DOI: 10.5281/zenodo. 15388011

Proximal sensing in carbon farming

Authors

Paulina Rajewicz, *Institute for Atmospheric and Earth System Research (INAR) / Dept. of Forest Sciences, University of Helsinki, Helsinki, Finland*
Jon Atherton, *Institute for Atmospheric and Earth System Research (INAR) / Dept. of Forest Sciences, University of Helsinki, Helsinki, Finland*

Contributors

Pablo Fernandez *(Cooperativas Agro-alimentarias de España - COOP),* Rafal Kadziela *(Agrocares),* Valentin Knitsch *(Fraunhofer Center for International Management and Knowledge Economy, IMW),* Hannes Mollenhauer *(UFZ), Chiara Piccini (CREA),* Juan Sagarna *(Cooperativas Agro-alimentarias de España - COOP),* Chris Tolles *(YardStick PBC),* Panagiotis Tziachris *(Soil and Water Resources Institute - ELGO),* Tessa van der Voort *(Nutriënten Management Instituut),* Elisa Vainio *(Finnish Meteorological Institute),* Guillaume Vial *(MyEasyFarm),* Jan Viljainen *(Tampere University)*

Key messages

BENEFITS AND CHALLENGES OF PROXIMAL SENSING IN CARBON FARMING

BENEFITS	CHALLENGES
Cost-effective: reduces costs and labor by minimizing soil sampling and lab analysis.	Standardization needed: requires standardization of methods, devices, and outputs across regions.
Rapid, non-destructive data: enables frequent, real-time data collection without damaging the soil.	Calibration required: needs in-field validation and calibration via traditional methods, especially for low-carbon soils.
Reduces dependence on lab tests: provides more data, reducing the need for lab-based tests with proper calibration.	Accuracy and precision: clear accuracy and precision standards are essential for reliable data.
Integrates with other tools: can be combined with remote sensing and digital tools to enhance MRV systems.	Integration with Remote Sensing: requires interoperable systems to connect proximal sensing with digital and remote sensing platforms.
Supports various land types: scales for agriculture, forestry, and other land uses, improving carbon monitoring.	Clarifying MRV role: proximal sensing role in MRV systems, accuracy, and cost-effectiveness needs better definition.
Adaptable to regions: flexible for different soils, land uses, and regional needs, offering broad applicability.	Regional adaptation: customization is needed for varying soil types, land uses, and digital readiness across regions.
Engages farmers: provides actionable insights for better land management and sustainability.	Enhancing technology acceptance: adoption depends on clear guidelines, local support, long-term guarantees, and quality service.

Introduction

Proximal sensing uses sensors placed near or in contact with the soil to quickly, accurately, and affordably measure properties like soil organic carbon (SOC) without significantly damaging the soil. A variety of technologies with potential for proximal sensing are available (*see* Scientific consensus). However, definitions of proximal sensing differ among organizations, highlighting the urgent need for a universally accepted understanding of the techniques involved.

Accurate, conventional lab-based analyses are costly and time-consuming. Proximal sensing offers a more efficient, cost-effective alternative for monitoring, reporting and verification (MRV), though lab analysis is still required for calibration and validation. Proximal sensing also excels at creating detailed spatial maps of soil properties, ideal for large-scale assessments.

Proximal sensing is particularly valuable for carbon farming (CF), enabling frequent, scalable monitoring of SOC, which is crucial for tracking carbon sequestration. Additionally, the real-time, non-invasive data provided by proximal sensing supports agriculture and sustainable farming. However, without rigorous procedures, accuracy may be lower than in traditional methods, requiring local or regional calibration for reliability.

