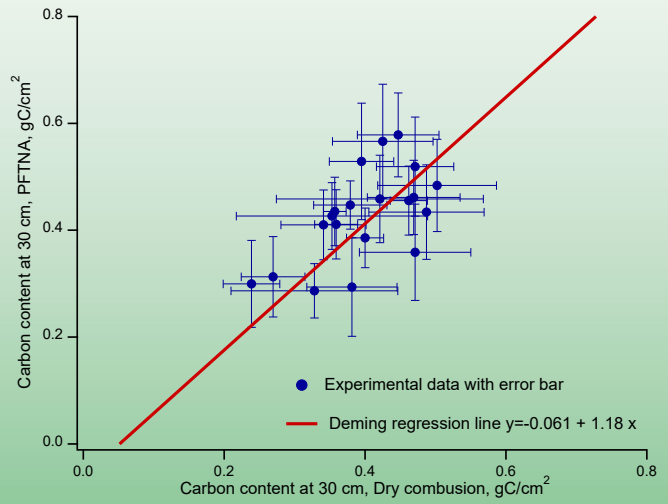
Weighing

Separate analysis of Soil Depth Increments Required

Separate sampling for soil Bulk Density Required

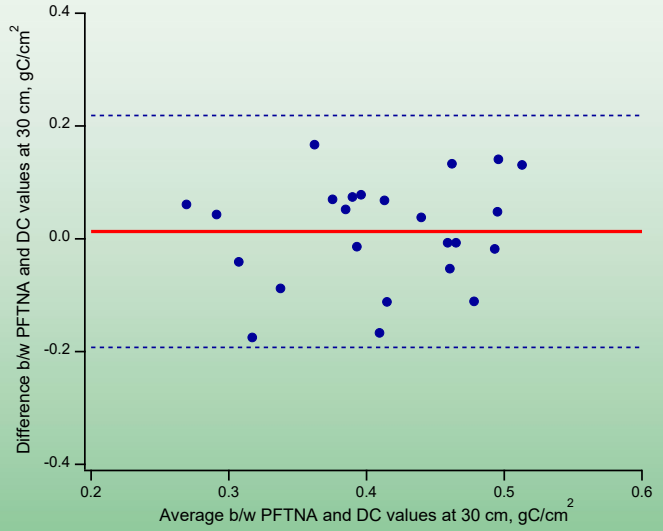
Verification of MINS for Soil C Analysis of 30 cm soil layer (static mode)

Deming Regression Plot



Deming regression plot of surface density in upper 30 cm soil layer measured by PFTNA and DC methods

Bland-Altman Graph



The Bland-Altman graph for surface density in upper 30 cm soil layer by PFTNA and DC methods

Jarque-Bera Test for Normality

JBStatistic = 1.28
Critical value = 3.35
at 0.05 significance level

These statistical methods support the workability of neutron stimulated gamma spectroscopy for soil carbon analysis in the 30 cm soil layer

