Atmospheric nitrous oxide (N_2O) destruction using Photocatalysts

Methodology

Summary

The methodology is applicable to project activities aiming at destroying N_2O from the air via deployment of photocatalysts on eligible surfaces like crop leaves. The landowners will apply the photocatalyst in their crop spraying practices. The impact is measured by N_2O flux calculations and monitoring the parameters that influence it. The photocatalytic performance and capacity have been determined through lab experiments and field trials, and the efficiency is adjusted to account for real world parameters to calculate the destruction of N_2O.

Methodology developer: Crop Intellect Ltd

Template version 3.1

Statement by Crop Intellect Ltd

The Crop Intellect Ltd states that Crop Intellect Ltd is responsible for the preparation and fair presentation of this methodology and all accompanying documentation has been provided for the validation of it. The Crop Intellect Ltd further states that the Atmospheric nitrous oxide (N_2O) destruction using Photocatalysts methodology ensures conservativeness, accuracy, entails scientific integrity, technical advancements, is scientifically proven and supported with peer-reviewed literature and research. The Atmospheric nitrous oxide (N_2O) destruction using Photocatalysts methodology encourages ambition over time; encourages broad participation; is real, transparent, conservative, credible, and beyond 'business as usual'; avoids leakage; recognizes suppressed demand. The Atmospheric nitrous oxide (N_2O) destruction using Photocatalysts includes relevant assumptions, parameters, data sources, and key factors. The Atmospheric nitrous oxide (N_2O) destruction using Photocatalysts methodology has also considered uncertainty, leakage, policies and measures, and relevant circumstances, including social, economic, environmental, and technological circumstances, and address reversals where applicable.

Basic information

Methodology Name	Atmospheric nitrous oxide (N_2O) destruction using Photocatalysts
Methodology ID	M-ICR011
Version	1.3
Type	Methodology
Date of version	10/06/2025
Sector(s)	15. Agriculture, Choose an item....
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Type (CDR, RAD, hybrid)	☐ CDR ☒ RAD ☐ Hybrid

Contents

1. Methodologies

1.1 Other methodologies

This is a **new** methodology aimed at destroying N_2O from the air through its breakdown via photocatalytic processes. Crop Intellect has not identified any existing published methodologies technologically similar to the proposed methodology. This novel approach deals with destruction of N_2O rather than its reduction as attempted by existing methodologies (for instance, VM0042 'Methodology for Improved Agricultural Land Management', v2.1 [1]), thereby contributing significantly to climate security in an effective manner.

Another comparable methodology is CDM methodology AM0028 'N_2O destruction in the tail gas of Caprolactam production plants' that also deals with N_2O breakdown. Both, AM0028 and the methodology proposed by Crop Intellect, aim to mitigate N_2O emissions, but they differ significantly in approach and application. The AM0028 methodology uses catalytic or thermal destruction within industrial settings, targeting concentrated emissions from caprolactam production, while Crop Intellect's methodology employs photocatalytic technology applied to crop canopy to destroy N_2O emissions resulting from agricultural practices. AM0028 focuses on localized emissions and requires complex equipment installation, whereas Crop Intellect's approach integrates seamlessly into existing farming practices through standard spraying. Monitoring methods also differ: AM0028 uses continuous emission monitoring systems, while Crop Intellect employs ambient air sampling. These distinctions highlight tailored solutions for industrial versus agricultural settings, addressing the unique challenges of each sector in mitigating greenhouse gas emissions.

Crop Intellect believes the proposed methodology represents an important step towards establishing verified N_2O destruction practices.

Methodology	Title	GHG Program	Comments
VM0042	Methodology for Improved Agricultural Land Management	Verra	This methodology addresses **emission reductions** from agricultural land management (ALM) practices, whereas Crop Intellect's proposed methodology focuses on **destroying N_2O emissions** generated from agriculture.
AM0028	N_2O destruction in the tail gas of Caprolactam production plants	CDM	This methodology targets concentrated emissions from caprolactam production in **industrial settings**,

			whereas Crop Intellect's methodology focuses on destroying N_2O emissions from **agricultural practices.**

1.2 Sources

This methodology is based upon the following methodologies:

ID	Version	Title	GHG Program

This methodology further refers to the following tools/modules/regulations/standards:

ID	Type	Version	Title	GHG Program
TOOL02	Tool	07.0	Combined tool to identify the baseline scenario and demonstrate additionality	CDM - UNFCCC

2. Summary

The proposed methodology is applicable to project activities aimed at destroying atmospheric N_2O through the deployment of technologically advanced photocatalysts on crop leaves. Photocatalysis is a well-established process in the field of research, and its use to break down N_2O under UV light is well-studied and documented [2]. Crop Intellect Ltd has conceived a disruptive innovation called R-Leaf, where the photocatalyst is modified through a specialized process known as double doping, enabling it to function under normal visible light. Through this innovation, Crop Intellect aims to achieve large-scale impact on greenhouse gas destruction.

The R-Leaf photocatalyst possesses high affinity for N_2O gas and has been formulated in a simple to use formula that can be tank-mixed with other agricultural inputs (which is already a part of standard agricultural practice) and sprayed on plant leaves or any other surface area. This facilitates easy deployment of R-Leaf directly on crop farming land and due to the vast area covered by arable or other crops, it presents an effective and economical solution to destroy N_2O at a significant and meaningful scale.

The photocatalyst works by enabling breakdown of N_2O into Nitrogen (N_2) and Oxygen (O_2), which are released into the atmosphere. As it is broken down on the surface of the plants, there is **no** sequestration of N_2O in soil or crops. This reaction is not reversible in atmospheric conditions, so there is no risk of reversal of the benefits, even after cessation of the use of R-Leaf. This stability is due to the energy barriers that would need to be overcome for N_2 and O_2 to recombine into N_2O, which generally requires conditions such as high temperature, pressure, or the presence of a specific catalyst, none of which are present in the open atmosphere.

R-Leaf is formulated into a liquid suspension concentrate with only one active compound, Titanium Dioxide (TiO_2), which has been processed with other minerals to enable photocatalysis under visible light. Other components are water and adjuvants (materials that are already approved and used in agricultural inputs). This process does not alter TiO_2's structure or properties. There is no environmental impact of R-Leaf on soil or water. The photocatalyst works independently of the type of crop it is applied to. The size of TiO_2 in R-Leaf is in micrometre range, which is well over the size of concern (nanometre size) and has no effect on soil ecology. The TiO_2 particles aggregate with other soil particles and become part of the soil structure [3]. The recommended usage of R-Leaf is 2 litres per hectare per season, thus only 1 kg of TiO_2 is added per hectare (10,000 m^2) per season, or 10 kg in 10 years. On average, soils contain 0.33% Ti [4] equating to some 2 t/ha considering the top few centimeters, and so the addition of 10kg of Ti in 10 years is negligible compared to the benefit it offers.