The growing use of proximal sensing in commercial applications can be attributed to the benefits outlined above, including a reduced, though not eliminated, reliance on lab testing and increased cost-effectiveness. To gain a comprehensive understanding of the state of proximal sensing and carbon farming, it is essential to consider the strengths and weaknesses of different technologies (see table above), their accuracy, readiness, and scalability (*see Scientific consensus*), as well as current commercial use cases *(see Market context).*

Scientific consensus: EVALUATION SUMMARY OF PROXIMAL SENSING TECHNOLOGIES IN CARBON FARMING

CONVENTIONAL LAB ANALYSES

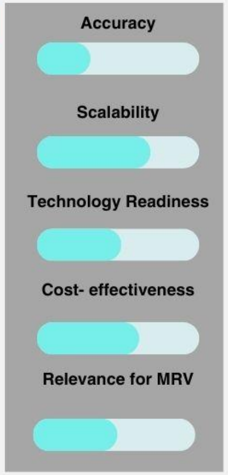
Conventional lab-based analyses refer to traditional and most widely accepted approach for determining soil organic carbon (SOC) levels. They involve physically collecting soil samples, transporting them to a lab, and using chemical reactions, e.g. combustion, to break down the soil and isolate organic carbon. The Walkley-Black method is one of the most well-known techniques used for this purpose. Due to its detailed chemical processes, this method provides highly accurate results and is often considered the gold standard for SOC measurements. However, it is time-consuming, labor-intensive, and expensive, limiting its use for large-scale or frequent monitoring. Despite these drawbacks, it remains the benchmark for calibration and validation of other SOC measurement techniques.

VIS-NIR-MIR SPECTROSCOPY

Spectroscopy-based methods, such as visible (VIS), near-infrared (NIR), and mid-infrared (MIR) spectroscopy, measure soil properties by analyzing how light reflects off soil samples. These techniques are non-destructive and can rapidly estimate SOC content. In general, MIR provides higher accuracy compared to VIS and NIR, especially in more complex soils. The method requires a good calibration model to ensure accuracy, which involves comparing spectroscopy data to a reliable reference, such as lab chemistry results. Once calibration is in place, spectroscopy becomes a fast and cost-effective tool for large-scale SOC monitoring, offering portability and the ability to cover large areas.

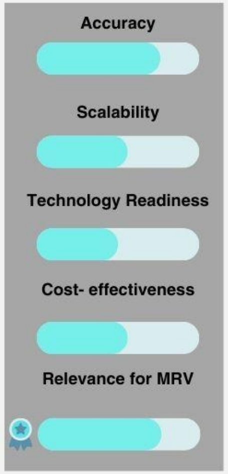
GAMMA-RAY SPECTROSCOPY

Gamma-ray spectroscopy (GRS) measures the natural gamma radiation emitted by soils, providing indirect information on soil properties like bulk density, texture, and moisture content. While not as precise for directly measuring SOC, gamma-ray spectroscopy can offer useful correlations with SOC in some cases. Its strength lies in its ability to rapidly assess large areas with minimal disturbance to the soil. This method is often integrated into soil monitoring systems that require broad-scale field assessments, such as land-use mapping or soil health evaluations. Its high scalability makes it a valuable tool for landscape-level assessments, although the equipment can be expensive and its ability to characterize deeper soils is limited.



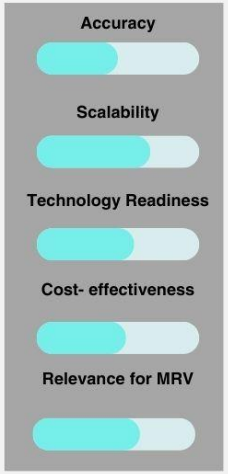
LASER-INDUCED BREAKDOWN SPECTROSCOPY

LIBS - Laser-Induced Breakdown Spectroscopy uses a high-intensity laser to vaporize small amounts of soil material, and the resulting plasma emission is analyzed to determine elemental carbon content, including SOC. This technique is highly accurate and can be performed in the field, making it an attractive option for direct, on site SOC measurements. LIBS is also relatively fast compared to conventional methods and offers high portability. However, it requires careful calibration to ensure precision, and the specialized equipment can be costly. Despite these challenges, LIBS is one of the more accurate field-deployable technologies for SOC analysis, offering a balance between accuracy and convenience.