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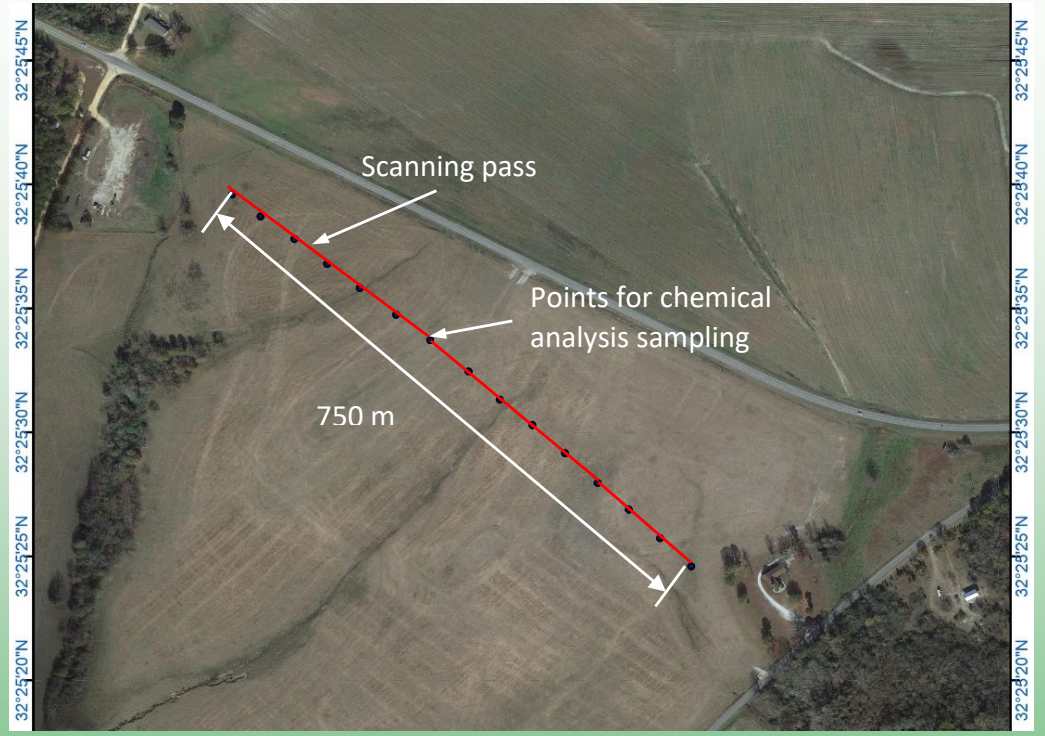
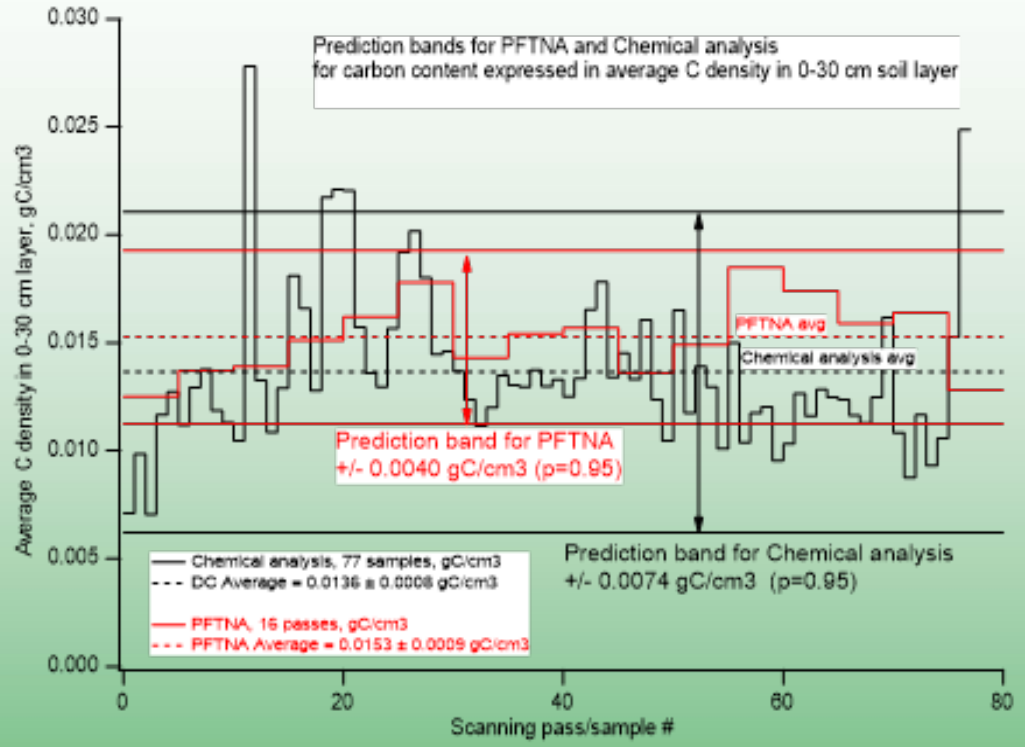
National Soil Dynamics Laboratory , Auburn, AL

Carbon Asset SOLUTIONS

Verification of MINS for Soil C Analysis of 30 cm soil layer (scanning mode)



Field site for scanning MINS scanning pass and soil sampling points



Prediction band for average carbon density in 30 cm (g C/cm^3) for chemical analysis with DC and MINS scan

