Agoro Carbon™ Research Brief

Regenerative Agriculture & Soil Carbon Measurement and Modeling

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Regenerative Agriculture and Soil Carbon

Changes in land use are a significant contributor to global greenhouse gas (GHG) emissions, with agriculture, forestry, and other land use representing about 21% of total GHG emissions today (EPA, 2024). Since 1850, human degradation of soils worldwide may have resulted in a loss of 44 to 537 billion tons of carbon stock, largely through land-use change and conversion from native ecosystems (forest and grasslands) to agricultural land (Lal, 2001). Globally, agricultural soils have lost 20% to 75% of their antecedent soil organic carbon (SOC) pool due to mismanagement (Lal et al. 2015), like soil erosion of cropland due to excess tillage and overgrazing of grasslands.

Assessing the economic impact of soil erosion on agricultural lands is difficult. However, a recent study by Thaler et al. (2021) suggests that soil erosion (primarily due to tillage) in the US Corn Belt causes nearly $3 billion in annual crop yield losses. This doesn't even include the loss of nutrients and soil carbon due to erosion which reduces the future productivity of these fields. Soil carbon or organic matter is critical to maintaining soil health and resiliency of our farms and ranches to water stress. For example, a study by Kane et al. (2021) showed that soil organic matter protects corn yields and lowers insurance payments under drought conditions. A summary of their work indicated that under severe drought, an increase of 1% in soil organic matter was associated with a yield increase of around 33 bushels per acre and a 36% reduction in insurance payments. Data on the impact of soil erosion on grassland productivity is more scarce. However, Weltz et al. (2014) estimate that 23% to 29% of U.S. non-federal rangelands are vulnerable to accelerated soil loss, resulting in reduced soil health and forage production.

While agriculture represents a significant share of global emissions, it can meanwhile be a significant lever to mitigate and adapt to the climate crisis. Regenerative agriculture is one of the most scalable solutions to mitigate the impacts of climate change, while also enabling higher farming profits to the more than 600 million farmers around the world and supporting more resilient food production. With proper management, these same carbon-depleted soils can serve as a large sink for the absorption of atmospheric carbon. In addition to the climate benefits, regenerative agriculture practices have been shown to increase farm and ranch profitability while increasing co-benefits or the suite of ecosystem services derived from agricultural land, including biodiversity, soil health, and water regulation (Derner et al. 2009 and World Wildlife Fund, 2023).

There is significant opportunity to reverse trends of soil erosion and loss of SOC with implementation of regenerative farming and grassland management practices. Considerable scientific research has shown that regenerative practices of reduced or no-till and cover cropping, which Agoro Carbon Alliance offers to row crop growers, can sequester soil SOC. For example, Kwang et al. 2023 have suggested that costly cropland erosion could be halted if farmers adopted more sustainable "no-till" or "low-till" practices. A meta-analysis by Nicoloso and Rice, 2020 of tillage studies conducted at 142 different global locations showed that no-till stores more SOC than tilled soils. Another paper by Liptzin et al. 2022 comparing SOC sequestration for several regenerative practices across 120 long-term study sites spanning from north-central Canada to southern Mexico provides one of the most definitive summaries of the benefits of no-till and cover cropping to increasing SOC sequestration. Adding cover crops as an additional practice not only halts but reverses the process of soil erosion because it provides additional soil protection, sequesters additional soil carbon (Jian et al.

Agoro Carbon Sequestration Practices

Improved Grazing

Biodiversity/ Seeding

Fertilization

Reduced Tillage & No-Till

Cover Crops

2020), and increases water infiltration rates, thus reducing erosion-causing runoff (Basche and DeLonge, 2019). Likewise, regenerative grassland management practices like rotational grazing and adding diverse species show great promise for restoring carbon-degraded grasslands while reducing erosion through increased ground cover, reduced disturbance, and increased SOC sequestration due to appropriate grazing management (Bai and Cotfuro, 2022; Apfelbaum et al. 2022).

In addition to the carbon sequestration benefits associated with regenerative agriculture practices, there are a wide range of associated environmental co-benefits (see Verra SD Vista page, where our projects are also currently ongoing SD Vista certification). An example of how regenerative management practices provide these benefits is illustrated by the water regulating services of no-till and cover crop practices. Figure 1 shows two adjacent watersheds in South Dakota, and the runoff from each watershed approximately 30 minutes after a significant rainfall event. The watershed identified as Blue (A) has been in primarily long-term no-till with a diverse crop rotation, cover crops, and grass waterways, while the Red (B) watershed has been conventionally farmed.

