

Microbial Carbon Mineralization (MCM)

Carbon Dioxide Removal Pathway

Methodology for Quantification and Crediting of Carbon Dioxide Removal

Version 1.0.1
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ISO 14064-2:2019

Version 1.0.1 of this methodology was developed by Andes and EcoEngineers. This methodology has been validated by Earthood in accordance with ISO 14064-2:2019 (<https://www.iso.org/standard/66454.html>).

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1. Summary Description

The Microbial Carbon Mineralization Methodology (MCM) provides procedures to quantify the greenhouse gas (GHG) removals resulting from soil inorganic carbon (SIC) increases attributable to the usage of a microbial inoculant on agricultural fields. It provides guidance to quantify, report, and verify carbon dioxide removals (CDR) generated through these practices. The SIC gains from the specific microbial activity are measured and attributed to the credits through the specified monitoring protocol. Before the start of the project, the ability of the microbial inoculant to fix CO_2 from the atmosphere needs to be demonstrated in lab and field studies. Credits are determined by measuring the difference in SIC generation between fields treated with microbial inoculant and untreated fields (i.e., baseline scenario).

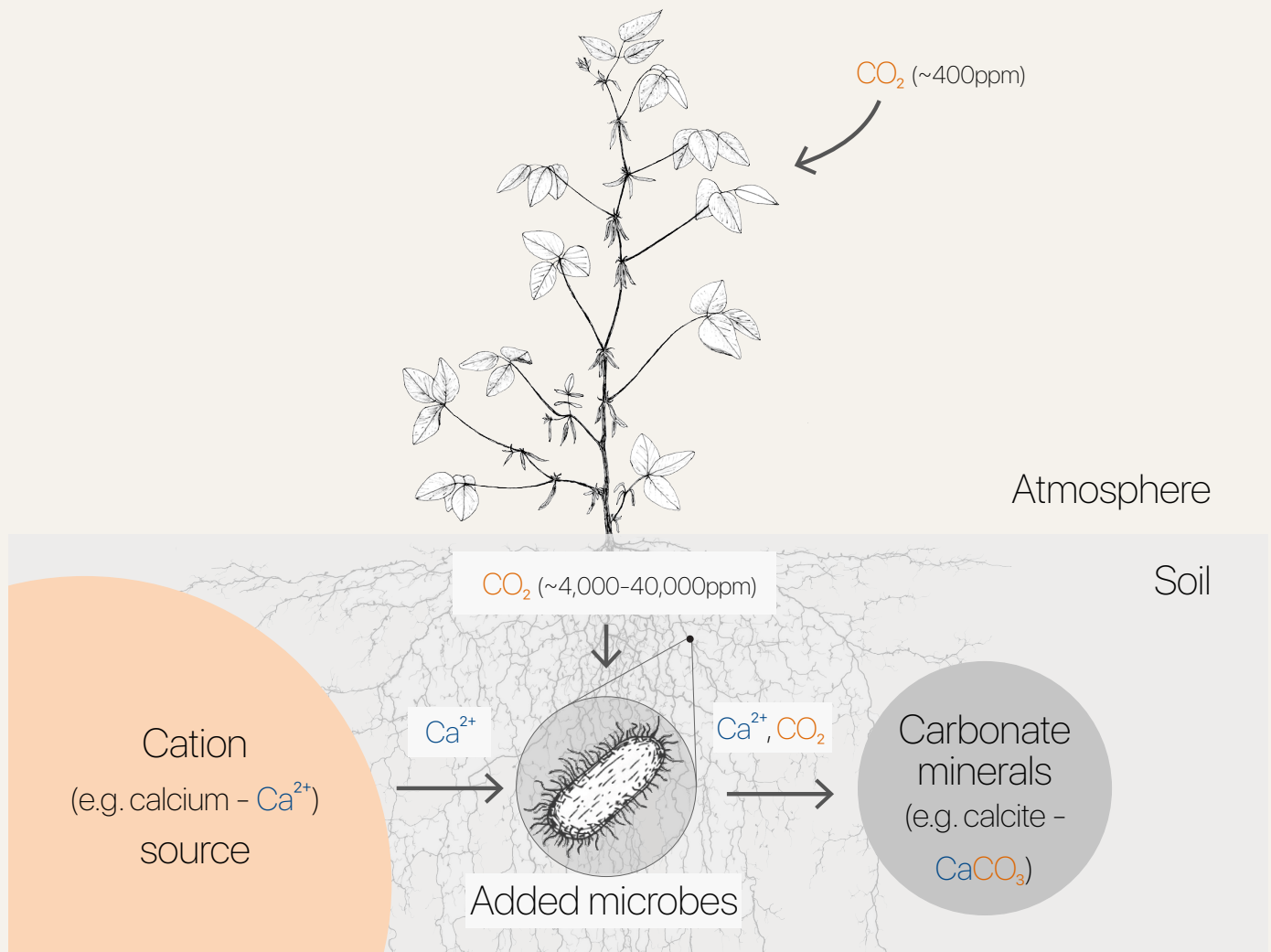


Figure 1. Illustration Demonstrating Use of Microbes for Carbon Dioxide Removal

This methodology, written in alignment with ISO 14064-2:2019, provides rules for eligibility, means of quantification, monitoring instructions, reporting requirements, and verification parameters. All projects will receive independent validation following procedures outlined under ISO 14064-3:2019 (<https://www.iso.org/standard/66455.html>). This methodology and associated measurement/quantification approach will be refined and improved over time following the best available science.

This version of the methodology (v1.0.1) exclusively follows a direct sampling approach and excludes removals from soil pools deeper than the reference sampling depth (i.e., 12 inches). Due to the nature of SIC generation and its permanence via these pathways, this methodology is intended for projects in areas with neutral to high soil pH. No avoided emissions credits will be generated

due to the displacement of traditional nitrogen fertilizer, increased agriculture yields, or other farm practices. CO₂ is the only GHG considered for sinks & reservoirs and only demonstrated increases in SIC attributable to microbial inoculant are credited.

The baseline scenario assumes the continuation of pre-project agricultural management practices and project activities may be combined with other beneficial farm practices. The methodology can be compatible with separate regenerative agriculture programs and practices (e.g., no-tillage, cover crops). Additionality is illustrated via a combined regulatory surplus and positive list.

Projects may be single fields or span multi-fields over multiple years with a monitoring period throughout the agricultural growing season. The exact monitoring period will differ depending on the project location and should correspond with the growing season (e.g., typically spring to fall in the US Midwest).

Project developers should select crop types that satisfy methodology requirements and are suitable for the project geography. It is important for the project developer to assess the time period for SIC generation to occur in microbial inoculant of interest and select a crop with a life cycle longer than that time period.

As farm operators join or leave the program, fields may be added or subtracted to a project for the purpose of validation/verification provided all monitoring requirements are met. Projects are valid for 5 years and can be renewed once.