While R-Leaf technology is specific and IP protected, allowing for widespread adoption, the methodology can also be used by projects based on other photocatalytic technologies for N_2O destruction. The amount of photocatalyst used in R-Leaf per hectare is 1000g and it is prepared into a formulation of 2 litres (500g per litre). This is applied at appropriate timings in crops when there is a good crop coverage to host R-Leaf and the release of N_2O through the nitrogen applications. There is no additional cost or environmental impact due to application of this photocatalyst for N_2O destruction. The period of functionality for R-Leaf is approximately 12 weeks. The amount of N_2O destroyed by R-Leaf technology has been quantitatively calculated and validated in laboratory experiments and field studies [5].

The photocatalyst can be sprayed on any surface to destroy atmospheric N_2O from various emission pathways. According to DEFRA National Statistics, Chapter 11: Environment (Updated 27 July 2022), agriculture was responsible for 69% of overall UK N_2O emissions in 2020, amounting to 14.5 million t CO2-e [6]. Hence, this methodology focuses on agricultural activities as they are a prominent source of N_2O emissions. Additionally, the spraying of the photocatalyst does not require any changes to standard farming practices as it is mixed in the spraying tank with other chemical or mineral inputs, thereby avoiding any additional cost or environmental impact that the spraying equipment could have otherwise i.e. in non-agricultural usage. As an additional benefit, the photocatalyst reacts with Nitrogen Oxides (NOx), released from nitrification-denitrification processes in the soil, to produce Nitrate (NO_3^-) which is an essential nutrient for plants. R-Leaf produces small amounts of nitrate daily whilst it resides on the plant leaves resulting in increased yield demonstrated in fields trials. Depending on the crop type, the effect typically leads to yield increases and provides an opportunity to reduce synthetic nitrogen fertilizer inputs.

The baseline scenario covers the N_2O emissions arising from standard farm practices without the intervention of photocatalytic technologies or any other technologies aimed at destroying N_2O. The project activities will destroy the ambient N_2O released from the agricultural activities and any other sources impacting the project boundary. The additionality shall be demonstrated, and the baseline scenario shall be identified based on the latest version of the "Combined tool to identify the baseline scenario and demonstrate additionality" which is available on the CDM - UNFCCC website [7].

The air from the treated field can be sampled using specialised air sampling bags which can be analysed using gas analysers i.e. LI-COR LI-7820 N_2O/H_2O Trace gas analyser or more commonly used analysis techniques such as Gas Chromatography (GC). This data shall be used to determine the N_2O concentration at the project location and fed into N_2O flux calculation equations that shall be used to obtain the total GHG destruction in terms of t CO2-e. For the flux calculations, the parameters such as wind speed, crop canopy height, and N_2O concentrations from air sampling bags are required to be monitored during the project.

3. Definitions

Photocatalyst means a material, such as R-Leaf, that facilitates the breakdown of N_2O under visible light when applied to surfaces like crop leaves.

GHG means greenhouse gas.

Double doping means a specialized process used to modify the photocatalyst to enable it to function under visible light conditions.

R-Leaf means a proprietary photocatalyst technology developed by Crop Intellect, designed for agricultural applications to destroy N_2O.

Light Intensity Factor means a specific factor used in the methodology to account for variations in light intensity in N_2O destruction calculations.

N_2O flux means the difference in N_2O concentration at crop canopy level and the atmospheric N_2O concentration, measured in the project using specific equations and parameters.

Exchange coefficient (K) means a parameter dependent on atmospheric turbulence and height, critical for calculating the N_2O flux in the methodology.

Eddy covariance method means a measurement technique used to calculate the vertical flux of N_2O in the project.

Canopy height (z_1) means the height of the crop canopy, a critical parameter in flux calculations.

Representative height means the average of crop canopy height and height of specific measurement points above the canopy used for determining N_2O concentration gradients.

Residual time means the effective period during which the photocatalyst remains active on the crop surface, typically 4–12 weeks.

Aggregate projects mean groupings of multiple project sites within a defined region, subject to similar environmental conditions, for efficiency in monitoring and reporting.

N_2O concentration gradient means the difference in N_2O concentrations between two specified heights, a key input for flux calculations.

Treated field means a field where the photocatalyst has been applied as part of the project activity.

Control field means a field comparable to a treated field where no photocatalyst has been applied.

GC means Gas Chromatography, which is an analytical technique used to identify chemical compounds in a gas mixture.

4. Applicability conditions

Geographical Scope:
The methodology can be applied globally to any land-based projects where plants/crops/vegetation are typically sprayed, or where such spraying operations can be performed. This encompasses the project boundary. The methodology applies to any region where local environmental conditions support effective spray application and photocatalytic activity.

Project Boundary and Aggregation of Project Areas:
The aggregation of several project boundaries into one larger project is encouraged for efficiency in measuring, reporting, and verification (MRV) processes, provided that either the geographic proximity ensures uniformity in regional parameters, or if different, these are measured (using project-relevant weather stations).

The spatial extent of the project boundary includes all areas where the photocatalyst is applied. This boundary is defined by the land or farmland directly subject to the intervention. For aggregate projects, multiple project sites within the same geographical region can be grouped together under one umbrella project, provided they are subjected to similar environmental conditions (e.g., temperature, rainfall, sunlight) that influence the photocatalytic efficiency of the intervention.

Aggregate projects may be formed where multiple project locations share comparable climatic, soil, and operational parameters. These aggregated areas should be located within a reasonably defined region to ensure consistency in environmental conditions and the uniform application of the photocatalyst.

Technology and Equipment Requirements:
This methodology is applicable only to projects that have access to photocatalytic technology with demonstrated evidence of its ability to destroy N_2O under visible light. Projects shall also have the necessary equipment to deploy the photocatalytic material, such as appropriate spraying systems or other relevant application methods.

In addition, projects shall be equipped with appropriate monitoring tools to track regional environmental conditions (e.g., light, humidity, temperature) that impact the efficiency of the photocatalytic process. Furthermore, equipment for accurately measuring the destruction of N_2O emissions, as outlined in this methodology, is required to ensure that the outcomes can be reliably reported and verified.

Type of surface for photocatalyst application:
This methodology applies to any project where photocatalysts for N_2O destruction can be sprayed or spread on an appropriate surface. If the surface is permanently shaded (e.g., indoors or lacking light in general), a suitable light source of sufficient intensity relevant to the surface area shall be provided to enable photocatalysis.

The most suitable surface for the photocatalyst application is the canopy of plant leaves either on a crop farm or any other crop area. In this case, the type of crop selected is required to maintain a canopy for at least 4 weeks to ensure adequate impact from the photocatalytic activity. Application of agrochemical input onto a plant canopy by spraying is a standard practice in crop production; the photocatalyst for N_2O destruction can be mixed with the agricultural inputs (e.g., fungicides) and therefore no further activity than the farm standard is required.