Likewise, in a study conducted by Apfelbaum et al. 2022 on paired ranches in the southeastern U.S., comparing conventional to rotational grazing, it was found that rotational grazing not only increased SOC sequestration rates but improved water infiltration rates, which in turn led to increased forage production. Both examples illustrate the positive feedback loop that occurs when implementing regenerative agriculture practices, whereby the practice changes increase SOC storage, restore degraded soils, and lead to increased productivity and profitability, with a continuing positive cycle.

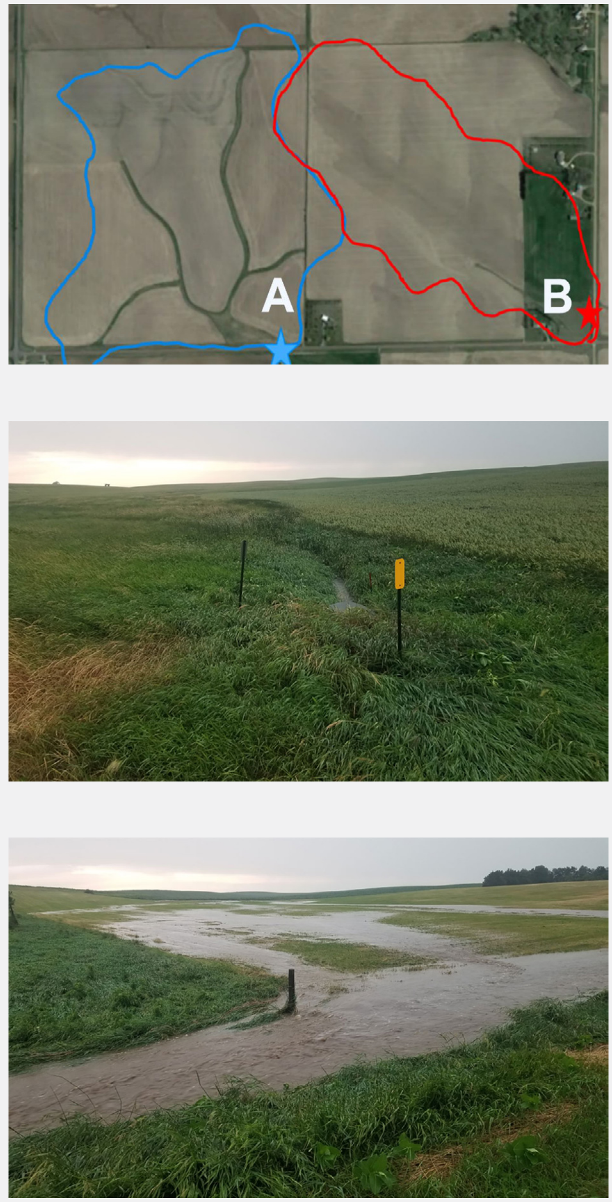


Figure 1. The top map shows adjacent watersheds. The above photos show the impacts of water runoff on these watersheds after a significant rainfall event. The photo in the middle is from a grower with long-term no-till crop rotation and cover crops and the photo on the bottom is from a grower with conventional farming practices.

Soil Organic Carbon Measurement and Agoro Carbon's Procedures

The integrity of a carbon credit depends on accurate measurement of the associated emission reductions or removals, as this directly affects its value and credibility. For a soil carbon credit to be considered high-quality, it is essential that the carbon sequestration and emissions reductions resulting from regenerative agriculture practices—undertaken by farmers and ranchers—are precisely measured.

Introduction to Soil Organic Carbon and Agoro Carbon's Approach to Accurate Soil Carbon Measurements

Most soil organic carbon (SOC) comes from atmospheric carbon dioxide (CO_2) that is captured by plants through the process of photosynthesis and stored as soil organic matter (SOM) along with a small amount originating from atmospheric methane (CH_4) that serves as an energy source for soil microbes. Soil organic matter comprises approximately 58% SOC and includes all biological carbon in the soil matrix, irrespective of origin or state of decomposition (the carbon cycle visualized).

In agricultural soils, SOC content is usually less than 5% of the soil mass and decreases with soil depth with much of SOC concentrated in the top 30 cm (Franzluebbers, 2020). The effective rooting zone, from which plants obtain 70-80% of water and nutrients, is typically less than 30 cm in rangeland and cropland environments. Most prairie grasses obtain water from the top 25 cm, saturating that shallower root zone with a dense web of roots that represents the primary zone from which plants draw water and nutrients (Wang et al. 2008, Eggemeyer et al. 2009 and Nippert et al. 2014). Meanwhile, irrigation management guidelines dictate that 70% of the plant available water is obtained from the top 30 cm of the soil profile in common pastureland or cropland systems (Evans et al. 1996). In drier environments this zone of enrichment can be much shallower, less than 10 cm in lower production, rain-fed environments (Hoyle et al. 2013). Collectively, these findings illustrate that the top 30 cm of the soil profile are the zone of enrichment in which the vast majority of biological activity, carbon deposition and nutrient cycling is occurring.