Figure 2
General Overview of Key Project Activities

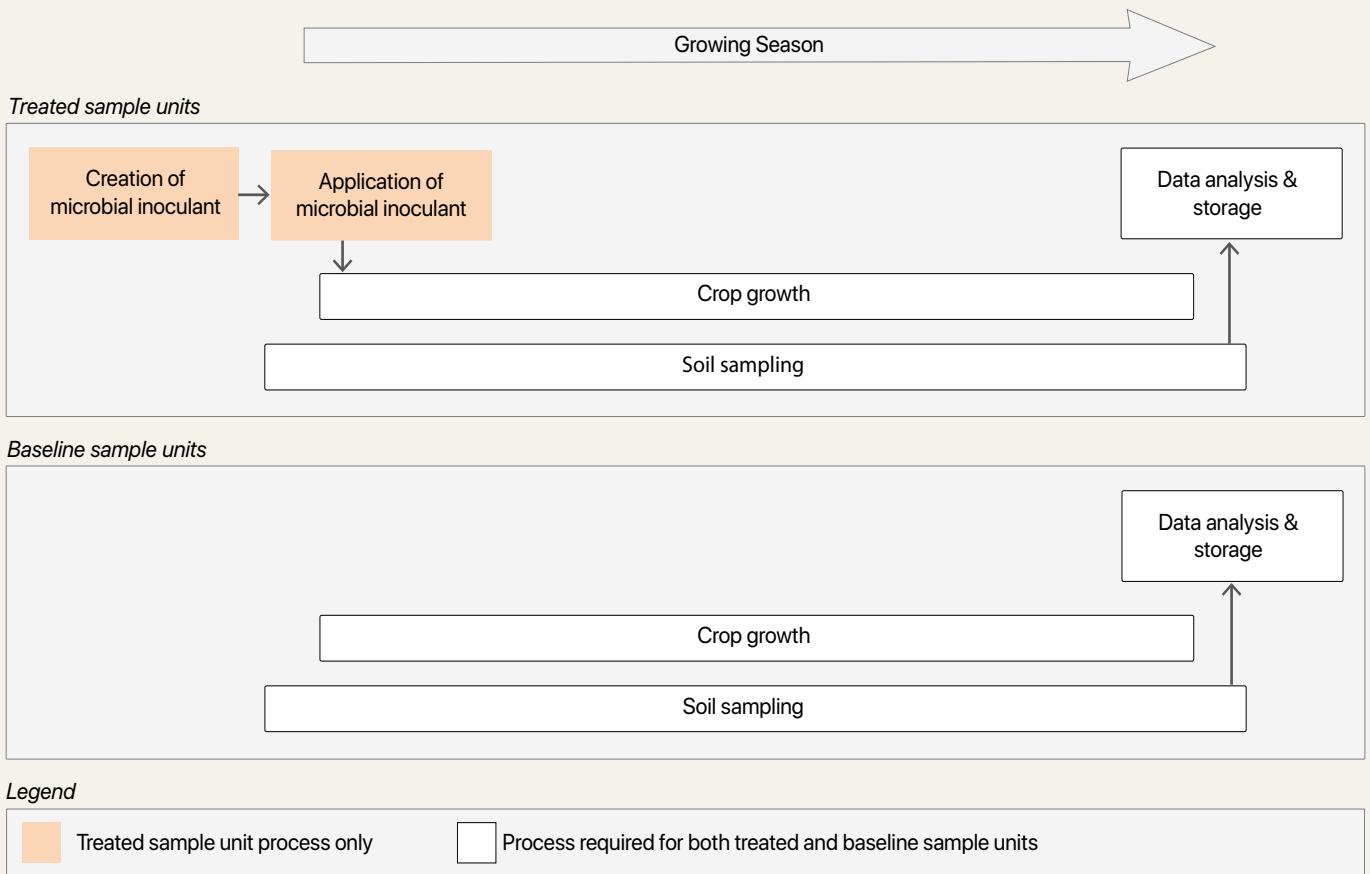


Table 1
Relationship to Existing Methodologies

Program	Methodology	Relevance	Disqualification
Verified Carbon Standard	VM0042 Methodology for Improved Agricultural Land Management v2.0	Crediting of carbon removals resulting from the adoption of land management practices to increase SOC (and thereby store atmospheric CO ₂).	The methodology does not address the application of microbial inoculant to increase SIC. Also, the methodology only considers soil organic carbon (SOC) generation.
Climate Action Reserve	Soil Enrichment Protocol; Version 1.1	Crediting of carbon removals resulting from the adoption of land management practices to increase SOC (and thereby store atmospheric CO ₂).	The methodology does not address the application of microbial inoculant to increase SIC. Also, the methodology only considers SOC generation.
Gold Standard for the Global Goals	Soil Organic Carbon Framework Methodology; Version 1.0	Crediting of carbon removals resulting from the adoption of land management practices to increase SOC (and thereby store atmospheric CO ₂).	The methodology does not address the application of microbial inoculant to increase SIC. Also, methodology only considers SOC generation.
Puro Standard	Enhanced Rock Weathering Methodology; Edition 2022	Crediting of carbon removals resulting from applying crushed rock or other material to soil to increase SIC (and thereby store atmospheric CO ₂).	The methodology does not address the application of microbial inoculant to increase SIC.

2. Definitions

Agricultural land: Land dedicated to agricultural production, including arable land, permanent cropland, and permanent pastures.

Alkalinity runoff: Water containing bicarbonate and carbonate ions that is leaving the open soil system.

Baseline area: Agricultural land used as a reference or control for the treated project area. This area should meet all applicability conditions except for the condition requiring application of a microbial inoculant for increasing SIC (see condition 1 in *Section 3*).

Baseline sample unit: A sample unit with no microbial inoculant applied, serving as a reference or control to compare against treated sample units.

Calcium Carbonate Equivalent (CCE): The measurement of all inorganic carbon molecules, including carbonate minerals and carbonate species.

Carbon Dioxide Removal (CDR): The process as well as the quantity of carbon dioxide (CO₂) removed from the atmosphere due to project activities, typically measured in metric tonnes. This term will be used interchangeably with GHG removal.

Cation Exchange Capacity (CEC): A measure of how many cations can be retained on soil particle surfaces. It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification.

Cropland: A land cover/use that includes areas used to produce adapted crops for harvest.

Existing cropland: Land that functioned as cropland prior to the project's start date, serving as a reference point for evaluating project applicability.

Farm operator: A person who runs the farm, making day-to-day management decisions. An operator could be an owner, hired manager, cash tenant, share tenant, and/or a partner, as defined by the USDA Economic Research Service glossary.

Field strata: Refers to the strata defined within a field, usually established through stratified random sampling.

Growing season: A period within a year during which growing conditions for crops are most favorable. The length of the growing season can vary significantly depending on geographical location, climate, and specific crop requirements. The growing season in the US Midwest typically occurs from late spring to early fall.

Greenhouse gas (GHG): A gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. GHGs include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF₆).

Microbial inoculant: A specific microbe or group of microbes intentionally introduced into the soil to promote the generation of soil inorganic carbon on agricultural lands.

Monitoring intervals: The time intervals between consecutive monitoring events or data collection points.

Monitoring plan: The guidance document that auditors shall use to develop a project-specific risk assessment and sampling plan. This will be incorporated into the Project Design Document.

Project area: Agricultural land subject to microbial inoculant application to generate soil inorganic carbon and meet all applicability conditions.

Project Design Document (PDD): The project document presented for validation which encompasses the plan for adherence to the requirements of this methodology.

Project proponent: The party responsible for documentation preparation, aggregation, and submittal to validation and verification body and to whom carbon dioxide removal credits are issued.

Sample unit: A defined area selected for measurement and monitoring, such as a specific section of a field. In the context of stratified random sampling, sample units refer to the field strata.

Sampling point: A predetermined location within a field or stratum where soil samples are collected for analysis.

Soil Inorganic Carbon (SIC): The collective term for all inorganic carbon molecules in the soil, encompassing carbonate minerals and bicarbonate. SIC is commonly measured and quantified as Calcium Carbonate Equivalent.

Soil Organic Carbon (SOC): Synonymous with Total Organic Carbon, referring to the carbon content stored within soil organic matter.

Soil Organic Matter (SOM): Material originally produced by living organisms that becomes incorporated into the soil and undergoes decomposition. Examples include plant roots, microbes, and other organic residues.

Soil pH: An indication of the acidity or alkalinity of soil and is measured in pH units. Soil pH is defined as the negative logarithm of the hydrogen ion concentration.

Stakeholders: Farm operators involved in applying the microbial inoculant on their land.

Stratification: The process of dividing a larger area or population into distinct subgroups or strata based on specific criteria or variables. Stratification aims to create homogeneous subgroups that share similar attributes within themselves while exhibiting differences between the subgroups, facilitating more accurate analysis, sampling, and understanding of the underlying patterns or characteristics within the larger population or area.

Strata (singular: stratum): The distinct subgroups created through the stratification process, each characterized by specific attributes or criteria.

Treated sample unit: A sample unit where a microbial inoculant has been applied for experimental or treatment purposes.

Total Carbon: The sum of both organic and inorganic carbon present in a given system or sample.

Total Organic Carbon (TOC): The amount of carbon stored within soil organic matter, derived from the decomposition of plant and animal residues, root exudates, living and deceased microorganisms, and soil biota.

Validation and Verification Body (VVB): Qualified and independent third-party auditors certified under ISO 14064-3, responsible for assessing and confirming the greenhouse gas statement of the project.

3. Applicability Conditions

This methodology is limited to the United States in scope and pertains to the application of a specific microbial inoculant intended to increase SIC on agricultural soils. The generation of SIC relates to the removal of CO₂ compared to the baseline scenario.

This methodology is applicable if the following conditions are met:

1. Projects must apply a microbial inoculant that leads to SIC generation.
2. Project activities must be implemented on existing cropland. This cropland should have been cropland during the year prior to project start (unless fallowing occurred that year) and must remain cropland throughout the project monitoring period.
3. The project area must be on non-irrigated cropland (i.e., fully rainfed).
4. Sample unit must have an average pH equal to or higher than 6.3 at the early-season sample timepoint (Dietzen, 2023).

The methodology is not applicable if any of the following conditions are met:

5. Agricultural limestone or other carbonate minerals applied the same year microbial inoculant is applied on the project area.
6. Project sites are enrolled in additional SIC generation programs.

Each treated field strata must meet the above applicability conditions. All applicability conditions, except condition requiring the application of a microbial inoculant for SIC generation (Applicability Condition #1), must be met for the baseline area (i.e., all baseline sample units).

4. Project Proponent Description

The project proponent must provide the following information in the Project Design Document (PDD):

- Roles and responsibilities, including contact information of the project proponent
- Evidence to confirm compliance with applicability conditions
- High level projection of tonnes per year over the lifetime of the project
- Description of planned (or completed) activities, including:
 - Description of the microbial inoculant applied and associated timing of the inoculant application
 - Initial number of fields to be included in project with location information
 - Date of project start
 - Date of project termination
 - Frequency of monitoring
 - Frequency of planned verification and validation
 - Description of how the applicability requirements are met for project area (i.e., field(s))
- If requested by the verification body, project proponent will share contact information of the farm operators where project activities take place
- Documentation supporting ownership of CDR credits
- Quantification of emission removals using the equations in the methodology
- Review of local and other relevant regulations in order to confirm regulatory surplus

5. Project Boundary

5.1 Carbon Pools

This methodology focuses only on the benefits of an increase of SIC pools. Therefore, accounting for generated CDR credits is limited to the SIC pool as shown in *Table 2*.

Table 2
Selected Carbon Pools

Pools	Description	Included?	Justification
Above ground	Stem, branches, bark, grass, crop biomass, and other organic matter containing materials.	No	Carbon pool not included because it does not contain inorganic carbon.
Below ground	Roots of grass, trees, herbs, crop biomass, and other organic matter containing materials.	No	Carbon pool not included because it does not contain inorganic carbon.
Litter	Leaves, fallen branches, and other organic matter containing materials.	No	Carbon pool not included because it does not contain inorganic carbon.
Soil organic carbon	Carbon content stored within organic material.	No	Carbon pool not included because it does not contain inorganic carbon.
Soil inorganic carbon	All inorganic carbon molecules in the soil, encompassing carbonate minerals and bicarbonate.	Yes	Major carbon pool affected by project activity that is expected to increase in treated fields.
Wood products	Standing and lying wood, as well as other wood-derived organic matter containing materials.	No	Carbon pool not included because it does not contain inorganic carbon.

