Carbontribe Methodology

Reducing Agricultural Emissions (Nitrous Oxide)

1. Introduction

Nitrogen-based fertilizers are vital for modern agriculture but pose significant environmental challenges, particularly through the emission of nitrous oxide (N_2O), a greenhouse gas with a much higher global warming potential than carbon dioxide over a century. Overuse of these fertilizers not only exacerbates N_2O emissions but also degrades soil health and disrupts ecosystems. Reducing their application presents a critical opportunity to mitigate climate change while fostering sustainable agricultural practices.

This chapter examines Carbontribe's methodology for mitigating N_2O emissions by optimizing fertilizer use, emphasizing the rigorous quantification and validation of emission reductions. Building on the foundational principles outlined in Chapter 1, it provides a specialized framework tailored to reducing agricultural emissions.

The first section outlines a systematic approach to project design, offering practical guidelines for developing effective, sustainable interventions. The latter part delves into detailed quantification methodologies, presenting calculations to measure emission reductions and assess project impacts.

2. Project Design

This chapter outlines the foundational framework for designing and implementing projects aimed at reducing N_2O emissions through sustainable agricultural practices. The principles of project design outlined here align with the broader phases of a Carbontribe project, as described in our common methodology.

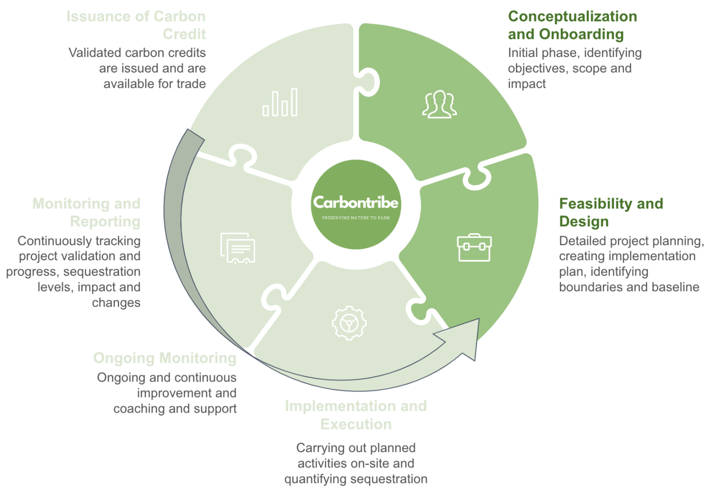

Figure 1: Initial Phases of the Project Cycle

This chapter focuses on the initial stages of project development, specifically conceptualization and design (see Figure 1). It provides an in-depth overview of the key components of Carbontribe's project design framework, detailing the essential steps for development. The framework covers the project's scope, objectives, and boundaries, alongside defining baseline scenarios, ensuring additionality, and establishing robust monitoring procedures. This methodology serves as a foundational guide for applicants, assisting them in accurately describing, justifying, and validating their projects. To support this process, a comprehensive application form has been developed, aligning with our methodology and guidelines. This form, provided in a separate document, must be completed prior to project commencement to ensure eligibility and compliance with our standards.

2.1 Project Description

2.1.1 Project Scope

Carbontribe's fertilizer reduction methodology exclusively focuses on projects that implement sustainable agricultural practices aimed at reducing nitrous oxide (N_2O) emissions. These activities include the reduction or substitution of synthetic nitrogen fertilizers with alternatives such as organic fertilizers, biofertilizers, or precision nutrient applications. By concentrating on the mitigation of N_2O emissions, this methodology targets the optimization of fertilizer use, supporting measurable greenhouse gas reductions while promoting soil health and sustainable farming.

Projects must demonstrate a verifiable reduction in N_2O emissions through detailed project plans, historical records of fertilizer use, and documented implementation of alternative practices. Activities involving unrelated emission reduction practices, such as those targeting carbon dioxide or methane outside the defined project framework, are excluded from this methodology. This focused approach ensures precision in estimating emission reductions and enhances the methodology's integrity by addressing direct sources of N_2O emissions from fertilizer application.