There is some scientific debate that tilled soils may be redistributing carbon to deeper horizons, however the knowledge of subsoil carbon behavior is incomplete, with insufficient information to make accurate estimates deeper in the soil profile (VandenBygaart et al. 2011, Ogle et al. 2019 and Button et al. 2022). The method of measuring and modeling SOC at a depth of 30 cm is a standard and a normalized practice that helps compare a variety of regions which have been in place for decades. The 30 cm standard is currently recommended by the Intergovernmental Panel on Climate Change (IPCC) and is required by soil carbon protocols.

Agoro Carbon has implemented best practices to account for the changes in soil bulk density realized when converting from conventional tillage to no-till systems and uses the equivalent soil mass (ESM) procedures according to Wendt and Hauser, 2013 to correct for these changes over time. We provide instructions to our third-party soil sampling and laboratory partners to ensure they follow our guidelines for soil sampling and lab procedure for measuring SOC, to minimize soil sampling and lab errors as sources of uncertainty. We go beyond non-governmental registry guidelines and industry standards in estimating statistical uncertainty in carbon accrual and correcting for changes in soil bulk density.

General Requirements from Verra on Greenhouse Gas (GHG) Quantification

VM0042 provides three approaches to quantifying emission reductions and removals from the adoption of improved agricultural land management practices in the project compared to the baseline scenario:

1. Measure and model
2. Measure and remeasure

"The quality of our lives depends on our active nurturing of our environment. Each of us can offer a chance to offset our impact and cultivate a sustainable future. Our growers are at the frontline, and my team is unlocking the power of soil carbon modelling to serve them fairly."

– Susan Wang, Carbon Modelling Lead

3. Calculation based on IPCC guidelines

Agoro Carbon uses Approach 1 (measure and model to quantify SOC), so that we can generate credits based on the carbon model between soil sampling periods. Approach 2 (measure and remeasure) requires in-depth sampling each time credits are issued, and control sites are required to estimate baseline emission and/or removal. Approach 3 (calculation of GHG fluxes) uses default IPCC value-based calculations with low accuracy (e.g., calculations for practice changes regardless of the quality of implementation).

Our stratified soil sampling design, soil sampling, and modeling processes are entirely aligned with VM0042 methodology. Agoro Carbon has designed a scientifically defensible approach to accurately measure and report changes in GHGs in our project area - and doing so in a way that enables a scale up of commercial operations with considerations for cost, efficiency, quality, and with an internal SOC accuracy standard of 10% of the margin of error at the 90% confidence limit.

Soil Sampling Design (Stratification)

Agoro Carbon uses a variety of data sources and tools to stratify and allocate soil sampling points for each contracted field using guidance provided by Verra's VM0042 methodology, outlined in Table 1.

Stratified random sampling design (see this reference for general description) is a method for delineating fields that vary in topography, soil type, land cover, etc. into different zones or strata. These strata are developed using different data layers (see Table 1), which are related to the variations of SOC stocks. Individual strata resulting from this process are more homogeneous than entire fields. And when soil samples are collected using a stratified random sampling design there is less variability in SOC compared to using a completely random sampling design for an entire field. Hence, this approach provides a more accurate estimate of SOC stocks with less uncertainty and more accurate representation for the field. This approach not only improves the accuracy of our SOC estimate but requires fewer soil samples compared to completely random sampling designs, allowing us to reduce sampling costs. We employ a proprietary stratification process that allows us to incorporate variation associated with landscape (i.e. soil texture, slope, vegetation cover), climate, and management.

The stratification protocol includes five key steps:

Key Data Sources	Tools
• Published scientific datasets from literature review • Property boundary/management units (practices) • NAIP aerial photos and Sentinel/Landsat satellite imagery • Digital Elevation Model (DEM) • SSURGO soil data • Climate/precipitation	• ArcGIS Pro (ESRI) • eCognition (Trimble) • SAS Analytics (SAS) • R • Python packages

Table 1. Tools and Key Data Sources Used for Soil Sampling Design

property (see Figure 2). For Agoro Carbon's projects, a minimum of 6 sample locations are planned for each stratum for accurate representation of the SOC variations (to meet our goal of measuring SOC with a 10% margin of error at a 90% confidence interval), and the number of samples per stratum increases proportionally to the area of the stratum. The number of samples are based on prior knowledge acquired from analyzing thousands of soil cores, supplemented by scientific literature. The sampling allocation will continue to improve as more and more soil samples are taken and their results subsequently analyzed by our data scientists.