The primary greenhouse gas monitored (non-emission source) with all SIC project activities is CO₂. For GHG emissions sources, CO₂e is used. To confirm project N₂O and CH₄ emissions due to microbial activities are immaterial, project proponents shall submit supporting documentation in the Project Design Document. Project proponents may incorporate sources, sinks, and reservoirs (SSRs) outlined in an ISO 14044-based Life Cycle Assessment or similarly rigorous accounting system but must include the SSRs identified in *Table 3*.

Table 3
Sources, Sinks, and Reservoirs

SSR	Type	GHG	Status of CDR accounting
Emission Sources	Microbial inoculant production & packaging	CO ₂ e	Declared
	Product distribution	CO ₂ e	Declared
	Field application	CO ₂ e	Declared
	Soil sampling (includes associated transportation)	CO ₂ e	Declared
	Soil Processing	CO ₂ e	Declared
Reservoirs	Soil inorganic carbon	CO ₂	Declared

5.2 Spatial Boundary

The spatial extent of the project boundary encompasses agricultural land, specifically cropland, subject to the implementation of the microbial inoculant that aids in the generation of SIC measured as CCE. There is no maximum project area if the applicability conditions are met.

5.3 Temporal Boundary

The temporal boundary will be from the start to the end of the growing season. The length of monitoring will be based on confirmed trials of duration between application and substantial SIC generation. A conservative estimate of the time needed to reach a substantial and detectable generation of SIC will be reported as described in the project monitoring section. The project proponent should monitor the SIC generation at intervals throughout the growing season to capture its increase driven by the application of the microbial inoculant.

5.4 Project Crediting Period

A project design document in relation to this methodology is valid for up to 5 years from the project start date. The period can be renewed once, therefore valid for up to 10 years.

5.5 Project Monitoring Period

The monitoring period should be one growing season, from before the microbial inoculant application or soon after (early-season) until the crop reaches maturity or post-harvest (late-season).

5.6 Project Start Date

In a single field, single year project, the project start date is determined by the date of microbial application on that field. In a multi-field project spanning different years and seasons, the project start date is determined by the earliest microbial application date within the included fields. Typically, this date coincides with the crop planting date, as the microbial inoculant is applied at that time.

Validating the start date can be achieved through various means, such as time-stamped photographs, attestations from the farm operator, or written documentation that details the treatment of the field with the microbial inoculant. These pieces of evidence serve to establish a clear record of when and how the microbial treatment took place, ensuring transparency and credibility in determining the project's initiation.

Project must undergo validation within 3 years from project start date.

6. Baseline Scenario

The baseline scenario is the continuation of standard agricultural practices, without the application of a microbial inoculant for increasing SIC. Untreated sample locations are used to represent SIC generation in the absence of project activities. These untreated sample units, which have representative soil types and conditions compared to treated sample units, are used to isolate the dependent variable, SIC generation attributable to the microbial inoculant treatment. See *Section 11* for more details. To quantify the tonnes of CO₂ removed, SIC generation on treated sample units throughout the growing season is compared to SIC generation on baseline sample units with the same key properties (see *Table 5* in *Section 11*). All applicability conditions except the condition requiring the application of a microbial inoculant that increases SIC (Applicability Condition #1) must be met for the baseline area (i.e., all baseline sample units).

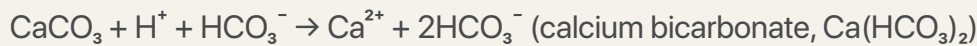
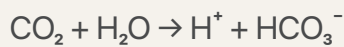
For projects using this methodology, it is recommended that the baseline area represents approximately 5-10% of the total project area. These baseline sample units may relate to an entire field or part of a field.

See *Section 11* and *Section 13* for baseline quantification and baseline sampling approach.

7. Permanence

Increases in SIC measured in the soil during the project time frame will predominantly be carbonate minerals. Carbonate minerals have low solubility in water, and migration through the soil can be slow. Bicarbonate is highly water-soluble and will percolate to deeper soil horizons relatively fast.

Carbonate minerals result from the reaction of bicarbonate with available cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) to form minerals such as calcium carbonate (CaCO_3) or dolomite ($\text{CaMg}(\text{CO}_3)_2$). In soils with high total cation content (e.g., due to a high CEC and an abundance of cation-bearing silicates) this reaction is favored. Carbonate minerals (e.g., CaCO_3) will redissolve to generate bicarbonates (e.g., calcium bicarbonate) with the introduction of CO_2 dissolved in rainwater. This occurs through the following chemical reactions (Sanderman, 2012):



As calcium bicarbonate ($\text{Ca}(\text{HCO}_3)_2$) is highly soluble in water, it will migrate into the subsoil with sufficient rainfall. With lower partial pressure of CO_2 ($p\text{CO}_2$) and water content, the calcium bicarbonate may reprecipitate and reform a molecule of calcium carbonate (CaCO_3), releasing a molecule of CO_2 in the process. By dissolving calcium carbonate (CaCO_3) into calcium bicarbonate ($\text{Ca}(\text{HCO}_3)_2$) there is a transient capture of an additional CO_2 molecule (two molecules in total) which is released back to the system once the calcium bicarbonate ($\text{Ca}(\text{HCO}_3)_2$) reprecipitates into calcium carbonate (CaCO_3). In summary, one molecule of CO_2 remains captured in the overall process (dissolution and precipitation).

The formation of terrestrial carbonate minerals depends on the source for cations, carbonate saturation state, and other local environmental conditions. Although carbonate minerals in the soil can have complex dynamics of dissolution and reprecipitation, there is a high likelihood of long-term durability (Chay et al., 2023). To favor the stability of bicarbonate and carbonate minerals, ideal soils are those with an average pH greater than 6.3 (Lindsay, 1979). In soils with a high buffering capacity (explained by a high content of primary minerals and carbonate minerals) as well as a near-neutral to alkaline pH and available exchangeable cations, carbonate minerals will likely accumulate in deeper horizons. The average turnover time of SIC in these calcium carbonate rich horizons globally has been estimated to be tens of thousands of years (Schlesinger, 1985). In some instances, carbonate minerals will eventually be exported from soils as water-soluble bicarbonate and end up in groundwater, rivers, and oceans. While the majority of bicarbonate in this instance will reach oceans and have durability of 10,000+ years (Kanzaki et al., 2023), some outgassing (evasion) may occur when groundwater reaches surface water and equilibrates with the atmosphere, experiences pH shifts, or interacts with the surface ocean (Chay et al., 2023). This scenario of alkalinity runoff leakage is accounted for in the uncertainty discount (see *Section 10*).

As addressed in *Section 13*, increases in SIC during the project timeframe are solely measured from soil samples. This method does not include measuring carbon in recharging waters and water deeper in the soil. Without measurements of the unprecipitated carbon in these water systems, there is a chance of overcounting or undercounting the amount of carbon removed. due to the application of the microbial inoculant This is currently under study and future versions of the methodology will be updated when complete.

For purposes of crediting, carbon dioxide removals are considered to be functionally permanent once shown to be incorporated into soil through direct soil sample measurements. Due to the inevitable uncertainties of carbon flows through natural systems, identifying and tracing small-scale reversals to their causal basis is often difficult or impossible. Recognizing that some reversals of CaCO_3 into CO_2 may occur regardless of any safeguards and guidelines introduced, this methodology utilizes an uncertainty discount based on the CDR verification framework and a conservative assessment of possible reversal scenarios (see *Section 10*).

Project proponents shall describe all measures taken to reduce the risk of reversal. Examples of measures proponents can take are described in *Table 3* in *Section 10*. The applicability conditions under this methodology will ensure most reversals are avoided; however, project proponents must have safeguards described as to specific practices employed to minimize the risk of reversals.

8. Additionality

8.1 Requirements for Additionality

1. Regulatory: Project shall not be the result of compliance with any mandated law, statute, or other regulatory framework.

The project activity of using a microbial inoculant to generate SIC, sequestering CO₂ permanently in the soil, is a novel approach. Whereas the absence of governmental acknowledgment does not alone guarantee additionality, the absence of such regulations pertaining to mandatory usage of SIC-enhancing microbes, along with the absence of prohibitions of the same, are required for projects to meet this regulatory additionality requirement for crediting.

2. Positive List

The project must demonstrate that it meets all applicability conditions, and in so doing, it is deemed as complying with the positive list and as being additional.

The activity penetration of this method is assumed to be near-zero at the time of the release of this methodology, and therefore activities meeting the conditions of eligibility are likely to be additional to any existing project and any project within 5 years after the methodology is published. The project will revisit the additionality baseline every 5 years to ensure that the project activity is still additional.

8.2 Credit and Payment Stacking

Projects generating credits under this methodology must demonstrate that there is no double counting of carbon/environmental benefits if combined with other credit types. Practices leading to increased SIC content instead of SOC are distinctly different and are logically separated into individual crediting programs. Growers can conduct regenerative agriculture practices under this methodology. Still in these instances, if credit stacking is desired, it must be clearly delineated and proven to the Verification and Validation Body (VVB) where the credits are being claimed. Examples of eligible programs would include those not specifically tied to carbon benefits, e.g., EPA Climate Smart Ag, regenerative ag programs.

Generally speaking, there are no restrictions on either payment or credit stacking under this methodology. In cases where payments or credits are attributed to CO₂ removed, payment or credit stacking is permitted when credits are clearly delineated by the project. Any type of conservation or ecosystem service payment or credit received for activities on the project area must be disclosed by the project proponent to the verification body on an ongoing basis.

9. Leakage

There are two leakage types considered for this project.