2.1.2 Project Boundaries

Land Eligibility and Use:
Project activities must occur on cropland or grassland at the project start date, with the land remaining as such throughout the project duration, except in two scenarios:

1. Temporary Grassland Integration: Grassland may be introduced into cropland if it is part of a documented, long-term agroforestry or integrated crop-livestock system. Documentation must outline management plans, proposed practices, and expected benefits over the project lifetime.
2. One-Time Land-Use Conversion: Conversion between grassland and cropland is allowed if baseline lands are degraded and improved land-use practices will significantly enhance soil health. Evidence of baseline degradation and ongoing pressures must be validated before project approval.

Projects must implement sustainable agricultural practices that go beyond legal requirements, reducing synthetic fertilizer use or replacing it with alternatives such as organic fertilizers or precision nutrient applications. Activities must not affect wetlands or significantly reduce agricultural productivity. These boundaries ensure reliable, verifiable emissions reductions aligned with the methodology's objectives.

Emission Reductions:
Within this methodology, Carbontribe focuses exclusively on agricultural practices aimed at reducing nitrous oxide (N_2O) emissions. These reductions will be analyzed through both direct (nitrogen-based fertilizers applied directly to the project site) and indirect pathways (arise from fertilizer byproducts). While the fertilizer application site must be clearly defined, the specific locations of byproduct redeposition outside the project area are not required to be specified.

Geographic Requirements:
To delineate the project area, applicants must submit precise geographic information:

- **Submission Format:** Provide either a Keyhole Markup Language (KML) file or an array of geographic coordinates.
  - KML File: Must include a single or contiguous polygon(s) representing the project area and be compatible with GIS software.

- Array of Coordinates: Latitude and longitude must be provided in WGS84 datum (EPSG:4326) with at least six decimal places, ensuring a closed loop of boundary representation.

Land must not involve clearing native ecosystems within the last five years and must maintain stable boundaries, ensuring consistent use without significant displacement of productive activities, livestock, or soil productivity.

- **Land-Use History:** Land must be cropland or grassland with no clearing of native ecosystems within the last 5 years.

2.1.3 Purpose and objective

The primary goal of this methodology is to reduce nitrous oxide (N_2O) emissions from agricultural practices by optimizing the use of nitrogen-based fertilizers. This includes fostering sustainable farming techniques that minimize environmental impact while maintaining or improving soil productivity.
Projects applying this methodology must clearly define their objectives, including measurable reductions in N_2O emissions, improvements in fertilizer efficiency, and broader environmental benefits. These objectives should align with sustainable development goals and demonstrate a commitment to advancing both climate change mitigation and the resilience of agricultural systems.

2.1.4 Stakeholder engagement

Stakeholder engagement is vital for the success and sustainability of fertilizer-focused agricultural projects, fostering collaboration and ensuring alignment with local and environmental priorities. Projects should actively involve farmers, local communities, agricultural organizations, government bodies, and other relevant stakeholders at every stage. This can include regular consultations, participatory decision-making, and transparent communication channels during project planning, implementation, and monitoring. Evidence of stakeholder involvement, such as meeting records, signed agreements, and feedback mechanisms, should be documented. Ongoing communication ensures stakeholders remain informed and engaged, fostering trust and long-term project acceptance.

2.2 Baseline Description

The baseline scenario reflects the continuation of historical agricultural practices, specifically the application of synthetic fertilizers at business-as-usual (BAU) rates. Under this scenario, nitrous oxide (N_2O) emissions from soils are expected to remain higher compared to the reduced emissions achieved through project implementation. This baseline serves as a reference point to measure the project's impact and additionality by demonstrating that emission reductions would not have occurred without the project.

The baseline must confirm that synthetic fertilizers were historically used as part of the agricultural management practices on the project land. Baseline emissions represent the estimated amount of N_2O released during the project crediting period if these practices continued without change.