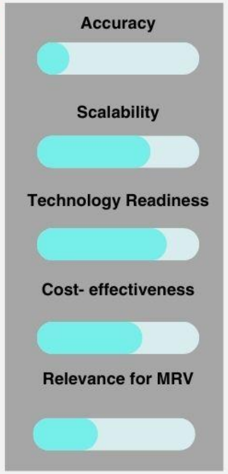
ELECTRICAL CONDUCTIVITY SENSORS

Electrical conductivity (EC) sensors measure soil's ability to conduct electrical current, which is influenced by soil properties like moisture, salinity, and temperature. While EC sensors do not directly measure SOC, they can provide valuable indirect information that may correlate with SOC in certain conditions. These sensors are highly scalable and can be deployed over large areas, often in combination with other soil sensors, to create soil property maps. EC sensors are commonly used in precision agriculture to manage soil health, irrigation, and crop production. Their low cost and ease of deployment make them attractive for large-scale applications, though their indirect nature limits accuracy for SOC measurement.



INELASTIC NEUTRON SCATTERING

Inelastic Neutron Scattering (INS) Soil Carbon Method uses fast neutrons to non-destructively measure SOC content by detecting inelastic interactions between neutrons and carbon atoms in the soil. This method provides a direct, in situ measurement of SOC without requiring soil sampling or extensive laboratory analysis. INS can scan large areas quickly and repeatedly, offering real-time data on SOC distribution at various depths.



Best in the category

<u>**Categories:**</u>

Accuracy – How accurate the technology is in measuring soil carbon stocks changes or related parameters.
Scalability – The ease with which the technology can be applied on a larger scale or across various regions and contexts.
Technology Readiness – The level of development and market readiness of the technology.
Cost-effectiveness – The balance between the benefits the technology provides and its associated costs.
Relevance – The significance of the technology in enabling or supporting an effective MRV (Monitoring, Reporting, and Verification) system for Carbon Farming.

The results are based on a questionnaire conducted among FG3.2 members and reflect their subjective statements.

Market context:
PRACTICAL APPLICATIONS OF PROXIMAL SENSING IN CARBON FARMING

AgroCares

Company Name: **Agrocares**
Location: **Netherlands**
Year Founded: **2013**
Type of Business: **AgTech Developer**
Geographic region of operation: more than 40 countries globally

Contact Information
Rafał Kądziela
- Business developer Europe
rafal.kadziela@agrocares.com
www.agrocares.com

Overview:
AgroCares is an AgTech company based in Wageningen, Netherlands, specializing in nutrient testing solutions for leaf, feed, and soil to enhance crop productivity and sustainable farm management. Through data-driven technology, AgroCares aims to help farmers adapt to climate change, improve soil health, and reduce their carbon footprint. Their mission is to revolutionize agriculture by offering real-time, accessible data, ultimately advancing global sustainable farming practices.

Operations and Services:
AgroCares offers scalable soil carbon stock measurement through its Carbon Monitor Solution, a comprehensive platform for carbon project managers. It includes farm management tools, traceability, sampling stratification, and ground-truthing. Their proprietary SoilCASTOR integrates data from Near InfraRed (NIR) scanners and remote sensing, supported by a global soil sample database. This approach provides cost-effective, scientifically-backed SOC (Soil Organic Carbon) monitoring for carbon insetting and offsetting projects.

Carbon Farming Initiatives:
AgroCares' Carbon Monitor Solution delivers a scalable method for SOC assessment via proximal sensing, enabling faster and more affordable soil analysis. Combining NIR scanners with remote sensing and a global soil database supports robust ground-truthing and advances sustainable farming and carbon initiatives.

Impact on Farmers and Policy Support:
AgroCares offers farmers a faster, more affordable alternative to traditional soil carbon measurement, enabling better participation in carbon farming. Their technology streamlines soil analysis for carbon offsetting projects, addressing a key market bottleneck. AgroCares advocates for stronger policy support for proximal sensing to accelerate carbon project development, aligning with EU and global frameworks.

Market and Outreach:
AgroCares fills a critical gap in Europe's carbon farming market by providing cost-effective soil analysis tools for carbon project managers and farmers. They lead in overcoming slow, traditional soil testing, collaborating with NMI Wageningen to advance carbon farming projects across the EU.

YardStick PBC

Company Name: **Yard Stick PBC**
Location: **USA**
Year Founded: **2021**
Type of Business: **Startup**
Geographic region of operation: USA, Australia (since 2024), potential to expand worldwide

Contact Information
Chris Tolles - Founder & CEO
chris@useyardstick.com
www.useyardstick.com

Overview:
AYard Stick is an innovative startup focused on low-cost, scientifically rigorous soil carbon quantification. Their mission is to enable gigaton-scale carbon removal through scalable and trustworthy measurement solutions. By reducing the cost of soil carbon measurement by over 90%, they unlock opportunities for regenerative farming and forestry, improving ecosystem health, increasing land managers' incomes, and addressing climate change.