Accuracy = +/- 9.0 mg C/cm^3

85% improvement in prediction bands compared to traditional soil sampling

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Carbon Asset SOLUTIONS

Accuracy Study

E.V. Smith Experiment Station Whole Field Site

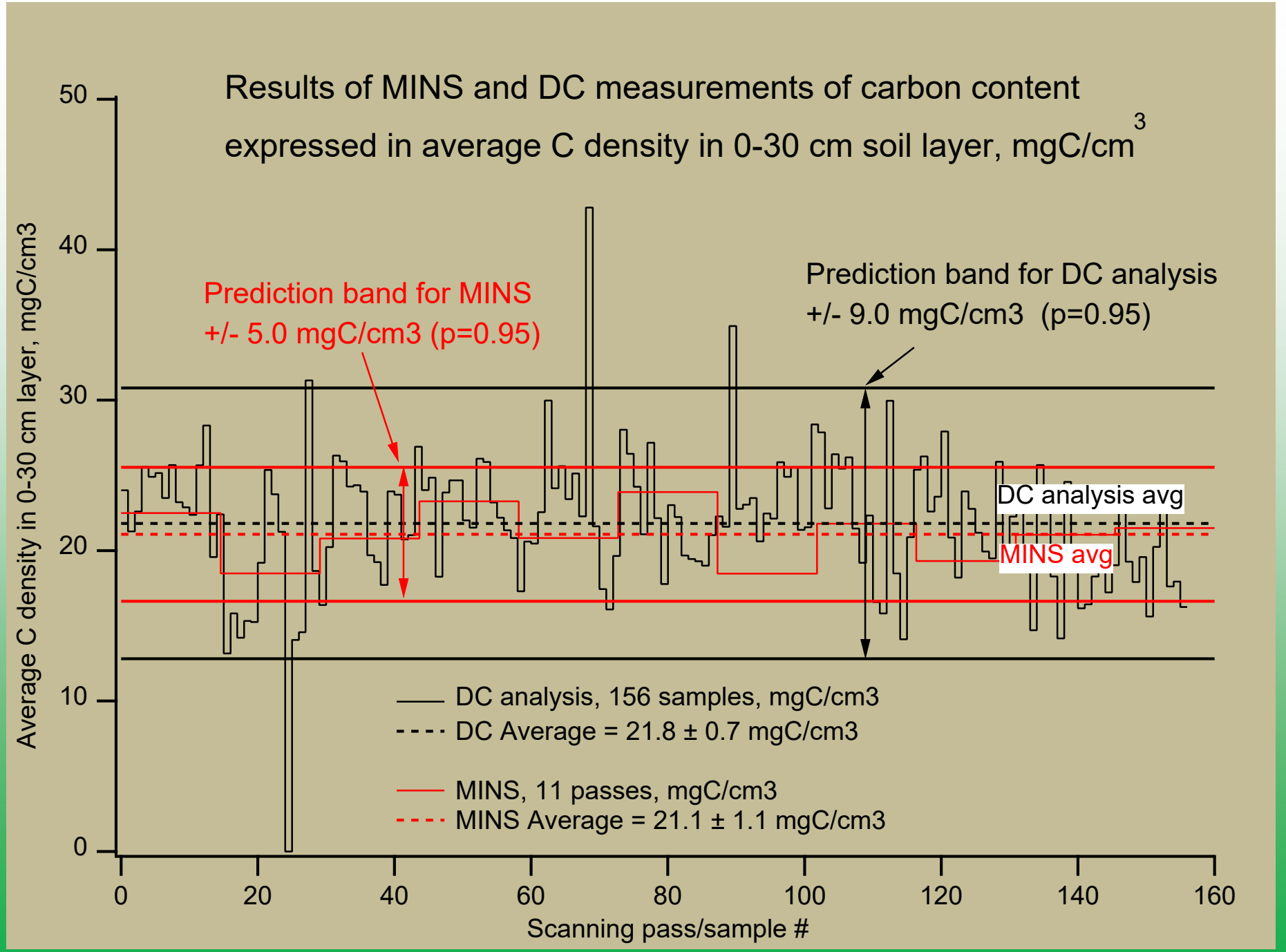
- 30-acre field study site was established at the Auburn University E.V. Smith Research station and grid sampled with 196 sample grid point core sampling scheme (one core/grid site) to establish a known soil C density.
- Each core was divided into 10 cm depth increments down to 30 cm (3 samples/core). Soil bulk density was determined on each soil core.
- At each gride site soil moisture and soil C density was independently determined using a Troxler soil moisture and density meter.
- The same field was scanned with 11 replications of the MINS measurements on a path that would include each of the 196 soil coring locations.