Project Duration:
Different types of plants/crops/vegetation have different sowing and harvesting time periods which also depend on the part of the world they are grown in. Due to this, the deployment times and rate of the photocatalyst can be different, resulting in varying project durations for different types of plants/crops/vegetation. The residual time of the photocatalyst on the leaves should be at least 4 weeks, and hence it can only be deployed on crops that maintain full leaves for a minimum of 4 weeks. The photocatalyst for N_2O destruction resides on leaves for a duration of 4-12 weeks. It is recommended to deploy further layers as deemed required to maintain a sufficient level of efficiency. This typically relates to the crop growth and development. Therefore, a minimum of two sprays of the photocatalyst (1 kilogram/hectare in total) during the growth period will be typically required.

In cases where two different crops are grown one after another on the same land over one year/season, each crop shall be considered separately regarding its impact, but can be included under the same project, and each shall receive photocatalyst applications. These applications will still align with agricultural inputs which is the standard farm practice.

In case that the project includes vegetation that does not require harvesting, for example, grasslands or evergreen trees, then the maximum duration for accounting should be one year, and a new accounting period should commence each year. As such, projects will have vegetation that maintains canopy or leaves year-round, the photocatalyst application shall be carried out every 4-12 weeks throughout the year.

The methodology is not applicable under the following conditions:
This methodology is not applicable to projects where the necessary environmental conditions for effective photocatalytic activity are not met. Specifically, the methodology cannot be applied in the following cases:

- Permanently Shaded Areas: Projects where the target surface is continuously shaded and lacks sufficient exposure to natural or artificial light necessary for photocatalysis.
- Non-Vegetative Surfaces: Projects that propose applying the photocatalyst to non-vegetative surfaces (e.g., soil, bare ground, or artificial structures) without a demonstrated ability to maintain effectiveness in N_2O destruction.
- Short-Lived Crops: Agricultural systems where crops do not maintain a canopy for at least four weeks, as this would not allow sufficient time for the photocatalyst to achieve its intended effect.
- Lack of Monitoring Capability: Projects that do not have access to appropriate monitoring tools to track environmental conditions affecting photocatalytic efficiency or the means to verify N_2O destruction in accordance with the methodology.
- Regulatory Restrictions: Areas where the use of photocatalytic substances is restricted or prohibited by local environmental or agricultural regulations.

5. Boundary

The methodology can be applied globally to any land-based projects where plants/crops/vegetation are typically sprayed, or where such spraying operations can be performed. This encompasses the project boundary which is defined by the land or farmland directly subject to the intervention. The methodology applies to any region where local environmental conditions support effective spray application and photocatalytic activity. All the surfaces, including crops, sprayed with photocatalyst for N_2O destruction are included in the project. Aggregate projects may be set up if the project locations are in the same geographical region and are subjected to similar environmental conditions and parameters. Hence, the project area can include several project boundaries aggregated into one project. Since the by-products of N_2O breakdown are N_2 and O_2, they are not required to be monitored. The N_2O concentration shall be measured by analysing air samples collected in the field using specialised air sampling bags. The project boundary ensures that key parameters, such as day light length, and the sprayed area does not vary significantly.

The greenhouse gases included in or excluded from the project boundary are shown in Table 1 below.

Table 1. *Emissions sources or sinks included in or excluded from the project boundary*

SSR		**Controlled/ related/ affected**	**GHG**	**Included? Y/N**	**Justification/ explanation**
Baseline	N_2O from fertiliser application	Related	CO_2	N	Not significant through this activity
	N_2O from fertiliser application	Related	CH_4	N	Not significant through this activity
	N_2O from fertiliser application	Related	N_2O	Y	Part of farm's carbon footprint. Application of synthetic fertiliser is a source in the baseline scenario
	Farming activities	Related	CO_2	Y	Part of farm carbon footprint. Farming activities are a source of direct or indirect CO_2 emissions
	Farming activities	Related	CH_4	N	Not significant through this activity
	Farming activities	Related	N_2O	N	Not significant through this activity
Project	Photocatalyst application	Controlled	CO_2	N	Not significant through this activity

	Photocatalyst application	Controlled	CH_4	N	Not significant through this activity
	Photocatalyst application	Controlled	N_2O	Y	Destroyed through application of the photocatalyst. Photocatalyst application is a N_2O sink in the project scenario
	Photocatalyst lifecycle (manufacture to delivery)	Related	CO_2	Y	Important source of emissions. Manufacturing, processing, packaging, storage, and delivery of the photocatalyst is a source of direct or indirect CO_2 emissions
	Photocatalyst lifecycle (manufacture to delivery)	Related	CH_4	N	Not significant through this activity
	Photocatalyst lifecycle (manufacture to delivery)	Related	N_2O	N	Not significant through this activity
	Farming activities	Related	CO_2	Y	Part of farm's carbon footprint. Farming activities are a source of direct or indirect N_2O and CO_2 emissions (this won't differ from baseline as application of the photocatalyst does not increase farming activities)
	Farming activities	Related	CH_4	N	Not significant through this activity
	Farming activities	Related	N_2O	Y	Part of farm's carbon footprint. Farming activities are a source of direct or indirect N_2O and CO_2 emissions (this won't differ from baseline as application of the photocatalyst does not increase farming activities)

6. Baseline Scenario

The baseline scenario covers the N_2O emissions arising from standard farm practices without the intervention of photocatalytic technologies or any other technologies aimed at destroying N_2O. The project activities will destroy the atmospheric N_2O released from the agricultural activities and any other sources impacting the project boundary.

The use of synthetic nitrogen fertilizers is the standard farming practice. These nitrogen inputs get converted to N_2O through nitrification and denitrification processes taking place in the soil. The N_2O is released into the atmosphere, thereby making agriculture a source of greenhouse gas emissions. Other farming activities also contribute to emissions, which together with N_2O, comprise the carbon footprint of a farming operation. The carbon footprint of a field or farms included in the project constitutes the baseline. The greenhouse gas (GHG) emissions generated by standard agricultural practices without the application of the photocatalyst for N_2O destruction shall be compared to the N_2O destruction achieved through the application of the photocatalyst. The photocatalyst application itself does not impose change on standard farming practices as it is tank-mixed with other agricultural inputs already being sprayed. This makes the comparison straightforward and reflective of real-world farm conditions. Also, as a part of the baseline, the background N_2O concentration shall be measured on the project field before commencement of the project activities. Since the project area is open and subject to free air movement, the N_2O concentration is assumed to be uniform within the project boundary.

Another approach to baseline is through Control fields. In the field trials conducted in 2024 [5], a control field was established near each treated field. The control field was comparable to the treated field in terms of crop type, soil type and inputs applied except for application of the photocatalyst. The control field served as a close comparison to measure the effect of the photocatalyst on N_2O emissions. The same sampling procedures were followed in both fields to achieve comparable dataset. The control field was considered as the baseline. However, this approach might not be feasible for large-scale projects. Standard farming operations typically involve a variety of crops and thousands of hectares, so setting up a control field is impractical in these scenarios.

Hence, the baseline approach that maximizes the feasibility of the implementation of the project should be selected by the Project Developer.

The project baseline activity can be demonstrated using the latest version of the “Combined tool to identify the baseline scenario and demonstrate additionality” which is available on the CDM - UNFCCC website [7].