Operations and Services:
Yard Stick offers an integrated suite of software and hardware solutions for soil organic carbon (SOC) measurement. Their flagship product is a handheld, in situ soil carbon probe based on VisNIR reflectance spectroscopy, capable of evaluating SOC stocks up to one meter deep. This replaces conventional soil sampling and lab analysis, significantly reducing costs and improving efficiency. Their software platform manages sample plans, fieldwork, and carbon data, providing a transparent, auditable solution for carbon quantification.

Carbon Farming Initiatives:
The Yard Stick spectral probe offers an advanced alternative to traditional soil sampling, enabling land managers to measure SOC stocks with precision and at scale. Their technology reduces barriers to evidence-based regenerative farming practices, contributing to carbon removal and better soil health.

Impact on Farmers and Policy Support:
Yard Stick provides farmers with affordable, scalable carbon measurement tools, making it easier to adopt regenerative practices and access carbon credits. As carbon farming demand grows, Yard Stick is preparing to expand globally, starting in Australia in 2024. They advocate for stronger regulatory support and higher carbon prices to ensure farmers benefit from carbon farming. Their technology aligns with standards like Verra VM0042, positioning them as a leader in rigorous carbon monitoring

Market and Outreach:
Yard Stick is building relationships in the European carbon farming market, aiming to expand as demand for soil carbon measurement grows. Their vision is to lead the adoption of proximal sensing technologies, supporting high-rigor carbon farming programs that drive market consolidation and improve farmer incomes.

MyEasyFarm

Company Name: **MyEasyFarm**
Location: **France**
Year Founded: **2019**
Type of Business: **Software editor**
Geographic region of operation: Europe and LATAM

Contact Information
Guillaume Vial
- Carbon Project Manager
gvial@myeasyfarm.com
www.myeasyfarm.com/

Overview:
MyEasyFarm is an AgTech startup focused on advancing regenerative and precision agriculture through digitalization. Their platform helps the entire agricultural supply chain—from farmers to agri-food companies—make the agroecological transition towards regenerative and low-carbon agriculture. MyEasyFarm's mission is to support sustainable farming through its two key solutions: MyEasyCarbon for carbon monitoring and MyEasySpheres for precision agriculture data management.

Operations and Services:
MyEasyFarm offers an MMRV software solution that integrates data from agricultural machinery using proximal sensing technologies such as yield, moisture, and input sensors. Their software aids in carbon monitoring and sustainability reporting, primarily focusing on Europe and Latin America. Through their MyEasyCarbon software, the company has supported over 40 carbon farming projects under the French Label Bas Carbone Grandes Cultures, contributing to a reduction of more than 250,000 tCO_2e over the next five years.

Carbon Farming Initiatives:
MyEasyFarm uses advanced digital tools to enhance carbon farming, supporting farmers in reducing emissions and improving soil health. Their platform helps manage data from farm operations, ensuring precision in carbon measurement and reporting. These initiatives play a key role in achieving regenerative agricultural goals.

Impact on Farmers and Policy Support:
MyEasyFarm helps farmers transition to sustainable practices by offering tools for efficient carbon management and compliance with certification frameworks. However, the diversity of standards (e.g., French Label Bas Carbone, Verra) poses challenges. MyEasyFarm works towards standardization, particularly in data collection, and sees the European CRCF as a potential path to harmonizing carbon farming certification. Policy innovations that reduce the costs and complexity of soil carbon measurement would further support their mission.

Market and Outreach:
MyEasyFarm is positioned to become a leading MRV platform in the European carbon farming market, aiming to bridge local certification schemes with global insetting programs for the agri-food sector. Their outreach focuses on aligning farmers and the food industry towards shared sustainability goals.