Map Unit Symbol	Map Unit Name
ReA	Riverview silt loam, 0 to 1 percent slopes, occasionally flooded
ToB	Toccoa fine sandy loam, gently undulating, occasionally flooded

Results

Core Soil C = 21.8 mg C/cm^3

MINS Soil C = 21.1 mg C/cm^3


Results of MINS and DC measurements of carbon content
expressed in average C density in 0-30 cm soil layer, mgC/cm3
Prediction band for MINS
+/- 5.0 mgC/cm3 (p=0.95)
Prediction band for DC analysis
+/- 9.0 mgC/cm3 (p=0.95)
DC analysis avg
MINS avg
DC analysis, 156 samples, mgC/cm3
DC Average = 21.8 ± 0.7 mgC/cm3
MINS, 11 passes, mgC/cm3
MINS Average = 21.1 ± 1.1 mgC/cm3
Average C density in 0-30 cm layer, mgC/cm3
Scanning pass/sample #
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160

Accuracy Study

E.V. Smith Experiment Station Whole Field Site

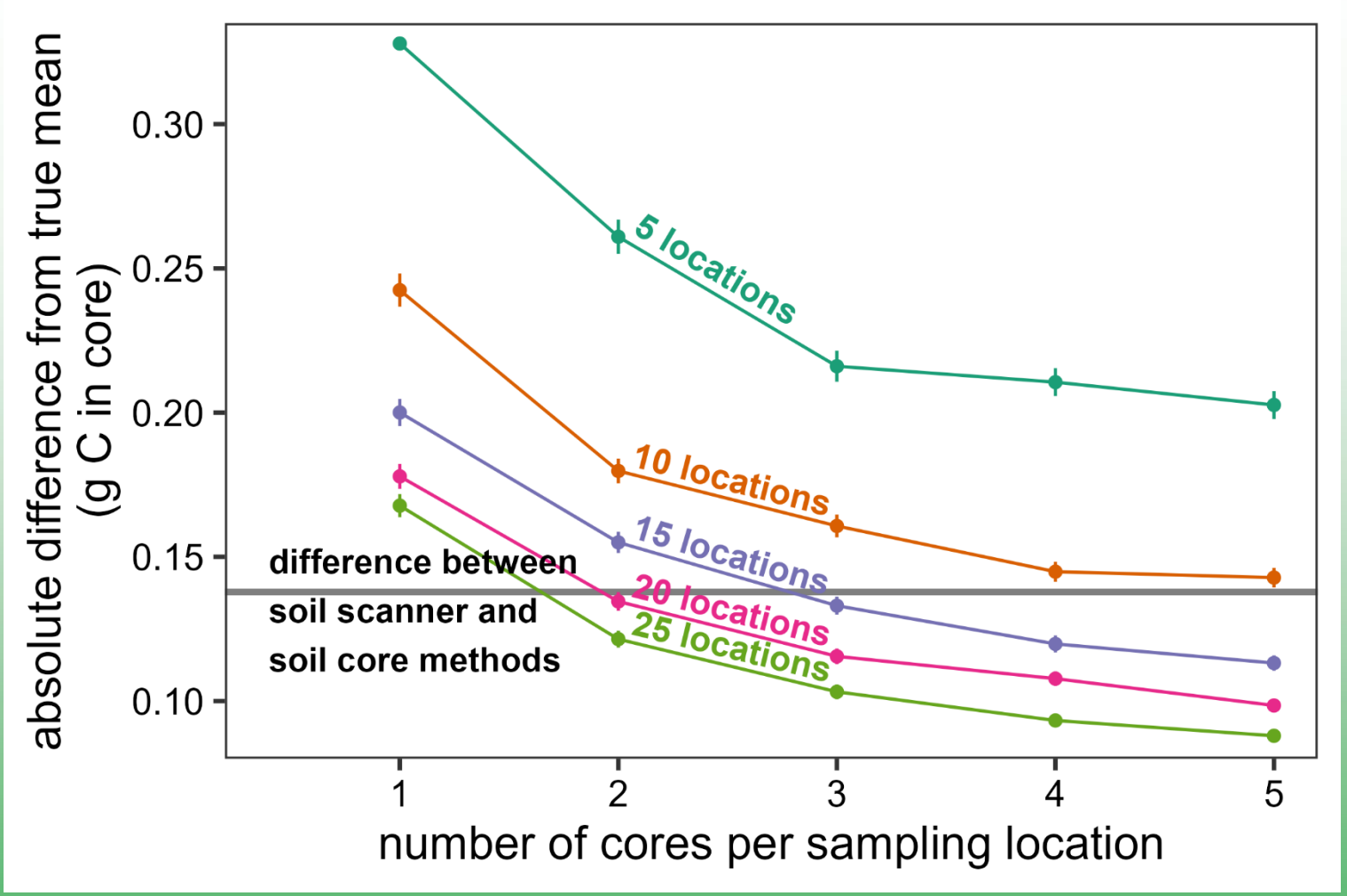
Soil Sampling Accuracy = +/- 0.7 mg C/cm^3