7. Additionality

The projects adopting this methodology to generate certified carbon credits shall demonstrate additionality. Any project can be determined as additional based on results of the Barrier Analysis and Common Practice Analysis. Crop Intellect proposes that demonstration of additionality is based on the latest version of the “Combined tool to identify the baseline scenario and demonstrate additionality” which is available on the CDM - UNFCCC website [7].

Furthermore, the project adopting this methodology shall comply with the multi-level additionality approach described in the ‘ICR methodology requirements v.3.0 section 6.7’ [8] and detailed in the ‘ICR requirement document v6.0 section 6.4.1 [9].’ The project proponents shall demonstrate the project's additionality and, at a minimum, meet level 1, and either 2a or 2b. It shall also meet at least one additional level from 3, 4 or 5.

Level 1: ISO 14064-2 GHG Emissions Additionality
Criteria: Verify that the project's GHG destructions go beyond what would occur under a business-as-usual scenario. This requires demonstrating that the project’s activities result in N_2O mitigation that would not happen without its implementation.
Procedure: Define and justify the approach used to establish GHG emissions additionality in accordance with ISO 14064-2 guidelines. Present supporting evidence in the Project Design Document (PDD) to confirm that the project leads to a net increase in N_2O destructions.

Level 2: Statutory Additionality
Criteria: Determine whether the project surpasses legal obligations (**Level 2a**) or addresses gaps in regulatory enforcement (**Level 2b**).
Procedure:

- **Level 2a:** Provide documentation confirming that the project's activities are voluntary and not mandated by existing laws or regulations.
- **Level 2b:** Demonstrate that statutory requirements are not effectively enforced in the project location and that widespread non-compliance exists in the absence of the project.

Level 3: Technological, Institutional, Common Practice Additionality
Criteria: Evaluate whether the project overcomes specific implementation barriers through carbon market incentives or facilitates the early adoption of innovative technologies.
Procedure: Identify and document key challenges (e.g., financial, technological, or institutional) that hinder project execution. Provide evidence illustrating how the project enables the deployment of improved practices or technologies that would otherwise face delays.

Level 4: Financial Additionality
Criteria: Demonstrate that the project faces financial limitations that carbon credit revenues could mitigate (Level 4a), or significant financial barriers where carbon credits are the only revenue source (Level 4b).
Procedure:

- **Level 4a:** Provide financial analyses, such as internal rate of return (IRR) or net present value (NPV), demonstrating financial limitations without carbon credit revenues and improved viability with credits. Document clearly in the PDD.
- **Level 4b:** Confirm that the project would have no financial viability or revenue streams without carbon credit sales. Provide clear evidence and documentation in the PDD.

Level 5: Policy Additionality
Criteria: Confirm the project activity surpasses national climate objectives and goes beyond the host country's existing climate action strategies or commitments.
Procedure: Provide clear documentation that the project's emission destructions exceed the national climate objectives. Detail how the project is not covered by or surpasses existing policies or national plans in the PDD.

8. Quantification of GHG emission mitigations

8.1 Criteria and procedures for quantification

It is essential to determine the amount of N_2O destroyed as a result of application of the photocatalyst to determine the GHG destruction in terms of t CO2-e. As the end products of the photocatalytic reaction (N_2 and O_2) are not stored but instead released into the atmosphere, the GHG destruction cannot be determined through soil or crop sample analysis as it is done in carbon sequestration methodologies, setting this methodology apart. Hence, the N_2O quantification is done by calculating flux and accounting for the parameters that affect it.

N_2O Breakdown Equation

The equation for calculating N_2O breakdown accounts for the interaction of key factors, focusing on measuring the most significant variables. By leveraging established knowledge and validated assumptions, reliable and practical calculations are conducted, achieving accurate estimation of reaction rates.

Scientific Background

Within a closed laboratory environment, the change in N_2O concentration is directly related to the amount of N_2O converted by the photocatalyst. However, in the atmosphere, any change in N_2O is related to gradients in its concentration close to the plants and that arises from uptake by the photocatalyst. Well above the plants, the concentration remains unchanged.

Specifically, the amount of N_2O converted by the photocatalyst (the vertical flux (F) of N_2O towards the plants, in units of mass per unit area per second) is given by:

$$F = \overline{w'c'} \qquad [Eq.\ 1]$$

where w' is the vertical velocity fluctuation due to turbulence and c' is the fluctuation in the N_2O concentration around the mean concentration C (mass per unit volume). The overbar represents the mean value of this quantity (the covariance), which can be measured directly using suitable instrumentation, and this is known as the eddy covariance method.

An approximate representation of *Eq. 1* is to express the flux of N_2O in terms of mean quantities as follows:

$$F = K.dC/dz \qquad [Eq.\ 2]$$

where K is the exchange coefficient which depends on the magnitude and length scales of the atmospheric turbulence and z is the height above the ground. The length scales of the turbulence increase with the height above the ground z, and so, for constant flux, dC/dz decreases with z and hence, the most easily measurable changes in C are likely to be relatively close to the plants (for example, within a few meters).

N_2O breakdown calculation from N_2O flux

To calculate the N_2O flux, it is important to determine the exchange coefficient. The exchange coefficient K depends on the atmospheric turbulence and height above the ground. Hence, it can be represented in terms of the wind friction velocity $u*$, von Karman's constant κ and representative height z. It is calculated using *Eq. 3*.

$$K = \kappa.z.u^* \qquad [Eq.\ 3]$$

The value of von Karman's constant κ is 0.4.
The wind friction velocity $u*$ is calculated using the following equation:

$$u^* = z_u\ \kappa / \ln(\ U_{(10)}/z_0) \qquad [Eq.\ 4]$$

Where,

$u*$	Wind friction velocity (m/s)
z_u	Height of wind measurement (taken as 10m)

κ	Von Karman's constant (0.4)
$U_{(10)}$	Average wind speed at 10m height (m/s)[A]
z_0	Surface roughness (taken as 0.1m for most crops)[B]

The representative height for exchange coefficient is calculated using the following equation:

$$z = (z_1 + z_2)/2 \qquad [Eq.\ 5]$$

Where,

z	Representative height (m)
z_1	Height of canopy measurement (m)
z_2	Height at least 1m above canopy (m)

Assuming that the concentrations over the untreated field at least 1m above the canopy represent the background concentration, the flux may be estimated using *Eq. 2* and *Eq. 3* as follows:

$$F = \kappa . z . u^{*} . dC/dz \qquad [Eq.\ 6]$$

Where,

F	Flux of N_2O from the atmosphere to canopy (ppb.m/s)

The gradient in N_2O concentration between the two measurement heights (in ppb/m) is represented by *dC/dz* and it can be calculated using the following equations:

$$dC = C_2 - C_1 \qquad [Eq.\ 7]$$
$$dz = z_2 - z_1 \qquad [Eq.\ 8]$$

Where,

C_1	N_2O concentration at canopy height (ppb)
C_2	N_2O concentration at least 1m above canopy (ppb)
z_1	Height of canopy measurement (m)
z_2	Height at least 1m above canopy (m)

Flux of N_2O is converted into the unit $\mu g_{N2O}/m^2/s$ and multiplied with Light Intensity Factor by using the following equation:

$$F_{N2O} = (F \cdot \frac{MW_{N2O}}{V_g}) \cdot I \qquad [Eq.\ 9]$$

Where,

F_{N2O}	Flux of N_2O from the atmosphere to canopy ($\mu g_{N2O}/m^2/s$)
F	Flux of N_2O from the atmosphere to canopy (ppb.m/s)
MW_{N2O}	Molecular weight of N_2O (44 g/mol)
V_g	Volume (approx.) of 1 mole of gas (22.4 L)

[A] If wind speed is measured at a height different from 10 meters, it is acceptable to apply a standard wind profile correction to convert the data to the equivalent at 10-meter height. This adjustment can be made using the logarithmic wind profile or power law formulas, depending on data availability and surface conditions.