Cense Analytics

Company Name: **Cense Analytics Oy**
Year Founded: **2024**
Location: **Finland**
Type of Business: **Startup**
Geographic region of operation: **Europe**

Contact Information
Dr. Jan Viljanen
Co-Founder and CTO
jan.viljanen@cense-analytics.com
www.cense-analytics.com

Overview:
Cense Analytics is a startup company delivering accurate and scalable soil carbon data for industries and farmers. It drives forward the availability of precise and cost-effective soil carbon data using advanced on-site proximal sensing and AI technologies. It integrates hardware and software - LIBS with satellite AI remote sensing - enabling data-driven decision making and farming practices.

Operations and Services:
Cense Analytics delivers soil carbon measurement solutions using Laser Induced Breakdown Spectroscopy (LIBS) and satellite-based AI remote sensing. By integrating proprietary hardware and software, Cense Analytics provides precise, scalable carbon data to food corporations for tracking soil carbon sequestration and enhancing sustainability reporting as end-to-end service.

Carbon Farming Initiatives:
Cense Analytics empowers carbon farming by offering reliable soil carbon data and monitoring services incentivizing the adoption of regenerative agricultural practices. These initiatives support farmers and corporates in pursuit of carbon neutrality and advancing sustainable land management.

Impact on Farmers and Policy Support:
Cense Analytics enables farmers to implement better land management practices with accurate soil carbon insights, driving the adoption of regenerative agriculture. It also aids policymakers by providing measurable data for carbon reporting, supporting alignment with global sustainability and compliance goals.

Market and Outreach:
Cense Analytics serves the global agribusiness sector, including food corporations, farmers, and public sector organizations, with a focus on agriculture's carbon monitoring and sustainability needs. Its strategy prioritizes partnerships with major food brands and leverages scalable AI-driven solutions to seamlessly integrate soil carbon data into supply chains, promoting transparency and climate action.

The case studies summaries presented here are based on a questionnaire conducted among companies involved in FG3.2. For full questionnaire results and more info, contact FG3.2 leaders or reach out to the companies directly.

Recommendations

- Proximal sensing technologies (e.g., VIS-NIR-MIR spectroscopy) provide a cost-effective and scalable measurement method for MRV (Measurement, Reporting, and Verification) of soil organic carbon (SOC), enabling more frequent, yet still accurate monitoring for carbon farming initiatives. Hence, relevant EU legislation (e.g., under delegated acts and implementing acts) should ensure that MRV strategies incorporate proximal sensing technologies alongside laboratory chemical analysis (used for calibration and validation).
- EU funding should be increased to support research and innovation in proximal sensing technologies. For example, funding aimed at enhancing the accuracy of proximal sensing technologies would accelerate their adoption in MRV. Such funding could focus on building or extending open-source proximal sensing data libraries, such as those developed by ISRIC, which are required to estimate SOC. At present, most extensive libraries are privately owned.
- A good-but-not-perfect methodological framework should be prioritized over delayed perfection to avoid stalling progress. Verra VM0042 is an example of a well-developed methodology. However, VM0042 has detailed guidelines on bulk density (BD) which potentially hinder proximal sensing-focused projects. To support carbon farming, a more flexible methodology could be developed to prevent valuable projects from being sidelined due to overly restrictive criteria. When an approach is peer-reviewed and published in a scientific journal this can be seen as an indicator of the quality of the approach.

Background information

These recommendations emerged from the collaborative efforts of Focus Group 3.2, which brings together scientists, private sector representatives, and consultancy experts. This multidisciplinary group meets regularly to assess the state of proximal sensing for soil organic carbon (SOC) monitoring within the context of carbon farming (CF) and Measurement, Reporting, and Verification (MRV) frameworks. The recommendations presented here reflect the collective expertise, discussions, and iterative evaluations of the group, drawing from both scientific perspective and real-world applications.

While the recommendations are based on expert consensus and existing data, further research is necessary to refine calibration techniques, cost structures, and integration with broader digital agriculture platforms. Additional work is also needed to quantify the economic benefits of proximal sensing for farmers and policymakers, making the case for stronger incentives.

In summary, these recommendations represent a practical, science-backed path forward to strengthen proximal sensing within carbon farming. By addressing standardization, incentives, and technological accessibility, the goal is to create a more reliable, equitable, and scalable system for soil carbon monitoring, ultimately supporting climate-smart agriculture and resilient food systems.