MINS Accuracy = +/- 1.1 mg C/cm^3

Predictive Band Soil Sampling = +/- 9.0 mg C/cm^3

Predictive Band MINS = +/- 5.0 mg C/cm^3

80% Increase



Core C = 16.0 mg C/cm^3

MINS C = 15.2 mg C/cm^3

Bootstrap Accuracy analysis indicates that a soil sampling of this 40-acre field needed 20 sites with 2 cores per site to match MINS scan accuracy.

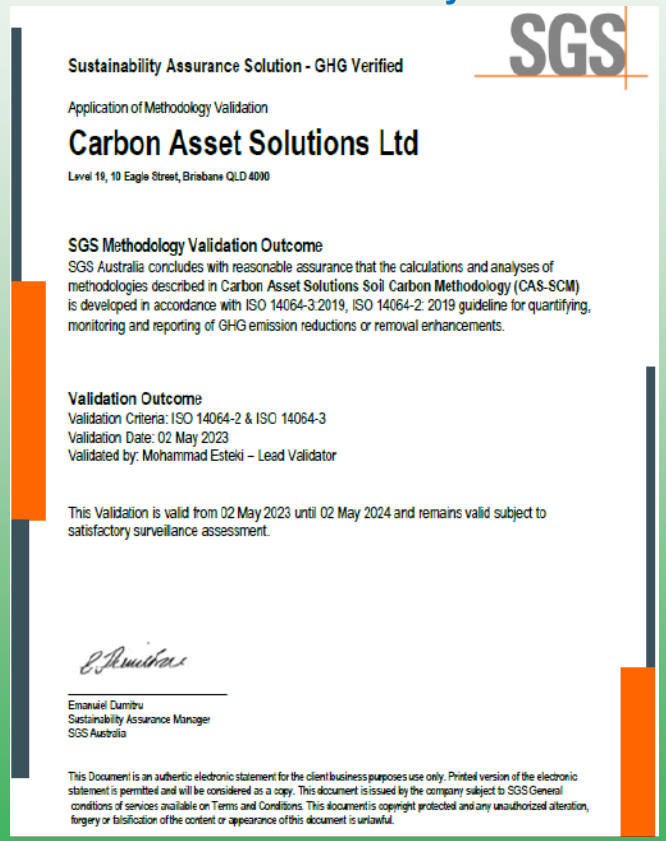
MINS commercial status 09/24

Technology Licensed to Carbon Assets Solutions or CAS

- ISO standard for a MRV certified carbon credit
- Global launch at AIM4C Washington DC
- USDA ARS awards for Technology Transfer, REE Under Secretary Award
- Commercial deployment USA, Canada, Australia
- USA Department of Defense Contract 2023
- First farms were credited under Voluntary Carbon program Q4 2023
- 3 new joint USDA/CAS patent applications

SGS Methodology Validation Certificate

Validation criteria: ISO 14064-2 & ISO 14064-3
Validation date: 02 May 2023



SGS

Sustainability Assurance Solution - GHG Verified

Application of Methodology Validation

Carbon Asset Solutions Ltd

Level 19, 10 Eagle Street, Brisbane QLD 4000

SGS Methodology Validation Outcome

SGS Australia concludes with reasonable assurance that the calculations and analyses of methodologies described in **Carbon Asset Solutions Soil Carbon Methodology (CAS-SCM)** is developed in accordance with ISO 14064-3:2019, ISO 14064-2: 2019 guideline for quantifying, monitoring and reporting of GHG emission reductions or removal enhancements.

Validation Outcome

Validation Criteria: ISO 14064-2 & ISO 14064-3
Validation Date: 02 May 2023
Validated by: Mohammad Esteki – Lead Validator

This Validation is valid from 02 May 2023 until 02 May 2024 and remains valid subject to satisfactory surveillance assessment.