Economic leakage: This describes the risk of affecting GHG emissions that might be shifted outside the system boundaries of the project due to its implementation. Economic leakage is separate from the life cycle assessment (LCA) which includes emissions directly resulting from the implementation of the project (e.g., transportation). Leakage common to AFOLU methodologies is unlikely to occur for projects within this methodology. One potential leakage scenario for this project is the risk of indirect land use change in a scenario where an agricultural field is newly created for purposes of CDR (carbon dioxide removal) generation. To address this, fields must have been in agricultural use prior to the project start date and may not be newly converted. Similarly, fields should not be converted from one crop to another to maximize CDR yield at the expense of the original commodity crop. As there are carbon intensity differences between crops due to production cycles and other inputs, it is worth consideration, however, the scenario is unlikely and impact on net CDR generation is likely *de minimis*. Where available, records of crop rotation, satellite images (minimum spatial resolution of 300m/pixel should be used and for fields that cannot contain a 600m square inside of the field polygon 30m/pixel should be used), or attestations may be used as evidence of continuity of agricultural activity.

Physical leakage: This describes the risk of reversal or re-emission that could occur when carbon that is sequestered due to the CDR project is released back into the atmosphere. Certain field management practices fall into this category (such as soil acidification due to nitrogen application) and these will be compensated for in the overall uncertainty discount percentage that is applied in *Section 11* (CDR Quantification).

10. Risks and Uncertainty Discount

All risks that have been identified, along with suggested mitigations and level of impact on the removal calculation, are detailed in *Table 4*.

Table 4

Project Risks with Suggested Mitigation and Impact

Risk	Description and potential mitigation	Level of impact on removal calculation
Soil heterogeneity	Heterogeneity exists in soil inorganic carbon even within field strata. To address this risk, the project proponent should conduct the rigorous soil sampling procedures following best practices outlined in this methodology. This procedure consists of stratification of fields based on soil texture, random determination of sampling locations, and composites of 5-12 cores for each sampling location (see <i>Section 13</i> for more details).	Medium
Soil carbonate durability	<p>There is a high likelihood of long-term durability of the carbonate minerals formed (Chay et al., 2023). Through dynamics of dissolution and reprecipitation, carbonate minerals may dissolve to form water-soluble bicarbonates and move deeper into the soil over time (Sanderman, 2012). However, over the thousands of years of durability proposed, acidification (e.g., application of nitrogen fertilizers, acid rain) could pose a potential risk to the stability of a small portion of the carbonate minerals in the soil. To favor the stability of bicarbonate and carbonate minerals, ideal soils are those with an average pH greater than 6.3 (Lindsay, 1979).</p> <p>In regards to acid rain, Environmental initiatives such as the Clean Air Act have led to a significant reduction in sulfur dioxide and nitrogen oxide pollutants in the United States and Europe. As a result, the risk of acid rain in these regions is now minimal, ensuring projects there have a negligible risk of reversal due to acid rain. For other regions, the potential impact of this risk should be assessed and no projects should be implemented in high-risk areas.</p>	Low

Alkalinity runoff leakage	<p>Leakage may occur from outgassing of alkalinity runoff if carbonate minerals dissolve into water-soluble bicarbonate and reach groundwater before reprecipitating to carbonate minerals. In this instance, some outgassing may occur when groundwater reaches surface water and equilibrates with the atmosphere, experiences pH shifts, or interacts with the surface ocean (Chay et al., 2023).</p> <p>It is recommended the project proponent apply its microbes on fields with a near-neutral to alkaline pH with an abundance of cations. In these environments alkalinity runoff leakage is a low risk to durability as these environments favor the precipitation of carbonate minerals and its associated long term storage in the soil.</p>	Low
Impact on soil health	<p>Given the novel approach, it is vital to ensure that this CDR pathway does not harm long-term soil health (e.g., SOC levels, microbiota diversity, reduction of basic cations) and crop yield. This risk is focused on the impact of the pathway by which the carbonates are generated, rather than any risk posed by presence of the carbonates themselves. Both historical agricultural practices and literature support the benefits of carbonates in soils. Limestone (calcium carbonate) has been used historically by farm operators to improve soil structure (among other benefits). Literature supports the benefits of carbonate minerals in the soil (Fernández-Ugalde et al, 2014; Rowley et al, 2018; Raza et al, 2021).</p> <p>With regard to the impact of the microorganisms on soil health, it is recommended that the project proponent select microorganisms belonging to taxonomic groups that have been studied and/or reported for their non-detrimental effect on soil and plant health.</p> <p>With regard to potential impact of this pathway on SOC and cations, it is recommended that the project proponent monitor SOC levels and the cation exchange capacity (CEC) on the project area.</p>	Not applicable - risk will not impact carbon removal calculation / accounting

Taking into account the open-system nature of this project and the complex interaction of carbon fluxes in soil, an "uncertainty discount" has been incorporated into this methodology. This uncertainty discount relates to the risks, recommended mitigations and associated level of impact on removal calculation detailed in *Table 4*, as some risks are estimated to impact the calculations of tonnes of CO₂ removed. The purpose of this discount, which is commonly used in various sectors to address uncertainty, is to be conservative in carbon removal accounting. Lessons from leaders

in the CDR field, such as CarbonPlan and Frontier, have informed the application of this concept.

In this methodology's current version (v1.0.1), the uncertainty discount to be applied to all CDR credits generated is 30%. This value is a conservative estimate and related to the specific pathway risks, as detailed in *Table 4*. In future versions of the methodology, efforts will be made to better map uncertainties associated with this pathway by partnering with additional third-party entities. As more research areas are explored, an accumulation of field data is verified, overall scientific knowledge advances, and previously unknown factors are uncovered, the expectation is that the uncertainty discount will decrease over time.

Overall, the inclusion of an uncertainty discount in this methodology acknowledges the complexities and evolving nature of the field, and it aims to provide a conservative estimate of carbon removal while accounting for uncertainties.

11. CDR Quantification

This version of the methodology exclusively follows a direct sampling approach. It is recognized that the approach of direct sampling, and the corresponding calculations below, is a conservative approach to calculating CO₂ removed. It is conservative as it only includes the CO₂ removed that is directly measured. Any SIC (measured as CCE) generated that percolates into soil horizons deeper than what is directly measured is not included in the CO₂ removal calculation. As a result, this approach likely undercounts the amount of CO₂ removed.

To quantify the tonnes of CO₂ removed, SIC generation on treated sample units throughout the growing season is compared to average SIC generation on baseline sample units with the same key properties. The baseline area represents land with similar conditions to treated fields, except for the application of the microbial inoculant. All baseline sample units are grouped into baseline categories determined by key similarity criteria, detailed in *Table 5*. When calculating the CO₂ removed from the atmosphere resulting from the application of microbial inoculant, individual treated sample units are linked to a single baseline category that meets its similarity criteria detailed in *Table 5*. Also, treated sample units should only be linked with baseline sample units that had a planting date within the same season / year. It is likely that multiple treated sample units will be linked to the same baseline category. There also is the possibility that within the project there are baseline sample unit categories without any baseline sample units and associated data. In these instances, any treated sample units that link with such baseline categories (i.e., categories without any representative baseline sample units) will not be included in the CO₂ removal calculations. The purpose of baseline categories is to increase the sample size used as a baseline while isolating the land with the same key characteristics.

Table 5

Similarity Criteria for Linking Baseline Categories to Treated Sample Units

Baseline Category Similarity Criterion	Description
USDA Soil Moisture Regime Class	USDA Soil Moisture Regime Class is the same as the linked treated sample units. Applicable USDA Soil Moisture Regime Classes are as follows: <ul style="list-style-type: none"> • Aridic • Aquic • Udic • Ustic • Xeric
Calcium Carbonate Equivalent (CCE) levels in the soil at the start of the growing season (t=0)	Calcium Carbonate Equivalent (CCE) levels in the soil at the start of the growing season falls within the same zone as the linked sample unit. CCE zones are as follows: <ul style="list-style-type: none"> • 0-3% • 3-6% • 6-9% • 9-12%

	<ul style="list-style-type: none"> • 12-15% • 15-18% • 18-21% • 21-24% • 24+%
Percentage clay content (%)	<p>The percentage clay content (%) falls within the same group as the percentage clay content (%) of the linked sample unit. Percentage clay content (%) groups are based on the USDA Family Particle Size Classification and are as follows:</p> <ul style="list-style-type: none"> • Coarse Loamy: 0-18% clay • Fine Loamy: 18-35% clay • Clayey (Fine): 35-60% clay • Clayey (Very Fine): 60+% clay

To measure SIC generation, both the treated and baseline sample units will have direct measurements of CCE taken at multiple sampling points at multiple time points throughout the season. Refer to *Section 13* for sampling protocols and details regarding how these locations and time points are defined.

In order to quantify the tonnes of CO₂ removed from the atmosphere resulting from the application of microbial inoculant on cropland, the following approach is taken. First, remove all treated and baseline sample units with an average slope greater than 6% from calculations (C slope classification based on the USDA SSURGO database). With the remaining data set, estimate the number of tonnes of CO₂ removed by calculating the difference between the newly generated CCE throughout the growing season (i.e., project monitoring period) measured on treated sample units, compared to the average newly generated CCE throughout the project time frame measured on baseline sample units with the same key properties. This represents the newly generated CCE throughout the project monitoring period directly attributable to the treatment. Finally, convert this CCE into tonnes of CO₂ removed from the atmosphere and incorporate the uncertainty discount and LCA emissions. The details of all associated calculations are outlined below.