The fifth and final step of the soil sampling design is a quality check evaluation. Two data layers (a point GIS data layer and a polygon GIS data layer) are shared with our soil sampling lead from Data Team along with property boundary files to examine each soil sampling location to ensure they are accessible to reach based on actual field conditions.

1. Quality land classification
2. Creating data layers for stratification
3. Stratification
4. Sample allocation
5. The final stage of data sharing and QA/QC evaluation by stakeholders.

The first step in the soil sampling design is to carry out a quality land cover classification on each contracted field. In this step, aerial and satellite imagery are used to delineate fields into different landscape classifications (e.g. trees, grassland, water, etc.) Agoro Carbon strives to include only quality and high carbon-sequestering potential land cover such as grassland, row crops, and grazing ground in our soil sampling design process. Dense tree areas or bush cover, barren ground, and water are removed from the soil stratification process because they are not expected to sequester carbon.

Step two of the process is preparing data layers for stratification. These data layers collected and processed for stratification often have covariations with SOC. Data from publicly available sources are processed with standardized procedures and tools provided in the ArcGIS software package (www.esri.com). Additionally, a polygon layer related to management practices is created with information provided directly by enrolled growers in Agoro Carbon's program.

The third step (stratification) is the process of subsetting the land into strata based on the similarity of the combined data layers (Figure 2 shows different strata represented by the different colors).

Sample allocation is the fourth step of soil sampling design, whereby soil sampling locations are identified within each stratum and within the entire grower's

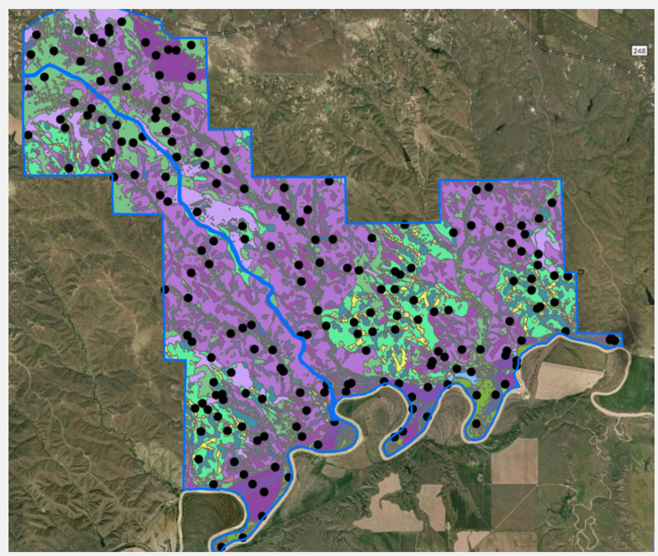


Figure 2. Example of different strata and sample points within each strata for ranch in South Dakota.

Soil Sampling, Lab Analysis, and SOC Reporting

Accurate SOC measurements depend not only on robust sampling design but also on the careful collection and precise analysis of soil samples. Agoro Carbon prioritizes minimizing measurement errors by using credible, certified third-party providers who are experts in soil

minimizing measurement errors by using credible, certified third-party providers who are experts in soil sampling and trained to follow our Standard Operating Procedures (SOPs) for soil collection to ensure the samples are collected in a scientifically sound and consistent manner. Collected soil samples are processed at certified laboratories for SOC and dry mass determination. The SOC analysis is performed using the dry combustion method following ISO 10694:1995.

Soil sampling commences after stratification and has indicated where samples should be taken in each stratum on a given farm or ranch. The process involves collecting a specific amount of soil from the specified sample locations, followed by lab analysis. The goal of soil sampling is to obtain measurements of soil carbon concentrations with enough statistical rigor to estimate soil carbon stocks per unit area. For a more detailed look at soil sampling and lab analysis procedures, please refer to Annex 1.

Partnering with companies who can take soil samples and measure soil organic carbon at scale is difficult. However, Agoro Carbon has been able to secure partnerships with several third-party soil sampling and laboratory partners who have agreed to implement Agoro Carbon's standard operating procedures, and which are taken directly from the VM0042 methodology. We have integrated our systems with these partners enabling us to extract real-time information. To date, these partners have provided us with sufficient capacity for soil sampling and laboratory analyses to maintain pace with the growers that enroll in our program.