Emanuel Dumitru
Sustainability Assurance Manager
SGS Australia

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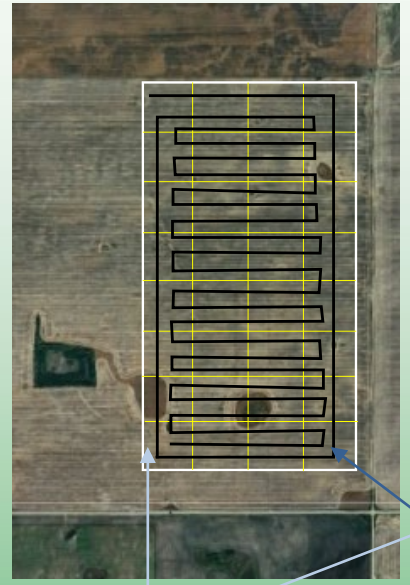
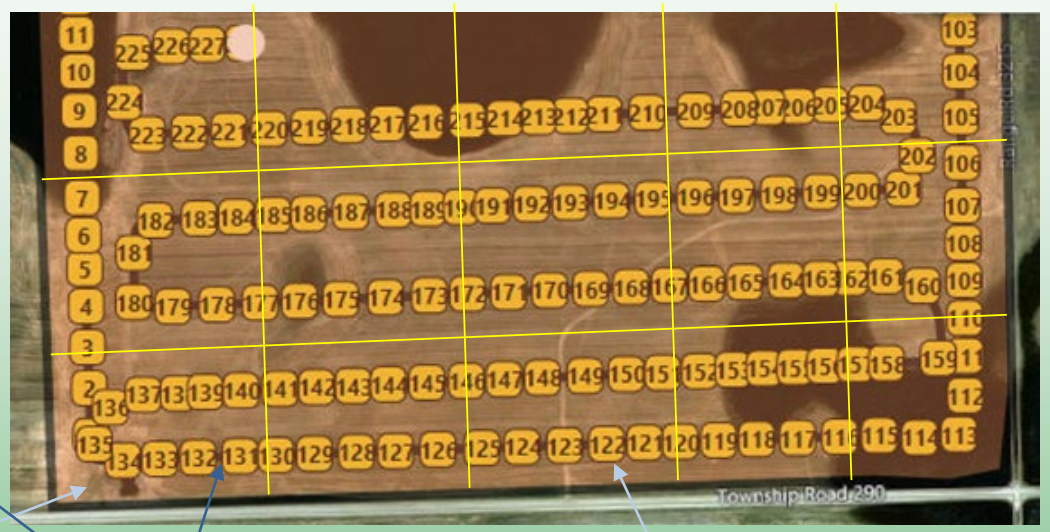
Methodology of MINS scanning measurements

Polygon creation
Path planning

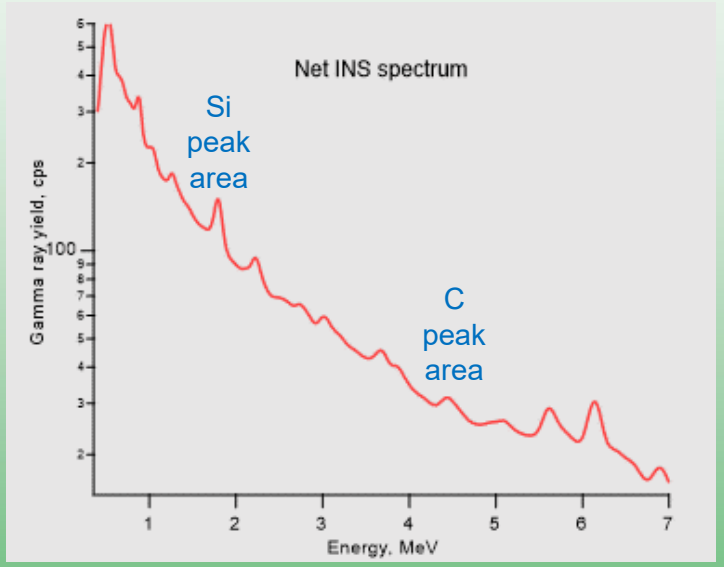


Data point recording



Average Weighted center spectrum of polygon

$$\text{Avg Spectrum of polygon} = \frac{\Sigma \text{ of spectra in polygon}}{\text{number of points in polygon}}$$