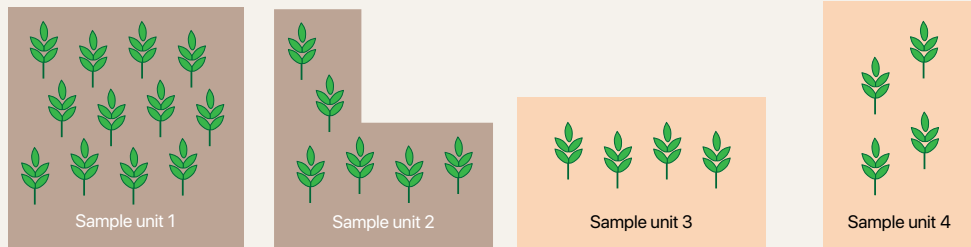
1. Calculate the newly generated CCE at each geographical point sampled in treated sample units throughout the project monitoring period (*Equation 1*)
2. Calculate the newly generated CCE at each geographical point sampled in baseline sample units throughout the project monitoring period (*Equation 2*)
3. For each treated sample unit, determine the tonnes of soil per acre within sampled depth (*Equation 3*)
4. For each treated sample unit, determine the average newly generated CCE throughout the project time frame in the treated sample unit (*Equation 4*)
5. For each baseline sample unit, determine the average newly generated CCE throughout the project time frame across all geographical points sampled within the baseline sample unit (*Equation 5*)
6. For each baseline category, determine the average newly generated CCE throughout the project time frame across all baseline sample units within the baseline category (*Equation 6*)

7. For each treated sample unit, determine the newly generated CCE throughout the project time frame directly attributable to the treatment. This is the difference between the newly generated CCE quantified for the treated sample unit and the newly generated CCE quantified for the associated baseline category (*Equation 7*)
8. Using the newly generated CCE quantified in *Equation 7*, for each treated sample unit calculate the tonnes of additional CCE generated per acre (*Equation 8*)
9. Using the tonnes of CCE/acre calculated in *Equation 8*, calculate the gross tonnes of CO₂ removed from the atmosphere (*Equation 9*)
10. Using the gross tonnes of CO₂ removed calculated in *Equation 9*, incorporate the uncertainty discount and LCA emissions to determine the net tonnes of CO₂ removed from the atmosphere (*Equation 10*)

Figure 3

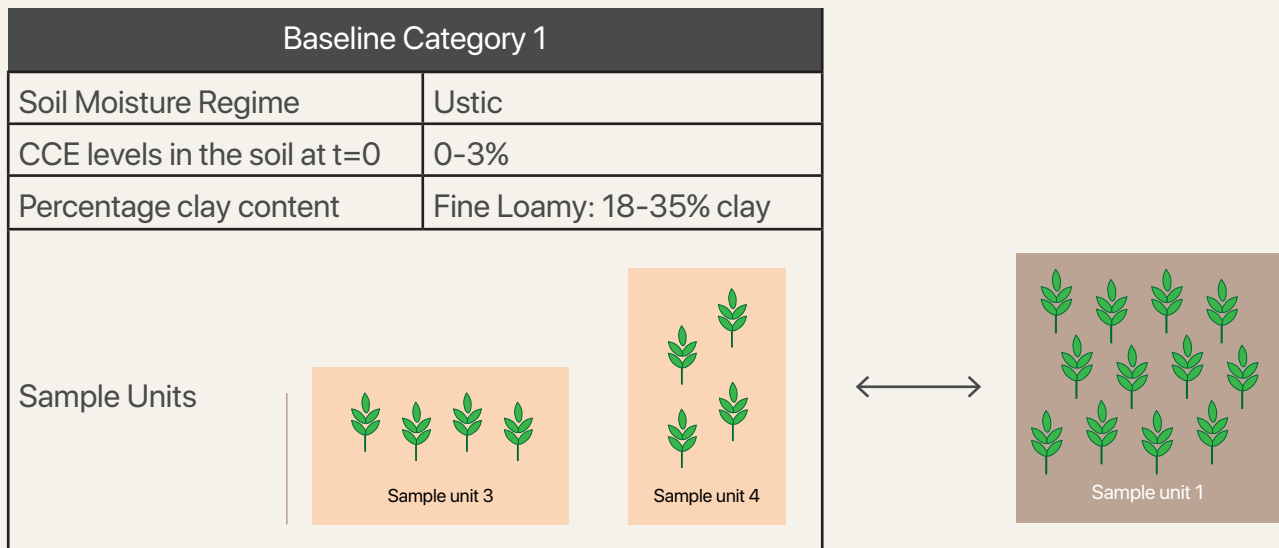
Illustrative Project to Demonstrate CCE Calculations and Baseline Linking

Example project



	Sample unit 1	Sample unit 2	Sample unit 3	Sample unit 4
Treatment	Treated	Treated	Untreated	Untreated
Soil Moisture Regime	Ustic	Ustic	Ustic	Ustic
CCE levels in the soil at t=0	0-3%	3-6%	0-3%	0-3%
Percentage clay content	Fine Loamy: 18-35% clay	Fine Loamy: 18-35% clay	Fine Loamy: 18-35% clay	Fine Loamy: 18-35% clay

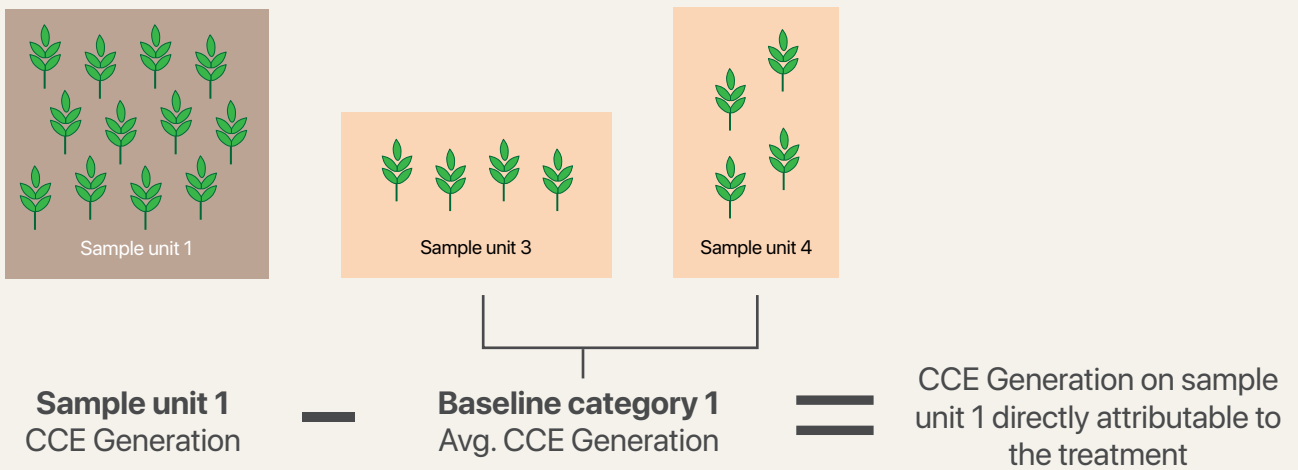
Baseline category linking



CCE measurements example



Attributable CCE generation calculations



Equation 1: CCE generation at each geographical point sampled in treated sample units throughout the project monitoring period (i.e., growing season)

$$\Delta CCE_{su} = \text{Max} [(CCE_{t=2,su} - CCE_{t=0,su}), (CCE_{t=1,su} - CCE_{t=0,su}), (CCE_{t=2,su} - CCE_{t=1,su}), 0]$$

Where		Definition	Unit
ΔCCE_{su}	=	CCE generation sampled at a single geographical point in a treated sample unit (<i>su</i>) throughout the project time frame (e.g., agricultural season)	CCE (%)
$CCE_{t=0,su}$	=	CCE from samples taken at the $t=0$ time point for treated sample units (<i>su</i>)	CCE (%)
$CCE_{t=1,su}$	=	CCE from samples taken at the $t=1$ time point for treated sample units (<i>su</i>)	CCE (%)
$CCE_{t=2,su}$	=	CCE from samples taken at the $t=2$ time point for treated sample units (<i>su</i>)	CCE (%)

CCE Note:

If the CCE% measured decreases between two points in time, that is indicative of either the lack of newly generated CCE or CCE moving to deeper soil horizons due to rainfall (Manning, 2008). As a result, if no CCE generation is directly measured, it is assumed to be zero. Given the fact that any CCE generated that moves into soil horizons deeper than what is included in the direct samples is not accounted for, this approach is a conservative estimate. In the future, this methodology can be amended to include a model to incorporate CCE generation that percolates to deeper soil horizons prior to the time direct samples are taken. For treated sample units, if samples are not collected at 2 distinct time points throughout the season for a single geographical point, then that geographical point is excluded from the calculation of CCE generation.