Additionally, Agoro Carbon utilizes a live soil sampling management platform, which enables our Quality Assurance and Quality Control (QA/QC) team to monitor the entire soil sampling process in real-time. The platform provides several key benefits: 1) Sampling location verification: the platform ensures the soil samples are collected at the pre-assigned locations. By tracking the GPS coordinates of each sampling point, it guarantees that no sample locations are skipped or mislocated; 2) Data integrity: The system records all relevant sample data (e.g., depth, date, field conditions), ensuring that the correct protocol is followed. Any discrepancies, such as deviations from the sampling plan, can be flagged immediately for review and corrective action can be communicated to the sampling partners. Our QA/QC team also plays a crucial role in reviewing the laboratory results to ensure they meet the required standards for accuracy and consistency. The key process include: 1) Outlier detection: the QA/QC team uses statistical tools to identify outliers in the data; 2) Resampling and reanalysis: when questionable data is identified, the QA/QC team immediately requests a resampling the original samples to verify the accuracy of the results.

By combining a robust soil sampling design, reputable high-quality sampling and lab partners, real-time sampling tracking platform, high-standard QA/QC system, and constant assessment of lab results, Agoro Carbon is well positioned to generate highly accurate SOC measurements.

Agoro Carbon's Soil Organic Carbon Measurement Accuracy Level

Soil samples provide estimates of soil organic carbon (SOC) stocks over larger areas of a field, and to assess the accuracy of these estimates, we use the margin of error (MoE) statistic. In addition to the MoE, we calculate a confidence interval for each SOC estimate to indicate the likely range within which the true SOC value falls.

The MoE is a key indicator of measurement accuracy, representing the range around an estimated SOC value based on soil samples collected across the entire field. For example, if we set a 95% confidence level, the MoE shows that we are 95% confident the true SOC value lies within the range of the mean SOC value ± the MoE. A larger MoE suggests lower accuracy, meaning the true SOC value could differ more significantly from the estimate. The MoE can also be expressed as a percentage of the average SOC value, normalizing the error for clearer reporting and interpretation.

The above sections of the memo indicate a robust process, but the proof, as they say, is in the pudding. Agoro Carbon has been collecting soil samples from its enrolled growers, analyzing the results in the labs, and analyzed the margin

of error on the measured soil organic carbon from these samples.

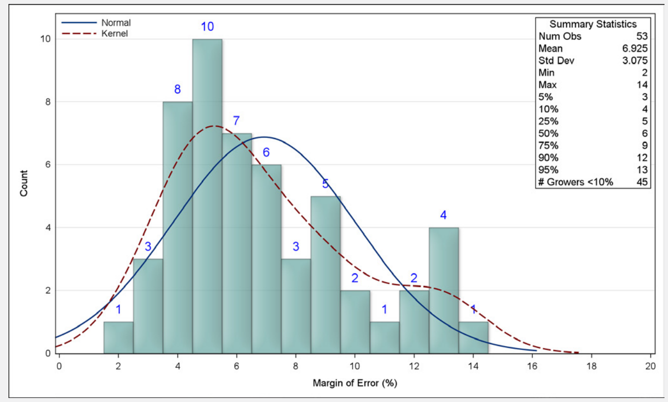
From Agoro Carbon's initial MoE analysis on the measured SOC of 5,147 soils samples collected from 53 growers in the US, we have found that:

- Our average MoE exceeds industry standards, with MoE of 6.9% at 95% confidence level, or 5.4% at 90% confidence level. For example, BCarbon1 MoE targets are 10%; also, per BCarbon standard, the estimated carbon mass needs to adjust or deducted if the MoE is larger than 10%
- Our results also show that 45 out of 53 growers' MoE are under 10% at a confidence level of 95% (Figure 3); but most (52 out of 53) growers' MoE are under 10% if a 90% confidence level is used (Figure 3).
- Our results show a MoE of 411.8 gram/m2, at 95% confidence level, with a mean SOC estimate of 6136.6 gram/m2. The analysis indicated that for all these collected samples, we are 95% confident that the true SOC stock lies between 5724.8 and 6548.4 grams/m2. We can also express the MoE as a percentage of the mean, 6.9%, indicating, on average, the error is 6.9% of the mean SOC stock.

These same strong results have also been replicated in Agoro Carbon Brazil. From Agoro Carbon's initial MoE analysis on the measured SOC of 828 soils samples collected from 9 growers in Brazil, we have found that:

- Our MoE analysis was well below our target of 10% with an average of 6% across the 828 samples and 9 growers.