[B] If the project activity is implemented in grassland or forest systems, the surface roughness value shall be adjusted accordingly, using literature-based or measured values.

I Light Intensity Factor (taken as 1)[C]

The Equivalent CO_2 flux (F_{CO2}) is calculated using the Global Warming Potential of N_2O, which is 273 times greater than that of CO_2 [10]:

$$F_{CO2} = F_{N2O}.273 \qquad [Eq.\ 10]$$

Where,

F_{CO2} Equivalent CO_2 flux ($\mu g_{CO2}/m^2/s$)

The Equivalent CO_2 is converted to the unit g/ha/day using the following equation:

$$F'_{CO2} = F_{CO2}.\left(\frac{1}{1000000}\right).10000 \times 3600 \times 24 \qquad [Eq.\ 11]$$

The estimated loss of efficiency of the R-Leaf[D] photocatalyst over time is 0.08%/day (0.92 factor), hence, the equivalent CO_2 destruction per hectare for a 90-day active period (assuming 13 hours[E] of daylight per day during the project period) in terms of t CO2-e is:

$$F_{tCO2eq} = (F'_{CO2} \times (\frac{90\times13}{24}) \times 0.92)/1000000 \qquad [Eq.\ 12]$$

Where,

$F_{t\,CO2\text{-}e}$ Equivalent CO_2 destruction (t CO2-e/ha)

This value is multiplied by the total area of application of the photocatalyst for N_2O destruction (treated area) to obtain the total GHG destruction in terms of t CO2-e.

$$TF_{tCO2eq} = F_{tCO2eq} \times TreatA \qquad [Eq.\ 13]$$

Where,

$TF_{t\,CO2\text{-}e}$ Total Equivalent CO_2 destruction (t CO2-e)

TreatA Total treated area with application of the photocatalyst for N_2O destruction (ha)

If the control field is established as the baseline, these calculations shall be performed for both the treated and the control fields.

For details on air sampling and analysis used to obtain data for the equation variables, please refer to Section 9.

[C] The Light Intensity Factor is taken as 1, and this will be updated once further experiments and modelling of light intensity are concluded. Photocatalysis is positively correlated with increasing light intensity; therefore, a factor of 1 is the most conservative assumption possible, indicating no additional enhancement. This conservative approach ensures that emission destructions are not overstated.

[D] If any other photocatalyst is used, efficiency of that photocatalyst shall be considered instead.

[E] The 13-hour period is based on the daylight period during the summer crop-growing season in the UK. If the project is set up outside the UK, then the average daylight period during the crop-growing season specific to that region shall be considered.

Selection of the Monitoring Area

The measuring points for monitoring shall be set up in all the fields included in the project where possible to ensure that the monitoring is reflective of the full spatial extent of the project (see section 9.1 for selection of the measuring points). However, representative fields within the project boundary can be selected for monitoring if the monitoring of all the fields is not feasible.

Conditions for selecting representative monitoring field:

- Weather conditions can be considered homogeneous within a 10km radius. Therefore, for aggregated projects spanning multiple locations, a representative field shall be selected for each site that is more than 10km apart from others.
- The size of the representative monitoring field shall be at least 10ha.
- A comprehensive explanation of the selection process and criteria for identifying representative field shall be provided and documented.

8.2 Baseline emissions

Continuation of pre-project N_2O emissions and no means of destroying that N_2O is the most plausible baseline scenario. The project activities will destroy the ambient N_2O that is released from the agriculture or other sources. Baseline is described as defined in section 6.

If the carbon footprint of the field or farms included in the project is considered as the baseline, the baseline emissions are calculated as follows:

$$BE = BE_1 \qquad [Eq.\ 14]$$

Where:

BE	Baseline emissions (t CO2-e)
BE_1	Baseline emissions from the carbon footprint of the field or farms prior to/without the intervention that are included in the project (t CO2-e)

If the control field is set up as the baseline, the baseline emissions are calculated as follows:

$$BE = BE_2 \qquad [Eq.\ 15]$$

Where:

BE	Baseline emissions (t CO2-e)
BE_2	Baseline emissions obtained from calculations in section 8.1 performed for control field (t CO2-e)

8.3 Project emissions

The Project Activity Emissions are the emissions that arise from the operations required to implement, run, monitor, and conclude the project. As these activities release the GHGs into the atmosphere which would not have occurred in the absence of the project, they need to be accounted for and deducted from the GHG destruction claims in the project.

As mentioned in section 2, the implementation of the project in crop farming will not affect the standard farming practices as spraying is already an operation performed regularly. Therefore, the emissions from the standard agricultural practices are not part of the project activities and hence shall not be deducted from the GHG destruction claims.

The activities resulting from procurement of raw materials, manufacturing processes, packaging and transportation for the production and supply of the photocatalyst for N_2O destruction will generate emissions. These emissions shall be calculated through established assessment methods for calculating embedded emissions (for example, as part of a full Life Cycle Assessment (LCA) of the photocatalyst), and then be deducted from the GHG destruction claims in the project. The emissions from other project activities like monitoring and measurements shall be considered and deducted from the total GHG destruction claim, unless they can be described as negligible.

Project emissions are calculated as follows:

$$PE = PE_1 + PE_2 \qquad [Eq.\ 16]$$

Where:

PE	Project emissions (t CO2-e)
PE_1	Project emission from procurement of raw materials, manufacturing processes, packaging and transportation associated with the production and supply of the photocatalyst for N_2O destruction (t CO2-e)
PE_2	Project emissions from other project activities like monitoring and measurements (t CO2-e)

8.4 Leakage

As described in Section 2, the photocatalyst works by enabling breakdown of N_2O into Nitrogen (N_2) and Oxygen (O_2), the two main gases already abundant and stable in atmosphere. As N_2O is broken down on the surface of the plants, there is **no** sequestration of it in soil or crops. Therefore, since N_2O is not stored, leakage is not a potential concern. The breakdown of N_2O into N_2 and O_2 is fundamentally irreversible under normal atmospheric conditions because recombining these gases back into N_2O requires very high-energy conditions, such as extreme heat, intense pressure, or specialized catalysts typically found only in controlled industrial settings. Such conditions do not exist naturally in open agricultural environments. Therefore, once the photocatalyst has converted N_2O into harmless gases, there is virtually no realistic scenario in nature for these gases to recombine into N_2O, ensuring that the emission destructions achieved by this reaction are permanent. Hence, there is no risk of reversal of the benefits, even after cessation of the use of the photocatalyst.