Equation 2: CCE generation at each geographical point sampled in baseline sample units throughout the project monitoring period (i.e., growing season)

$$\Delta CCE_{bu} = \text{Max} [(CCE_{t=2,bu} - CCE_{t=0,bu}), (CCE_{t=1,bu} - CCE_{t=0,bu}), (CCE_{t=2,bu} - CCE_{t=1,bu}), 0]$$

Where		Definition	Unit
ΔCCE_{bu}	=	CCE generation sampled at a single geographical point in baseline sample units (<i>bu</i>) throughout the project time frame (e.g., agricultural season)	CCE (%)
$CCE_{t=0,bu}$	=	CCE from samples taken at the <i>t=0</i> time point for baseline sample units (<i>bu</i>)	CCE (%)
$CCE_{t=1,bu}$	=	CCE from samples taken at the <i>t=1</i> time point for baseline sample units (<i>bu</i>)	CCE (%)
$CCE_{t=2,bu}$	=	CCE from samples taken at the <i>t=2</i> time point for baseline sample units (<i>bu</i>)	CCE (%)

CCE Note:

*If the CCE% measured decreases between two points in time, that is indicative of either the lack of newly generated CCE or CCE moving to deeper soil horizons due to rainfall (Manning, 2008). As a result, if no CCE generation is directly measured, it is assumed to be zero. Given the fact that any CCE generated that moves into soil horizons deeper than what is included in the direct samples is not accounted for, this approach is a conservative estimate. In the future, this methodology can be amended to include a model to incorporate CCE generation that percolates to deeper soil horizons prior to the time direct samples are taken. In instances where samples are taken at 3 unique time points (i.e., *t=0*, *t=1*, *t=2*), baseline sample units must have samples taken at all 3 time points, else the geographical point must be excluded from the calculation of CCE generation.*

Equation 3: Tonnes of soil per acre within sampled depth of the treated sample unit			
$\text{tonnes of soil / acre}_{su} = \text{m}^3 \text{ of soil per acre} * \text{bulk density}_{su} * (1 \text{ tonne}/1,000,000\text{g}) * (1,000,000\text{cm}^3/1 \text{ m}^3)$			
<i>Where</i>		<i>Definition</i>	<i>Unit</i>
<i>tonnes of soil / acre</i> _{su}	=	tonnes of soil per acre within the sampled depth of the treated sample unit (<i>su</i>)	tonnes of soil / acre
<i>m</i> ³ <i>of soil per acre</i>	=	m ³ of soil per acre within sampled depth (1,233.48 m ³ of soil per acre in the 0-12" horizon)	m ³ /acre
<i>bulk density</i> _{su}	=	The oven dry weight of the less than 2 mm soil material per unit volume of soil at a water tension of 1/3 bar	g/cm ³
<i>Note: there are 1,000,000 grams in 1 metric tonne and 1,000,000 cm³ in 1 m³</i>			

Equation 4: Average CCE generation throughout the project time frame in the treated sample unit

$$\text{Avg. } \Delta\text{CCE}_{su} = (\Sigma \Delta\text{CCE}_{su} / \# \text{ of points}_{su})$$

<i>Where</i>		<i>Definition</i>	<i>Unit</i>
$\text{Avg. } \Delta\text{CCE}_{su}$	=	Average CCE generation throughout the project time frame in the treated sample unit (<i>su</i>)	CCE (%)
$\Sigma \Delta\text{CCE}_{su}$	=	Sum of newly generated CCE during the season from samples taken within the treated sample unit (<i>su</i>)	CCE (%)
$\# \text{ of points}_{su}$	=	Number of points sampled (replicates) within the treated sample unit (<i>su</i>)	

Equation 5: Average CCE generation throughout the project time frame within the baseline unit

$$Avg. \Delta CCE_{bu} = (\Sigma \Delta CCE_{bu} / \# \text{ of points}_{bu})$$

<i>Where</i>		<i>Definition</i>	<i>Unit</i>
$Avg. \Delta CCE_{bu}$	=	Average CCE generation throughout the project time frame within the baseline sample unit (<i>bu</i>)	CCE (%)
$\Sigma \Delta CCE_{bu}$	=	Sum of newly generated CCE during the season from samples taken within the baseline sample unit (<i>bu</i>)	CCE (%)
$\# \text{ of points}_{bu}$	=	Number of points sampled (replicates) within the baseline sample unit (<i>bu</i>)	

Equation 6: Average CCE generation throughout the project time frame within the baseline category

$$Avg. \Delta CCE_{bc} = (\Sigma Avg. \Delta CCE_{bu_{bc}} / \# \text{ of units}_{bc})$$

<i>Where</i>		<i>Definition</i>	<i>Unit</i>
$Avg. \Delta CCE_{bc}$	=	Average CCE generation throughout the project time frame within the baseline category (<i>bc</i>)	CCE (%)
$\Sigma Avg. \Delta CCE_{bu_{bc}}$	=	Sum of average newly generated CCE during the season from baseline sample units (<i>bu</i>) (from <i>Equation 5</i>) within the baseline category (<i>bc</i>)	CCE (%)
$\# \text{ of units}_{bc}$	=	Number of baseline sample units within the baseline category (<i>bc</i>)	

Equation 7: CCE generation throughout the project time frame directly attributable to the treatment

$$\Delta CCE_{\text{Additional, su}} = \text{Max}(\text{Avg. } \Delta CCE_{\text{su}} - \text{Avg. } \Delta CCE_{\text{bc}}, 0)$$

<i>Where</i>		<i>Definition</i>	<i>Unit</i>
$\Delta CCE_{\text{Additional, su}}$	=	CCE generation throughout the project time frame directly attributable to the treatment in each treated sample unit (<i>su</i>)	CCE (%)
$\text{Avg. } \Delta CCE_{\text{su}}$	=	Average CCE generation throughout the project time frame in the treated sample unit (<i>su</i>)	CCE (%)
$\text{Avg. } \Delta CCE_{\text{bc}}$	=	Average CCE generation throughout the project time frame within the baseline category (<i>bc</i>)	CCE (%)

Note: If $\text{Avg. } \Delta CCE_{\text{su}} - \text{Avg. } \Delta CCE_{\text{bc}} < 0$, it is assumed that 0 CCE generation can be directly attributed to the treatment in a given sample. Per *Section 7*, any carbonate species generated will be durable.

Equation 8: Tonnes of additional CCE generated per acre

$$\text{Tonnes CCE / acre}_{su} = \Delta CCE_{\text{Additional, su}} \times (1/100) \times \text{tonnes of soil / acre}_{su}$$

<i>Where</i>		<i>Definition</i>	<i>Unit</i>
<i>Tonnes CCE / acre</i> _{su}	=	Tonnes of CCE generation throughout the project time frame directly attributable to the treatment in a given treated sample unit (<i>su</i>)	tonnes of CCE / acre
$\Delta CCE_{\text{Additional, su}}$	=	CCE generation throughout the project time frame directly attributable to the treatment in a given treated sample unit (<i>su</i>)	CCE (%)
<i>tonnes of soil / acre</i> _{su}	=	tonnes of soil per acre within the sampled depth of the treated sample unit (<i>su</i>)	tonnes of soil / acre

Equation 9: Gross tonnes of CO ₂ removed from the atmosphere			
$\text{Gross tonnes CO}_2 = (\text{Tonnes CCE} / \text{acre}_{su}) \times \# \text{ of acres}_{su} \times 0.44$			
<i>Where</i>		<i>Definition</i>	<i>Unit</i>
<i>Tonnes CO₂</i> _{su}	=	Tonnes of CO ₂ removed from the atmosphere throughout the project time frame directly attributable to the treatment in a given sample unit (<i>su</i>)	<i>tonnes of CO₂</i>
<i>Tonnes CCE / acre</i> _{su}	=	Tonnes of CCE generation throughout the project time frame directly attributable to the treatment in a given treated sample unit (<i>su</i>)	<i>tonnes of CCE / acre</i>
<i># of acres</i> _{su}	=	Number of acres included in the treated sample unit	<i>acres</i>
0.44	=	Conversion of CaCO ₃ to CO ₂ based on the molecular weight (MW) of both compounds MW of CO ₂ / MW of CaCO ₃ = 44.009/100.09 = 0.44	unitless

Equation 10: Net tonnes of CO₂ removed

$$\text{Net tonnes CO}_2 = \text{Gross tonnes CO}_{2\text{su}} (1 - \text{UNC}) - \text{LCA}$$

<i>Where</i>		<i>Definition</i>	<i>Unit</i>
<i>Gross tonnes CO₂</i>	=	Tonnes of CO ₂ removed from the atmosphere throughout the project time frame directly attributable to the treatment in a given sample unit (su)	<i>tonnes of CO₂</i>
<i>UNC</i>	=	30% uncertainty discount	%
<i>LCA</i>	=	Tonnes of CO ₂ emitted from project operations, determined by LCA	<i>tonnes of CO₂</i>

Conservative factors

The above series of equations makes conservative assumptions to ensure the calculations are not over-estimating the net tonnes of CO₂ removed (i.e., SIC generation). These conservative factors are detailed below.

- Molecular weight conversion - to convert tonnes of CCE into tonnes of CO₂, the equation uses the molecular weight ratio of CaCO₃ to CO₂ (0.44). This is conservative, as the SIC (measured as CCE) could be in the form of calcium bicarbonate (Ca(HCO₃)₂), which has a molecular weight of 162.1146 g/mol. If calcium bicarbonate was used in the ratio to convert CCE to CO₂ the resulting ratio would be $((2 \times 44.01)/162.1146) = 0.54$. Using the calcium bicarbonate conversion value (0.54) in the equation to calculate tonnes of CO₂ would result in a greater final value of tonnes of CO₂ than the calcium carbonate conversion value used (0.44).
- Generation of SIC - the calculations only account for the generation of SIC (quantified as CCE) measured in the soil, rather than purely the difference in CCE between treated sample units and baseline sample units. This is conservative as the calculations do not account for tonnes of CO₂ removed in the scenario in which (a) both the treated sample units and baseline sample units experience a net depletion of CCE and (b) the Δ CCE of the treated sample unit is less negative than the Δ CCE of the untreated sample units. In this scenario given the calculation methodology outlined above, the tonnes of CO₂ removed would be 0. This is due to the fact that in *Equation 1* and *2*, all negative values are converted to 0.
- Uncertainty discount - 30% discount to account for uncertainties in the calculation of tonnes removed given the open system nature of this project and the complex interaction of carbon fluxes in soil. See *Section 10* for details.