Carbon Modeling



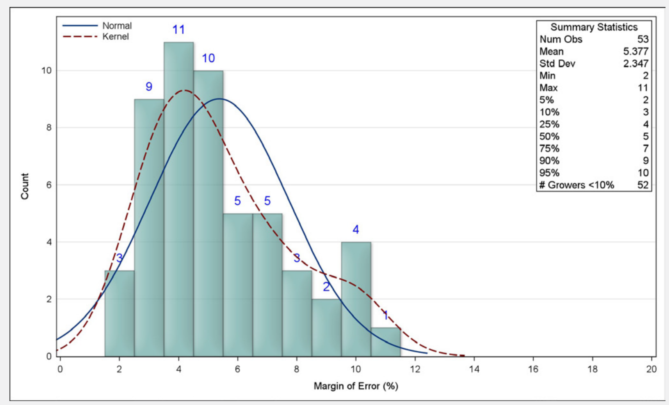


Figure 3 (top). MoE distribution histogram of all 53 growers at a Confidence level of 95%. Figure 4 (bottom). MoE distribution histogram of all 53 growers at a Confidence level of 90%

Greenhouse gas (GHG) models are mathematical representations of complex biogeochemical processes taken from ecological theory which describe movement of chemical elements between living organisms (i.e. plants and soil microbes), the atmosphere, and the soil. These models are capable of simulating SOC sequestration in the soil and emission of other GHG when provided with information on the specific site conditions (i.e. soil type and climate) and management practices (i.e. cover cropping and reduced tillage) for a given field. They can accommodate different time (i.e. daily to yearly) and spatial (i.e. square meters to large fields) scales, providing the user with the flexibility to simulate SOC and GHG dynamics under various scenarios.

Based on VM0042 quantification approach 1, an acceptable model can be used to quantify net emissions of CO_2, CH_4, and N_2O based on physical, chemical, and biological properties of soil and actual agricultural practices

implemented, measured initial SOC stocks, and climatic conditions in sample fields. For more information on carbon model validation, data needed, and Agoro Carbon's assessment of different carbon models, please refer to Annex 2 below.

The SOC baseline is established by utilizing 3-year historical management data, while the project simulation of SOC is carried out using management data reflecting the new project practice(s). Both the baseline and project scenarios employ the same daily weather data. The distinction between the two scenarios lies in implementing the new practice(s) during the project years. As a result, the SOC stock change is determined as the difference between projected SOC stocks resulting from the corresponding practice changes and the baseline SOC stocks at a particular project year.

Agoro Carbon will use our initial soil sample SOC measurements to initialize soil carbon pools and simulate SOC accrual from year one until another round of soil samples are collected (i.e. year 5). We will use the re-measured SOC to true-up the DayCent model. The true-up model will be used to simulate SOC accrual until the next round of soil samples are collected ([VM0042, pg. 68](VM0042, pg. 68)).

Not all the modeled SOC stock changes can be claimed as Verified Carbon Units (VCUs) via Verra. Agoro Carbon deducts some carbon out of the modeled carbon pool from additional greenhouse gas calculations as detailed under VM0042.

These items include: N2O and CH4 emissions, uncertainty deduction, and leakage deduction. Credits are also held aside in a buffer pool to cover reversals, following requirements in VM0042 Section 8.7. buffer contribution.

Agoro Carbon's Progress to Date On Carbon Model Calibration

We have completed model validation for our US row crop and pastureland projects. The sites for the row crop calibration depicted in Figure 5 below indicate where peer-reviewed experimental data was used for model validation for the row crop project (the geographical distribution was similar for the pastureland sites).

Supported by these sites covering the entire geographical domain for our row crop and pastureland projects, a regression analysis of the calibrated DayCent model on the validation datasets reveals an impressive R_2 value of

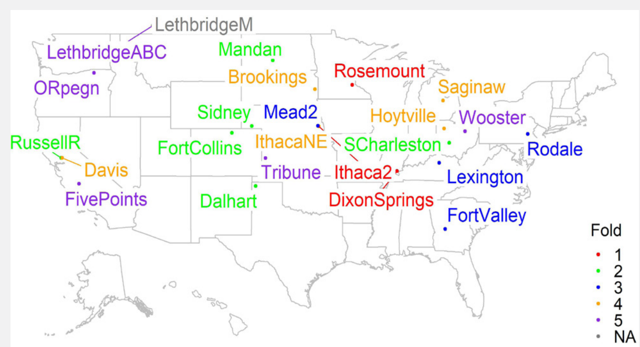


Figure 5. Sites where experimental data were collected for DayCent model calibration for croplands. The additional folds include sites outside the US with similar climate and soils to the project area.