Polygons
System present in polygon at least 15 min

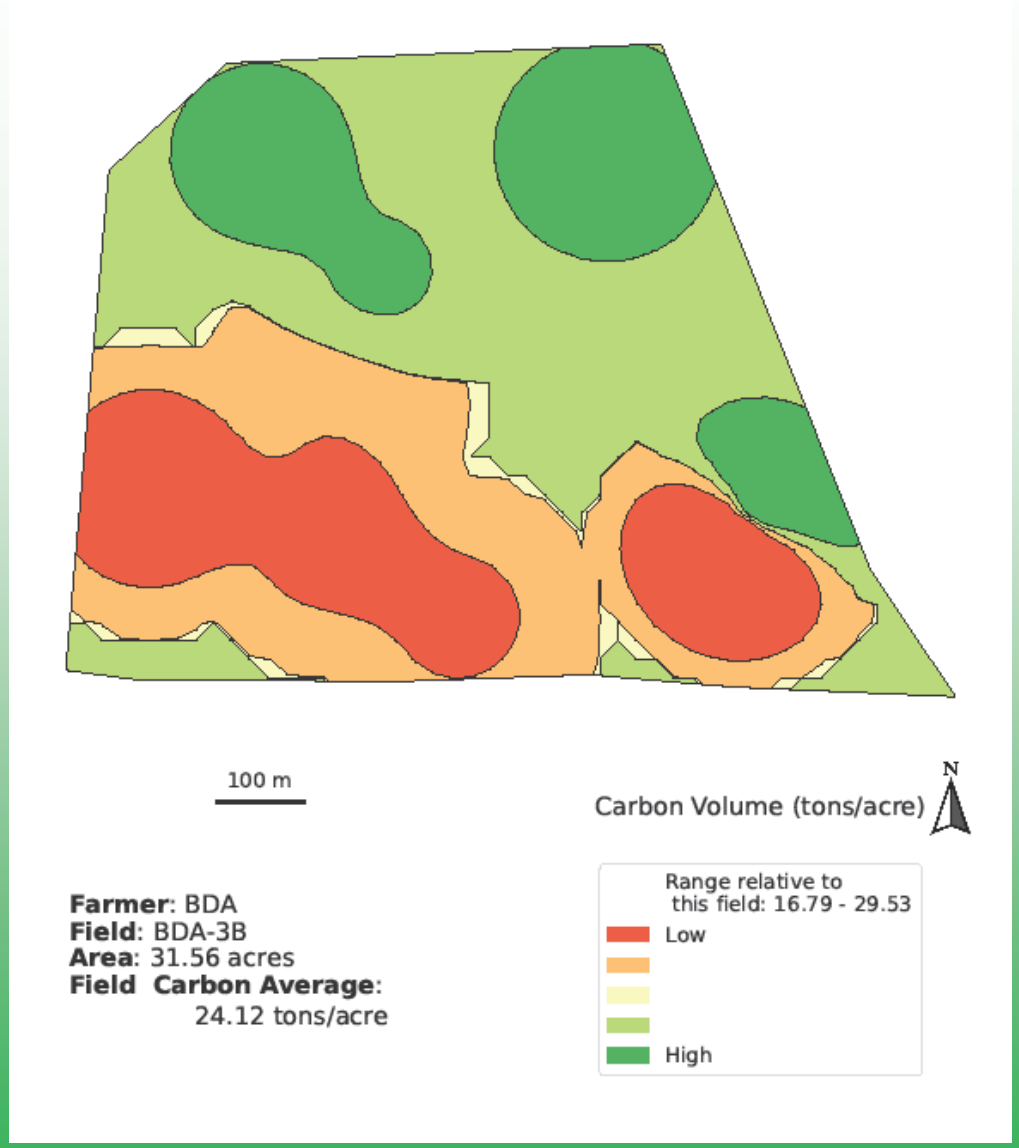
Scanning pass ~5 km/h
(black line)
Data acquiring permanently