12. Managing Data

Project proponent will follow the below practices to ensure high-quality data management:

1. Data Acquisition

- a. Farm operators must provide geographic coordinates of fields included in the program to the project proponent.
- b. Polygons (digital shapes with coordinate data) encompassing the area of the fields participating in the program must be created by the project proponent and information registered in the project proponent's database.
- c. Random sampling points within each polygon are generated, and their coordinates are stored in the database.
- d. Sampling personnel must be provided with the exact location (coordinates) and dates for retrieving soil samples. Any deviation from the soil sampling protocol must be documented and justified.
- e. Soil samples must be collected, labeled, and shipped to an analytical laboratory (external or internal) for analysis.
- f. After the planting event, data reconciliation is needed to adjust the final treated area and final labels (treated vs baseline sample units).

7. Data Processes

- a. When working with an external laboratory, data generated by the external analytical laboratory must be sent to the project proponent by an electronic medium.
- b. In both scenarios (external or in-house analysis), the data must be checked for consistency and incorporated into the database.
- c. Data will be processed to perform CDR calculations.
- d. Processed data must be stored in the database.

3. Distribution of Data

- a. Data is accessible directly from the database through a web-based software by select project proponent team members. View-only access to the necessary data is also provided for external due diligence needed to be conducted by third parties, including external verification bodies.
- b. All transactions including generation, transfer and retirement of CDR credits are logged and viewable in a registry database.

13. Monitoring

This version of the methodology allows for only a direct sampling monitoring approach. Monitored parameters are collected and recorded at the sample unit scale, and CO₂ removed is estimated independently for every sample unit (see *Section 11* for equations). The main objective of the monitoring is to quantify the generation of SIC, measured as CCE, and the removal of CO₂ resulting from the project scenario.

The monitoring period should be one growing season, from before the microbial inoculant application or soon after (early-season) until the crop reaches maturity or post-harvest (late-season).

13.1 Monitoring Plan

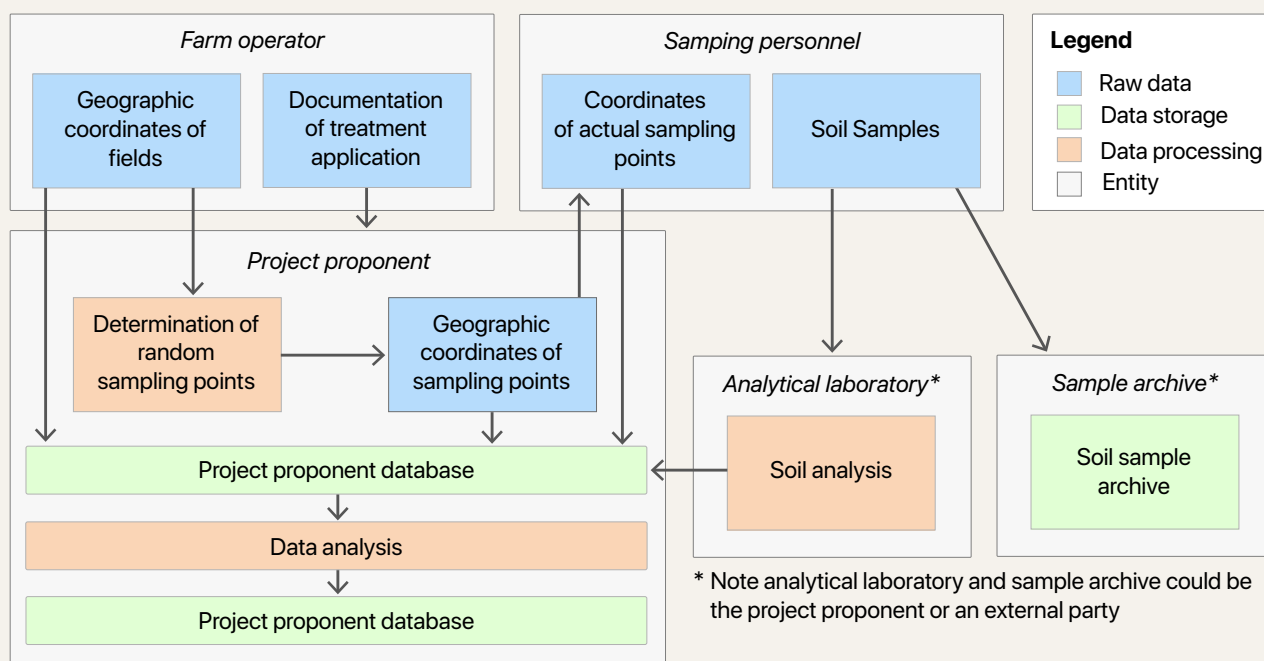
The project shall maintain a monitoring and reporting plan that will be used for both validation and verification. The monitoring plan must contain at least the following information:

1. General description of the project that includes:
 - a. Number of fields and location information (boundary coordinates, georeferenced map, or geo-spatial vector data);
 - b. In cases where the project monitoring plan will be a public document, projects may request that information relating to the location of specific fields be redacted;
 - c. Description of the microbial inoculant applied and associated timing of the inoculant's application.
2. Definition of the roles and responsibilities of the monitoring team. This includes identifying the key personnel involved in data acquisition, monitoring, reporting, and their corresponding job titles. The plan should outline the capacity and expertise of the monitoring team, including training practices and associated training materials.
3. Details on how data is controlled for the project, such as data storage, access controls, and data security measures. It is recommended to include a diagram illustrating the data flow, indicating the responsible parties at each stage. *Figure 4* is an example framework the project proponent would define further.
4. Data collection plan including the type of data to be collected, associated details, and data collection techniques. The plan must specify the frequency of monitoring and sample designs for directly sampled parameters. At a minimum, the data required for quantification shall be monitored and recorded (or documented, as appropriate) for each monitoring period (i.e., growing season).
5. Data archiving procedures, including procedures for any anticipated updates to electronic files. All data collected as part of the monitoring process, including QA/QC data, must be archived electronically and kept at least two years after the end of credit verification.
6. Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection and for example, correct anomalous values, perform independent checks on analysis results, and other safeguards as appropriate.
7. List the equation(s) used to calculate CO₂ removed.

8. Descriptions of measurement devices, equipment, or instruments used to report data (if relevant) and how acceptable accuracy is demonstrated, e.g., installation, maintenance, and calibration method and frequency. If applicable, this would also include:
 - a. Original equipment manufacturer documentation or other documentation that identifies instrument accuracy and required maintenance and calibration requirements for all measurement devices used to collect necessary data for reporting;
 - b. The dates of measurement device calibration or inspection, and the dates of the next required calibration or inspection. This should include lab practices for calibration analytical methodology as well as procedures such as internal lab QC.

Figure 4

Example Information Flow for the Project



13.2 Sample Design and Timing

A stratified sampling approach should be used to collect samples from both the project and baseline areas to assess SIC generation. Each field should be stratified based on soil texture and average slope (0-6% and >6%). The USDA SSURGO database (<https://websoilsurvey.nrcs.usda.gov/>) can be used to perform the stratification maps for the fields, where each stratum will represent the sample unit of the current methodology.

Within each stratum, random sampling points are defined before the first sampling event. It is recommended to collect 3-5 sampling points per stratum (a minimum of 2 sampling points per stratum is required). Each sampling point is a soil composite consisting of 5-12 sub-samples taken in a radius of 10 ft around the center point (i.e., sampling point). The sampling points are recorded with coordinates and are kept the same throughout the monitoring period (e.g., the growing season) but also remain the same throughout the upcoming years if the same land is used repeatedly.

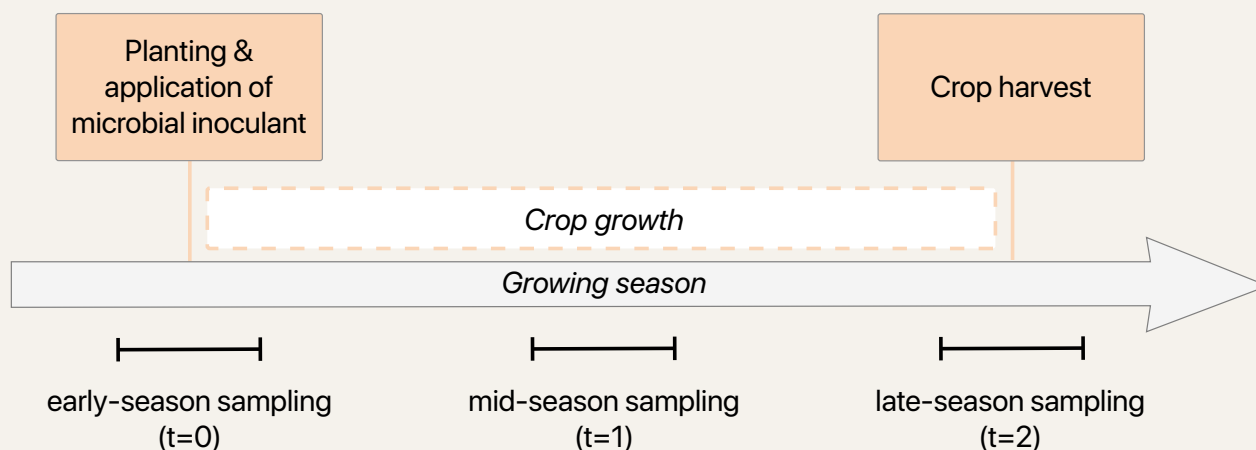
It is recommended to collect samples to a depth of at least 12 inches to measure the SIC signal resulting from the addition of microbial inoculant while minimizing potential interference from background SIC already present in the soil. In topsoils with an existing pool of carbonate minerals, the deeper the soil sampling is performed, typically the higher the SIC background noise resulting in a lower signal-to-noise ratio.