0.93 (Figure 6), signifying that the simulated SOC stocks can explain 93% of the observed SOC's variation in the validation datasets. Additionally, the regression line closely aligns with the 1:1 line (represented by the dashed line), indicating a robust and proportional association between the simulated and observed SOC stocks.

Agoro Carbon's Daycent model has been audited by an independent Daycent expert hired by the Validation/ Verification Body (VVB) - Dr. Gerard Ros, a faculty member at Wageningen University and Research, with considerable expertise and experience in working with biogeochemical

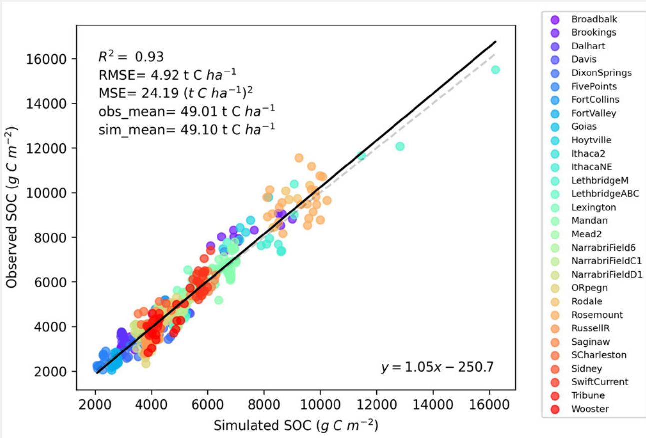


Figure 6. Regression analysis comparing simulated and measured SOC stock for the validation date sets for croplands.

carbon models. His conclusion was the following: "The Project uses the DAYCENT model and assesses the model performance per PC and crop type using published data from 30 experimental locations, extended with data from open datasets where needed. The calibration and validation procedure follows a clear, consistent and valid approach, where the quality of the procedures followed are outstanding, being an example to others."

Annex 1: Soil Sampling and Lab Analysis

Soil carbon stocks of a given sample are calculated using the Equivalent Soil Mass (ESM) approach, which requires two input variables, determined in the laboratory: 1) dry soil mass, expressed in grams, for a determined volume of soil and 2) concentration of organic carbon present in the soil. In the SOC calculation, where coarse material is present, we subtracted the mass of the coarse material from the total mass. The organic carbon concentration is the fraction of carbon derived from biological materials expressed as a percentage and is determined by dry combustion. The SOC stocks, in tons per hectare, is derived by multiplying the SOC concentration by the dry soil mass, with a factor used to convert grams to tons per hectare (see Figure 7).

Sampling must be undertaken using the following 6 steps:

1. Sampling equipment preparation
2. Field assessment and site preparation (e.g. soil condition)
3. Selection of sampling parameters
4. Sampling
5. Laboratory procedures for labeling and quality assurance
6. Logging soil sampling data including GPS coordinate, QR Code, lengths of core and phone numbers

Collected samples are processed at certified laboratories for SOC and dry mass determination. The SOC analysis will be performed using the dry combustion method following ISO 10694:1995. The standard operating procedure (SOP) is from Soil Survey Staff (2014), pp. 464–471. If the soil sample is above pH 7.2, then it must be corrected for inorganic carbon content. Dry soil mass is determined by air-drying samples for 48 hours to remove all water. For all the eligible project areas, baseline SOC stocks are calculated and reported as the sum of stocks in each stratum multiplied by the stratum area (acres).

Annex 2: Carbon Model Validation and Data Needed, and Agoro Carbon's Assessment of Carbon Models

A carbon project developer must calibrate and validate the model using peer-reviewed long-term experimental research data before applying the model to a carbon project.

1. The model must be validated following the guideline of model requirements in VMD0053 "Model Calibration, Validation, and Uncertainty Guidance for the Methodology for Improved Agricultural Land Management" "Model Calibration, Validation, and Uncertainty Guidance for the Methodology for Improved Agricultural Land Management"
2. VMD0053 model requirements indicate that for each Practice Category (PC) with the set of conditions (including crop type, soil texture, and associated clay%, and climate zone) within a particular project, "the model must be shown to have an acceptable goodness of fit and unbiased representation of the underlying biogeochemical process governing the effect of that practice." A model is judged as valid if 1) the model bias is not greater than pooled measurement uncertainty for the validation datasets

$$M_{n,dl,SOC} = \left(\frac{M_{n,dl,sample}}{\pi \left(\frac{D}{2}\right)^2 \times N} \times 10\,000 \right) \times OC_{n,dl}$$

Where:

$M_{n,dl,SOC}$	=	SOC mass in soil sample *n* in depth layer *dl* (kg/ha)
$M_{n,dl,sample}$	=	Soil mass of sample *n* in depth layer *dl* (g)
D	=	Inside diameter of probe or auger (mm)
N	=	Number of cores sampled (unitless)
$OC_{n,dl}$	=	Organic carbon content in sample *n* in depth layer *dl* (g/kg)
10 000	=	Conversion factor from g/mm² to kg/ha

Figure 7. ESM equation from VM0042 methodology.

from the collected experimental studies, and 2) at least 90% of the measurements are within the 90% prediction intervals for each PC and crop functional group combination which is declared in our project.