8.5 Quantification of Net-GHG emissions and/or removals

Net GHG Emission Mitigations are calculated as follows:

$$EM = TF_{tCO2eq} - BE - PE \qquad [Eq.\ 17]$$

Where:

EM	Net GHG emissions mitigations (t CO2-e)
$TF_{t\ CO2\text{-}e}$	Total Equivalent CO_2 destruction calculated from Equation 13 (t CO2-e)
BE	Baseline emissions calculated from Equation 14 or 15 (t CO2-e)

PE	Project emissions calculated from Equation 16 (t CO2-e)

8.6 Risk assessment for permanence

The permanence of N_2O emissions destruction achieved through the proposed methodology is influenced by various risk factors. However, since the breakdown of N_2O via the photocatalytic reaction is irreversible under atmospheric conditions, there is no risk of reversal once the emissions are mitigated. This ensures that even if the photocatalyst application ceases, the previously destroyed N_2O will not re-form, distinguishing this methodology from other carbon sequestration approaches that face risks of reversal. Below are key risks and mitigation measures:

- **Natural Risk:** Extreme weather may reduce photocatalyst efficiency but does not reverse mitigated emissions.
  Mitigation: Optimized application timing and reapplication protocols.

- **Political Risk:** Policy changes may affect future deployment but not past emission destructions.
  Mitigation: Regulatory engagement to promote regulatory alignment.

- **Abandonment Risk:** Project discontinuation would halt future GHG mitigation but not undo past benefits.
  Mitigation: Provision of financial incentives to landowners, farmer training to ensure competency and confidence; and close monitoring of the project budget and spend to identify bottlenecks.

- **Legal Risk:** Regulatory restrictions could limit deployment but do not affect past emission destructions.
  Mitigation: Compliance, approvals, and collaboration with authorities.

- **Performance Risk:** Variability in effectiveness impacts ongoing GHG mitigation, not permanence.
  Mitigation: Field assessments, optimized application rates, and third-party verification.

- **Internal Risk:** Governance or financial instability may disrupt operations but not affect past results.
  Mitigation: Strong oversight, funding diversification, and training.

Non-Permanence Risk Quantification and Mitigation Procedures

Unlike biological carbon sequestration projects that require buffer credits to account for potential reversals (e.g., forest fires or land-use changes), the proposed methodology does not require a non-permanence buffer since N_2O destruction is permanent. However, the methodology incorporates measures to address risks affecting ongoing GHG mitigation, including:

- Conservative credit issuance based on verified N_2O destruction.
- Regular monitoring and reassessment to optimize performance of the photocatalyst and ensure its continued application.
- Use of weather data and performance tracking to refine application protocols and maintain efficiency.

9. Monitoring

9.1 Monitoring plan

Monitoring Plan

The monitoring plan is based on the data required for the equations described in section 8.1 for accurate N_2O emission quantification. These include average wind speed at height 10m above the ground, the measurement of canopy height and height over the canopy to assess exchange coefficients and N_2O concentration gradients. N_2O concentrations at both canopy height and at least 1m above canopy are also analysed from air samples collected from the field. Collected data, managed by the Project Developer, supports flux calculations for estimating emissions destructions.

Uncertainty Analysis

A complete quantitative uncertainty analysis associated with parameters, model variables and results of emission or destructions shall be performed according to IPCC protocols [11]. As stated in those protocols, when a variable cannot be statistically quantified, a pedigree matrix assessment shall be performed, and the result included in the total uncertainty for the intervention. To combine the uncertainties of the different parameters, a propagation of error approach shall be used in accordance with *IPCC 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1, Chapter 3 Uncertainties* [11]. A report explaining the importance of the parameter uncertainties shall be provided as well as any peer-reviewed document used in the uncertainty evaluation.

Sampling and Analysis

The Flux calculation described in Section 8.1 requires N_2O concentration data at canopy height and at least 1m over the canopy. To obtain this data, air sampling in the field at two heights vertically over each other needs to be conducted, and then analysed for N_2O.

Measurement points shall be set up centrally in the field based on factors such as wind direction and accessibility. It shall be ensured that the measurement points are far from roads or obstructions to reduce external influences on N_2O readings. Geo-locations of all measuring points shall be marked for consistency in repeated visits.

The air samples can be collected in multilayer foil sampling bags or Tedlar sampling bags using electric pumps. The samples shall be collected from the measurement point; the first sample should be collected between 1 to 5 days after each application of the photocatalyst. Further samples should be taken after 5 days of each application (post each application, three sets of samples recommended at collection interval of 3 to 5 days) to obtain a robust data set.

A uniform and portable setup is required to take samples at two heights (see *Figure 1*). A tube shall be attached to the pump's inlet and the other end of the tube shall be moved to the desired height, instead of the pump being moved. This shall be done for all the pumps used for the sample collection. A stick with uniform markings shall be set up in the field at the measuring points. Two pumps are required at each measuring point to collect air samples at two heights. The tube inlet of the first pump shall be attached to the stick at canopy height and inlet of the second pump attached at least 1m above canopy. Both pumps shall be operated simultaneously. The bags shall be attached to the pump outlets via tubes.