For treated and baseline sample units, soil samples should be collected at a minimum of two different instances (i.e., timepoints) during the growing season. One of the timepoints must be at the start of the season, referred to as the early-season timepoint ($t=0$). The early-season timepoint must be collected within the following time frame: 5 weeks before microbial inoculant is applied to 3 weeks after planting. Ideally, the early-season timepoint should be conducted as close to planting as possible. The other time point can be any time after the early-season timepoint (within 8 months). It is recommended that samples are collected at two time points after early-season: mid-season ($t=1$) and late-season ($t=2$). When taking mid-season samples, it is recommended the samples be collected toward the end of the vegetative stage of the crop. For example, the target for the mid-season sample would be the V11 growth stage for corn, with an optimum window between V9 and R1 (Rochette & Flanagan, 1997). Late-season samples should be taken within the following time frame: when crop reaches physiological maturity to 4 weeks after crop harvest. For example, the late-season target for corn would be within a day of crop harvest, but the required window is between crop physiological maturity and 4 weeks after crop harvest. See *Figure 5* illustrating these timepoints.

In instances where samples are taken at 3 unique time points (i.e., $t=0$, $t=1$, $t=2$), baseline sample units must have samples taken at all 3 time points, else the geographical point must be excluded from the calculation of CCE generation.

Figure 5

Illustrative Diagram Showing Sample Timepoints



Soil sampling should follow established best practices, such as those found in the USDA GRACEnet Sampling Protocol, Chapter 1 (Liebig et al., 2010).

All samples should be inventoried, labeled, and packaged for shipping to ensure they are accurately recorded and ready for laboratory analyses and archival preservation.

13.3 Sample Analysis

CCE % is the primary measurement to determine SIC generation. CCE represents all inorganic carbon molecules, including carbonate minerals and bicarbonate, and reports the amount of inorganic carbon as equivalent to calcium carbonate (CaCO_3). CCE % can be measured by pressure calcimeter, gas chromatography, or gravimetric loss approaches. Pressure calcimeter involves using a strong acid to dissolve inorganic carbon molecules present in a known amount of dried soil and measuring the pressure from the resulting CO_2 generation. The measurement unit is volts which with a standard curve is converted to milligram (mg) of calcium carbonate. The result is expressed as a percentage of calcium carbonate equivalent (CCE) taking in consideration the known amount of soil used for the analysis.

Ideally, other analyses can be included such as pH, CEC, SOC, OM, and individual measurement of exchangeable base cations (i.e., calcium, magnesium, potassium, and sodium).

The laboratory results shall be recorded appropriately and in accordance with the *Section 13.1*.

13.4 Sample Archiving

To ensure that samples can be re-tested in the future, if necessary, it is important to collect a sufficient volume of each sample and store all samples in an archive. The samples can be stored in-house or arrangements can be made with an external laboratory to create an archive. Archived samples must be completely dried or frozen, to prevent ongoing biological activity from changing soil carbon densities and to stop ongoing chemical reactions. Samples must be stored for a minimum of two years after credit verification.

13.5 Data and Parameters Collected for CDR Calculations

All parameters should be collected for both treated project areas and baseline areas.

Data/Parameter:	Calcium Carbonate Equivalent (CCE)
Unit	%
Description	The measurement of all inorganic carbon molecules, including carbonate minerals and carbonate species
Source of data	CCE measurements taken on collected soil samples from field strata (method to collect soil samples detailed below)
Value(s) applied	0-100%
Measurement procedures	Can be measured by pressure calcimeter, gas chromatography, or gravimetric loss approaches
Monitoring frequency	The project proponent should monitor CCE generation by taking soil samples at multiple intervals throughout the season. See <i>Section 13.2</i> for details
QA/QC procedures	Each sample is a soil composite consisting of 5-12 core samples taken in a radius of 10 ft around the center point (i.e., sampling point). It is recommended to sample to a depth of 12 inches

Data/Parameter:	m ³ of soil per acre within sampled depth
Unit	m ³ per acre
Description	Measurement of the volume of soil in an acre within the sampling depth of the project
Source of data	US customary units
Value(s) applied	Can vary based on project sampling depth; for a depth of 12" the value of 1,233.48 is used
Measurement procedures	N/A
Monitoring frequency	N/A
QA/QC procedures	N/A

Data/Parameter:	Bulk Density
Unit	g/cm ³
Description	The oven dry weight of the less than 2 mm soil material per unit volume of soil at a water tension of 1/3 bar
Source of data	USDA
Value(s) applied	Varies by sample unit
Measurement procedures	N/A (Sourced from database)
Monitoring frequency	N/A (Sourced from database)
QA/QC procedures	N/A (Sourced from database)

Data/Parameter:	# of acres _{SU}
Unit	acres
Description	Area of land in acres of given sample unit
Source of data	
Value(s) applied	Varies by sample unit
Measurement procedures	N/A
Monitoring frequency	N/A
QA/QC procedures	Confirmed by GIS or grower documentation (e.g., carbon program agreement, legal document, farm operator management system)

Data/Parameter:	USDA Soil Moisture Regime Class
Unit	N/A
Description	Soil moisture regime classes are defined by the level of ground water and the seasonal presence or absence of water
Source of data	USDA SSURGO Database
Value(s) applied	Aridic Aquic Udic Ustic Xeric
Measurement procedures	N/A (Sourced from database)
Monitoring frequency	N/A (Sourced from database)
QA/QC procedures	N/A (Sourced from database)
Additional comments	Baseline linking criteria Soil moisture regimes are determined on a field-level, based on the dominant soil moisture regime by area for that field

Data/Parameter:	Percentage Clay Content
Unit	%
Description	Clay soil particles as a percentage of total soil particles
Source of data	USDA SSURGO Database
Value(s) applied	0-100%
Measurement procedures	N/A (Sourced from database)
Monitoring frequency	N/A (Sourced from database)
QA/QC procedures	N/A (Sourced from database)
Additional comments	Baseline linking criteria Percentage clay content for a target field is the area-weighted average of representative values of polygons contained in the target field.

14. Reporting

This report is to provide comprehensive information for the VVB while ensuring the protection of confidentiality for the farm operators involved. A table of information is provided for each treated sample unit (field stratum), with the following minimum data:

- Relevant project dates (e.g., farm operator signing of carbon program agreement, date of microbial inoculant application)
- Sampling dates and sampling point geolocations
- SIC (CCE) generation in the treated sample unit
- SIC (CCE) generation in linked baseline category
- Acreage
- Tonnes of carbon dioxide removed (credits generated)
- Field location

It should be noted that the report(s) may include additional elements from the monitoring plan as required or provide the entire plan, depending on specific needs. To protect the confidentiality of the farm operators, only a subset of this information will be made available to the public while ensuring the comprehensive reporting required for the VVB.

All indicated and relevant project data shall be compiled and presented at validation in the form of a Project Design Document (PDD). The PDD will reflect the project proponent's plan for adherence to this methodology, encompassing all requirements herein. The monitoring report will be representative of the in-situ application of the PDD for every field incorporated into the project boundary, and shall be updated for each activity period (growing season).

15. Verification and Validation

The project shall maintain a monitoring and reporting plan that will be used for both validation and verification. The document is designed to be the guidance document that auditors shall use to develop a project-specific risk assessment and sampling plan.

Validation is required for initial project design and initiation of a new project. Verification is required for each reporting period in order to assess ongoing conformance to the project design and confirmation of credits generated. Verification is conducted after the growing season is finished. Validation and verification are to be conducted according to ISO 14064-3:2019 or to the most recent version of this standard.

All validation/verification bodies (VVBs) must be able to demonstrate either accreditation from: (a) a domestic or international accreditation body to ISO 14064-3:2019; (b) the Clean Development Mechanism (CDM) Accreditation Standard for Designated Operational Entities; (c) a relevant governmental or inter-governmental regulatory body or the most recent version of the standard. All validation/verification activities are to be conducted according to this standard, and conflict of interest must be avoided according to ISO 14065:2020 (<https://www.iso.org/standard/74257.html>) between project proponents, VVB, and individuals involved with the project and verification teams. The level of assurance for each verification is to be reasonable, with a materiality threshold of +/-10%. All credits issued are to be on an ex-post basis following a positive project validation and subsequent positive verification report being issued.

16. Social Safeguards

The project proponent shall identify potential negative environmental and social impacts, not limited to those identified by this methodology, and shall take steps to mitigate them to ensure that activities do not cause any net harm to the environment or to society.

Community engagement activities

- *Local stakeholder consultation:* The project proponent shall demonstrate local stakeholder consultation by documenting how they acquired the feedback from local stakeholders to inform the project's design. In these projects, local stakeholders refer to farm operators but may include other individuals or bodies as well. The project proponent shall demonstrate to the validation body what action, if any, it has taken as a result of local stakeholder consultation. The project proponent must document evidence on how they acquired consent from local stakeholders (i.e., farm operators) to implement the project.
- *Continued dialogue:* The project proponent shall detail procedures for continued dialogue with all project stakeholders as part of each subsequent verification of carbon removals and demonstrate this to the verification body and/or standard. This should include evidence of engagement with local stakeholders, such as surveys.
- *Grievance mechanism:* The project proponent will share project activities and changes to the project transparently with the stakeholders. Local stakeholders' opinions, concerns, and objectives will be genuinely heard and addressed. The project proponent must have multiple options for local stakeholders to be able to express their grievances (for example, by phone, email, or in-person) and actively participate in the project implementation.

Environmental considerations

- *Regulatory safeguards:* The project proponent is responsible for understanding and abiding by all relevant laws and regulations. As an example, this could mean registering the product with state Agricultural Departments where implemented.

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