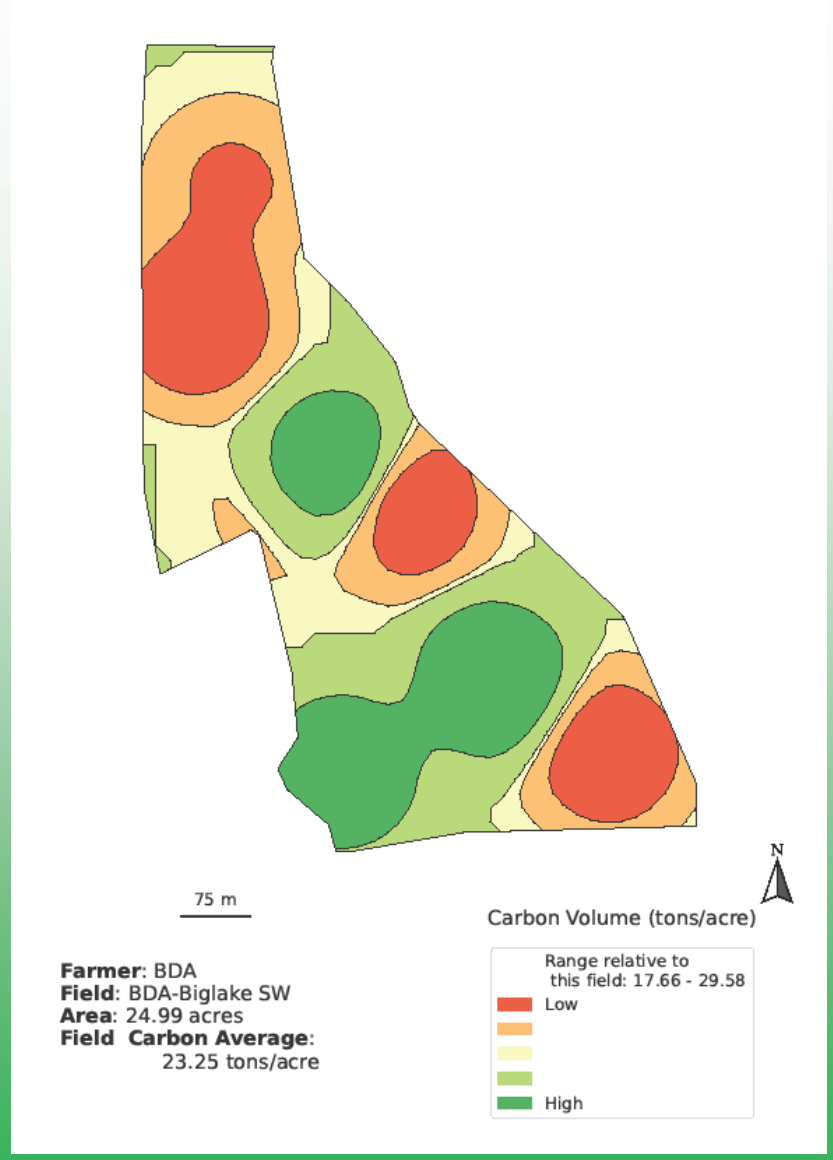
Yellow Points of data saving
Data are saved each 30s
Spectra and coordinates

$$\text{C content} = \frac{[(CPA - BkgCPA) - k_1 \cdot (SiPA - BkgSiPA)]}{k_2}$$

Set of data:
Latitude, Longitude & Carbon content → Mapping by ArcMap software

Soil carbon map examples





Cost of Soil Analysis

Average cost for lab analysis USA
$21 USD/ sample
300 acres farm @ 100 samples
$12,340
$48/ acre

Cost for the MINS analysis ≤ **$10/acre**

MINS Key Benefits

Accurate

- +/- 0.9 mgC/cm^3 95% confidence level
- Highly increasing result representativity due to massive increase in sample volume

In situ

- 3-dimensional measurement without soil disturbance
- No lab samples or secondary field calibration
- No additional bulk density measurements

Instant results

- Digital results direct to cloud based data management using Microsoft Azure

Verifiable

- Designed to meet ISO 14064-2 2019 and ISO 14064-3 2019

Scalable

- Low operational cost

CAS Business Model

- **Approach 1 – Enroll the farm/project in the CAS carbon monetization program CAS Soil Carbon Methodology.**

  No cost to farmers

  The farmer would store carbon through regenerative Ag practices, and the 'additional' carbon that is measured in the soil would be sold as a carbon credit, with farmer receiving 60% of the total sale price

- **Approach 2 – per acre fee for service scanning**

  Negotiated into a NRCS program.

  CAS would conduct a soil carbon scan for the farm. A map would be provided along with a tally of the carbon in the field. Repeat scans several years hence would confirm gain.

Questions