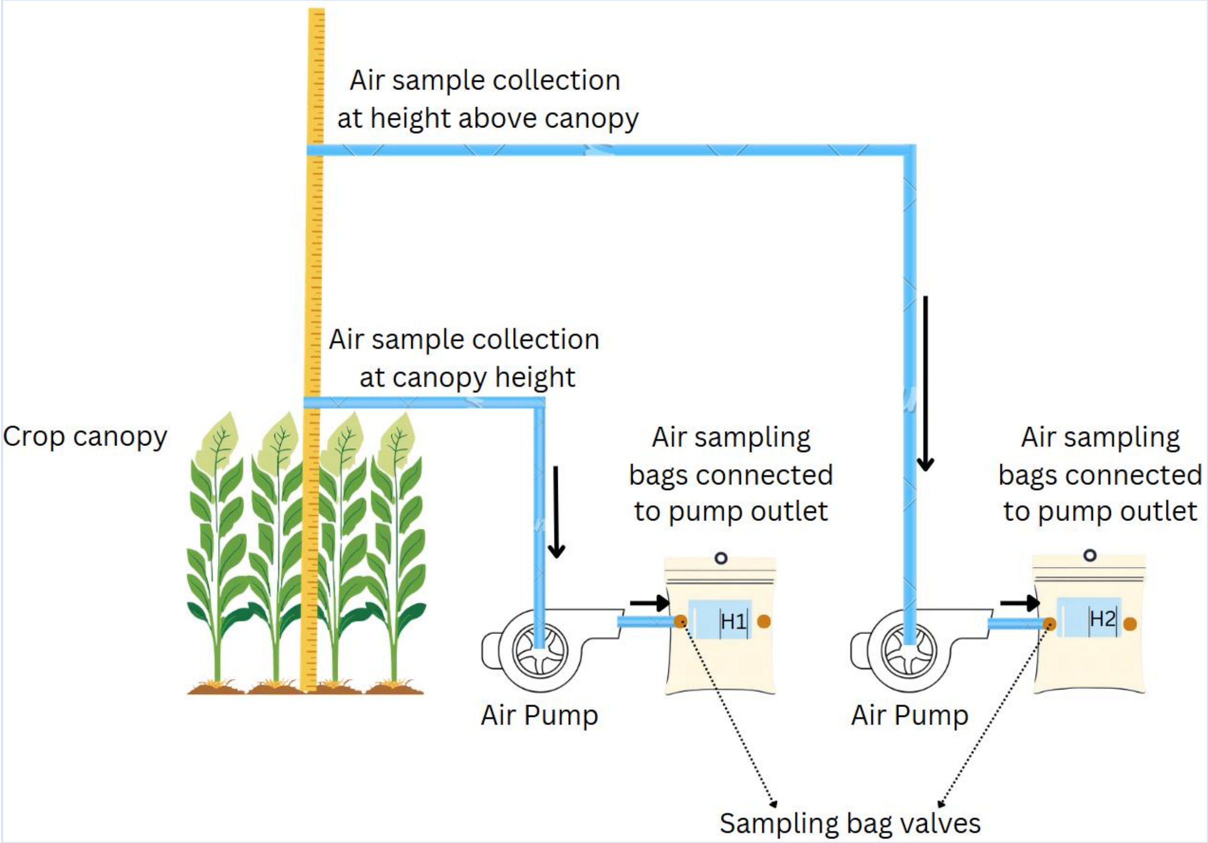

Figure 1. Setup for air sampling in the field

Following steps should be followed for air sample collection:

- Connect the valve of the bags to the outlet of the pumps.
- Open connected valve of both bags (for both heights) and start the pumps.
- To account for short time fluctuations in N_2O concentrations, the bag should represent a composite sample of 1-2 minutes of environmental activities, i.e., the flow of the pump should be controlled so that bag is full in 1-2 minutes.
- Once full, close the bag valves and detach from the pump.
- Connect the next set of bags and repeat the procedure.
- Collect 8 to 10 set of bags.

The sampled air shall be analysed using gas analysers such as LI-COR LI-7820 N2O/H2O Trace gas analyser (analysers with ability to detect N_2O changes at ppb levels) or more commonly used gas analysis techniques such as Gas Chromatography (GC). The output of the analysis should be the N_2O concentration in ppb which needs to be averaged and applied to *Eq. 7* and *Eq. 8* as *C1* and *C2*.

To test the method of N_2O sampling, analysis and calculations, field trial experiments were conducted [5]. The air samples collected from the field were analysed using LI-COR LI-7820 N2O/H2O Trace gas analyser to determine N_2O concentration. The instrument uses Optical Feedback Cavity Enhanced Absorption Spectroscopy (OF-CEAS) to detect N_2O at sub-ppb levels which is measured every second. A detailed sampling and analysis procedure used at field-scale is available in Appendix I. Control fields were set up along with the fields treated with the photocatalyst, and the same sampling and analysis was conducted in both types of fields. This was done to perform a comparison of the N_2O fluxes with and without the photocatalyst application.

9.2 Data and parameters remaining constant

Parameters remaining constant throughout each project, (a) Von Karman's constant, (b) Height of wind measurement, (c) Surface roughness, (d) Molecular weight of N_2O, (e) Volume (approx.) of 1 mole of gas, (f) Light Intensity Factor.

(a)	
Data / Parameter	**Von Karman's constant (κ)**
Unit	(Unitless)
Description	Refers to Von Karman's constant, a dimensionless constant in fluid dynamics that is used to describe the distribution of velocity in turbulent fluid flow near a boundary
Origin of data	Commonly known
Value applied	0.4
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine wind friction velocity for flux calculations.
Purpose of Monitoring	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Comments	N/A

(b)	
Data / Parameter	**Height of wind measurement (z_u)**
Unit	m
Description	Refers to the height at which the wind speed measurement is taken
Origin of data	Recommended by Cambridge Environmental Research Consultants (CERC)
Value applied	10m
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine wind friction velocity for flux calculations.
Purpose of Monitoring	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Comments	N/A

(c)	
Data / Parameter	**Surface roughness (z_0)**
Unit	m
Description	Refers to surface roughness or unevenness caused by presence of crops on land
Origin of data	Recommended by Cambridge Environmental Research Consultants (CERC)
Value applied	0.1m
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine wind friction velocity for flux calculations.
Purpose of Monitoring	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Comments	N/A

(d)	
Data / Parameter	**Molecular weight of N_2O (MW_{N2O})**
Unit	g/mol
Description	Refers to the molecular weight of N_2O gas
Origin of data	Commonly known
Value applied	44 g/mol
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine wind friction velocity for flux calculations.
This parameter is required for flux calculations.	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Comments	N/A

(e)	
Data / Parameter	**Volume (approx.) of 1 mole of gas (V_g)**
Unit	L
Description	Refers to the approximate volume occupied by 1 mole of gas
Origin of data	Commonly known
Value applied	22.4L
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required for flux calculations.
This parameter is required for flux calculations.	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Comments	N/A

(f)

Data / Parameter	**Light Intensity Factor (I)**
Unit	(unitless)
Description	Refers to the factor for light intensity
Origin of data	Assumed
Value applied	1
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required for flux calculations.
This parameter is required for flux calculations.	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Comments	N/A

9.3 Data and parameters monitored

Parameters monitored throughout each project, a) Average wind speed at 10m height, b) Height of canopy, c) Height at least 1m above canopy, d) N_2O concentration at canopy height, e) N_2O concentration at least 1m above canopy height.

(a)	
Data / Parameter	**Average wind speed at 10m height ($U_{(10)}$)**
Unit	m/s
Description	Refers to average wind speed at the height of 10m from the ground for the project duration.
Equations	Eq. 4
Origin of data	Meteorological station readings/weather reports
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine wind friction velocity for flux calculations. The Project Developer shall be responsible for noting daily wind speed at 10m height throughout the project in order to calculate the average.
Monitoring frequency	To be noted every day throughout the project

Purpose of data	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Quality assurance and control	This data shall be taken from website of official weather station. The QA/QC standards of the weather station are applicable.
Comments	N/A

(b)	
Data / Parameter	**Height of Canopy (z_1)**
Unit	m
Description	Refers to the height of crop canopy where photocatalyst is applied
Equations	Eq. 5 and Eq. 8
Origin of data	Field measurements
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine the exchange coefficient and the gradient of N_2O for flux calculations. The Project Developer shall be responsible for gathering this data.
Monitoring frequency	The data should be noted during air sampling in the field.
Purpose of data	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Quality assurance and control	The height shall be measured using a standardized tape measure ensuing consistent measurement location by trained personnel.
Comments	N/A