3. Datasets needed for model calibration and validation: to validate model performance and uncertainty for each declared PC and crop functional group (with their corresponding climate zone and soil texture), the combination must be high-quality observed experimental data reported in peer-reviewed scientific studies. Each climate zone must be represented in the validation dataset, at least three declared soil textural classes must be represented, and the range in clay% must span at least 15%. "The purpose of these minimums is to ensure testing for generalized model performance, i.e. that a model is not hyper-calibrated for a specific combination of factors that leads to poor model performance in other contexts." (VMD0053)
4. A Model Validation Report following the VMD0053 requirements and guidance must be submitted with each monitoring report and assessed and confirmed by a third-party independent expert. A successfully validated model has to be appropriate to the specific project, including demonstrating model validation for the project's domain and combinations of crop functional groups, practice categories, soil types, and climate zones, for example.
5. The parameter sets used when validating the model are the same as those used when the model is applied to simulate baselines and project practices.
6. A validated model has to be able to apply initial direct SOC measurement to initialize soil C pools for modeling and subsequent direct SOC measurement (at least every five years) to re-initialize the model. A process called true-up can be used in the same manner as in the first year of the project to simulate SOC changes for the following years.

Agoro Carbon has evaluated the strengths and weaknesses of commonly used models, including DNDC, APEX, DayCent, RothC and PaSim.

- All models had GHG outputs of CH4, N2O and CO2, along with SOC and crop yield/biomass - except for APEX which does not have CH4 output.
- All models employed a daily time step, except for PaSim, which utilized an hourly time step.
- The DNDC model uses a single input file encompassing site information, soil properties, and management practices, and it has been used in other carbon projects. However, it lacks detailed characterization of the soil profile, which can be a limitation when assessing carbon dynamics in different soil layers or depths, and users are limited to calibrating only DNDC inputs rather than adjusting model parameters.
- APEX is widely used with a crop growth model covering over 200 crops/plants and a detailed soil profile characterization. It is also capable of incorporating flexible, intensive rotational grazing schedule. However, no calibration/validation studies against measured CO2 and N2O exist, and APEX cannot simulate CH4 flux.
- PaSim is widely used in European grassland soils. It was developed in France and has limited use in the U.S. The model represents specific crop varieties or cultivars only in the U.S. context and may not fully capture the genetic diversity of crops grown in different regions of the U.S.

The DayCent model is widely used in other carbon projects. It has an open-source code, offers a detailed soil profile characterization, and is of intermediate complexity. Specifically, the DayCent model has several strengths for its application in carbon projects:

- Detailed carbon cycling representation: It considers factors such as plant growth, litter decomposition, soil organic matter dynamics, and microbial activity. This level of detail allows for accurate and comprehensive assessments of carbon sequestration, carbon losses, and greenhouse gas emissions in carbon projects.
- Adaptability to different ecosystems: This versatility enables its application in diverse carbon project settings (e.g. cropland, grassland, and forest), allowing for evaluating carbon dynamics in various land use types and ecosystem types.
- Consideration of management practices: The model

integrates management practices such as tillage, irrigation, fertilization, and crop rotation. It can simulate and evaluate the impacts of these different management strategies on carbon sequestration potential and greenhouse gas emissions.

- Validation and application track record: The model has been extensively validated using field measurements and experimental data from various locations worldwide, including a strong track record of application in carbon projects, providing reliable estimations of carbon fluxes and helping to understand the drivers of carbon dynamics in different ecosystems.

The primary weakness of the DayCent model is the large number of model and input parameter files and binary/ASCII output files. Overall, its many strengths make it a robust tool for assessing carbon dynamics in carbon projects, hence our decision to use the DayCent model for our carbon projects.

Agoro Carbon's Data Team

Names: John Pullis, Susan Wang, Mehedy Hassan, Thomas Pudil, Adri Chamorro, Katy Miles, Austyn Sanchez, Rodrigo Miranda, Fugui Wang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