(c)	
Data / Parameter	**Height at least 1m above the canopy (z_2)**
Unit	m
Description	Refers to the height above the crop canopy
Equations	Eq. 5 and Eq. 8
Origin of data	Field measurements

Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine the exchange coefficient and the gradient of N_2O for flux calculations The Project Developer shall be responsible for gathering this data.
Monitoring frequency	The data should be noted during air sampling in the field.
Purpose of data	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Quality assurance and control	The height shall be measured using a standardized tape measure ensuing consistent measurement location by trained personnel.
Comments	N/A

(d)	
Data / Parameter	**N_2O concentration at canopy height (C_1)**
Unit	ppb
Description	Refers to the N_2O concentration at canopy height, analysed from air samples collected in the field.
Equations	Eq. 7
Origin of data	Field measurements
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine the gradient of N_2O for flux calculations. The Project Developer shall be responsible for gathering this data. Refer to Appendix I section 4 for Data Processing and Statistical Analysis
Monitoring frequency	The data should be collected at least once during the project, three times is the recommendation.
Purpose of data	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details

Quality assurance and control	The data shall be collected and analysed as described in section 9.1. It shall be conducted by trained personnel strictly following sampling protocols for consistency. The data shall be analysed using statistical methods (e.g., IQR for outliers).
Comments	N/A

(e)	
Data / Parameter	**N_2O concentration at least 1m above the canopy height (C_2)**
Unit	ppb
Description	Refers to the N_2O concentration at height at least 1m above the canopy, analysed from air samples collected in the field.
Equations	Eq. 7
Origin of data	Field measurements
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	This parameter is required to determine the gradient of N_2O for flux calculations. The Project Developer shall be responsible for gathering this data. Refer to Appendix I section 4 for Data Processing and Statistical Analysis
Monitoring frequency	The data should be collected at least once during the project, three times is the recommendation.
Purpose of data	☒ Calculation of baseline emissions ☒ Calculation of project emissions ☐ Calculation of leakage ☐ Other, Provide details
Quality assurance and control	The data shall be collected and analysed as described in section 9.1. It shall be conducted by trained personnel strictly following sampling protocols for consistency. The data shall be analysed using statistical methods (e.g., IQR for outliers).
Comments	N/A

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Appendix I – Sampling and data analysis procedures in 2024 trials

1. Materials and Equipment

- **Air Sampling Bags**: Two main types of air sampling bags were used:
  - **Two-valve multilayer foil sampling bags** (5-liter capacity): Comprised of four layers (nylon, polyethylene, aluminium foil, and polyethylene). These bags were

preferred due to their suitability for loop analysis, creating stabilized conditions and ensuring consistent results.
    - **One-valve Tedlar bags** (5-liter capacity): Initially used, but some concerns arose regarding N_2O retention and release, potentially leading to inaccuracies. One-valve multilayer foil sampling bags are acceptable to use.
- **Pumps**:
    - **Manual electric pumps**: These are capable of filling bags in 20-30 seconds, reducing variations between sample points. Models included pumps with built-in batteries (e.g., D Cell Electric Air Pump Powertouch™), which allowed for quicker and simultaneous sampling at multiple heights.
- **Other Equipment**:
    - Tubes for connection.
    - **UV Light Meter**: To measure the UV intensity during sampling.
    - **Weather station**: To record environmental conditions, such as wind speed and direction.

2. Field Setup and Sampling Procedure

- **Field Selection and Preparation**:
    - Measurement points were selected in treated and control fields based on factors such as wind direction and accessibility. Fields sprayed with R-Leaf were confirmed to have visible product coverage on the leaves.
    - It was ensured that the measurement points were far from roads or obstructions to reduce external influences on N_2O readings.
    - Geo-locations of all measuring points were marked for consistency in repeated visits.
- **Sampling Heights**:
    - Samples were collected at two heights: at canopy level and 1 meter above the canopy. This dual-height approach, recommended by Cambridge Environmental Research Consultants (CERC), was adopted to measure vertical fluxes accurately.
- **Procedure**:
    - Each bag was filled using manual pumps. The bags were purged or vacuumed before use to remove any residual air.
    - Bags were filled over approximately 2 minutes with controlled air flow.
    - A total of 6-8 sets of bags were collected sequentially from both the treated and control fields on each visit. The control and treated field measurements were ideally conducted simultaneously to account for changing environmental conditions.
- **Sampling recommendations:**
    - Conducting air sample collection at multiple points and heights within the same field would improve data reliability and reduced uncertainty.
    - Sampling under various weather conditions (e.g., sunny, overcast) would provide insights into how these factors influence R-Leaf's performance.

3. Sample Analysis with LI-COR LI-7820 N2O/H2O Analyser

- **Analyser Setup**:
    - The Licor analyser uses Optical Feedback Cavity Enhanced Absorption Spectroscopy (OF-CEAS) for precise, sub-ppb N_2O measurements.
    - The equipment was powered either by batteries or connected to an external power source.

- **Analysis Procedure**:
    - Air sample bags were attached to the analyser using specialized compression fittings (e.g., Swagelok fittings).
    - Each sample was analysed for 10 minutes, with the first minute considered as a purging period.
    - Bags were looped for continuous analysis when necessary, ensuring no air leaks occurred.
- **Data Export**:
    - Data was exported from the Licor in '.data' format, with files labelled to correspond to specific sample bags. The exported data was then processed in Excel.

4. Data Processing and Statistical Analysis

- **Data Organization**:
    - Raw data from '.data' files was imported into Excel. A custom computer program was utilized to organize data efficiently into time and N_2O concentration columns.
- **Outlier Identification**:
    - Outliers were identified using the interquartile range (IQR) method. The quartile function in Excel was used to determine Q1 and Q3, with a stricter IQR multiplier (1.25) to enhance sensitivity.
- **Outlier Filtering**:
    - Data flagged as outliers was excluded from the statistical analysis to improve the accuracy and reliability of the results.
- **Descriptive Statistics**:
    - Mean and standard deviation of the filtered data were calculated using Excel's data analysis tools. These statistics provided a foundational understanding of the N_2O concentration changes observed.
- **Application of the CERC Model**:
    - The Cambridge Environmental Research Consultants (CERC) model was used to calculate vertical N_2O flux, considering environmental data and N_2O concentration gradients between the two heights.
    - The model output was converted into tons CO_2 equivalents using standard conversion factors, considering R-Leaf's active period and efficiency.

5. Comparison and Interpretation of Results

- **Data Comparisons**:
    - N_2O flux data from treated and control fields were compared. Positive flux indicated N_2O destruction attributed to R-Leaf.
    - Control field concentrations served as a baseline for background N_2O levels, essential for distinguishing R-Leaf's impact.
- **Field Variability**:
    - Results often varied due to factors such as weather, time from application, and UV intensity. High UV conditions correlated with more effective N_2O destruction which is consistent with the behaviour expected from a photocatalyst.