2.2.1 Baseline Validation

Developers must provide detailed records of synthetic fertilizer application, including type, quantity, and timing, for at least one year prior to project initiation. This data ensures that the baseline scenario accurately reflects historical farming practices.

- **Baseline Period:**
  To ensure an accurate representation of historical fertilizer use and practices, a minimum of one year of pre-project data must be collected. However, a longer period (e.g., 3–5 years) is recommended when possible to account for variations in weather, crop rotation, and farming practices. If only one year of data is available, supplementary sources such as regional agricultural records or farmer surveys should be used to strengthen the baseline assessment.

- **Project Period:** Post-project implementation data must span at least one year to demonstrate the reduction or replacement of synthetic fertilizers and the corresponding decrease in N_2O emissions.

2.2.2 Additionality

To demonstrate additionality in fertilizer reduction projects, it is essential to show that the emission reductions are real, measurable, and exceed business-as-usual (BAU) practices. This can be achieved by implementing actions that go beyond legal or regulatory requirements and represent a significant departure from standard agricultural practices. Key considerations for proving additionality include:

1. **Clear Identification of Project Activities**:
   The project should outline specific actions taken to reduce fertilizer use, such as transitioning to precision application, using slow-release fertilizers, switching to organic alternatives, or introducing nitrogen-fixing rhizobia. Rhizobia, used with leguminous crops, help convert atmospheric nitrogen into a form plants can use, reducing reliance on synthetic nitrogen fertilizers. These interventions must be significantly different from standard practices in the region to demonstrate a meaningful shift towards sustainable nutrient management.
2. **Baseline Comparison and Emission Reduction Evidence**:
   Evidence must be provided to show that, without the project, fertilizer application rates and the associated N_2O emissions would have remained at or near BAU levels. This may involve using historical data or modeling to estimate emissions under typical practices.

3. **Technological and Financial Barriers**:
   The project should address and overcome barriers that would otherwise prevent the adoption of the new practices, such as high upfront costs or limited knowledge and resources among farmers.
4. **Regulatory Surplus**:
   The project must demonstrate that reducing fertilizer use is not mandated by any law or regulation. The reductions must go beyond legal requirements, ensuring that the actions taken are voluntary and not a result of regulatory obligations.

2.2.3 Leakage

Leakage risks in fertilizer reduction projects are considered negligible due to the continued use of land for agricultural production. Historical evidence demonstrates that reducing nitrogen fertilizer to optimal economic levels does not compromise crop yields, eliminating incentives for production shifts that could increase emissions or reduce soil carbon pools outside the project boundary (Zhao, Lu, Zhang, Li, & Liu, 2017; Nasiro & Mohammednur, 2024; Hoben, Gehl, Millar, Grace, & Robertson, 2011).

To ensure thorough monitoring, CarbonTribe can utilize advanced computer vision models to detect increased agricultural activities or emissions in neighboring areas, providing an additional safeguard against potential indirect impacts.

2.3 Monitoring and Verification

Monitoring and verification are critical to ensuring the credibility of greenhouse gas (GHG) emission reductions and the integrity of carbon credits in CarbonTribe's fertilizer reduction methodology. These processes adhere to internationally recognized standards, including the IPCC 2006 Guidelines, and reflect scientific and operational best practices.

The monitoring framework focuses on tracking nitrous oxide (N_2O) emissions to evaluate the effectiveness of fertilizer management practices. These emissions are measured with precision to accurately quantify greenhouse gas reductions within the project boundaries. The framework integrates field-based measurements with advanced technologies, including remote sensing, GIS, and machine learning models, to enhance accuracy and efficiency. This comprehensive, multi-tiered approach enables the early detection of deviations, facilitating timely adjustments and ensuring the project's objectives are met. Specific monitoring protocols for each parameter are detailed in the *Quantification of Estimated Reduction* chapter (Chapter 4.3.5).

2.3.1 Verification

Verification involves an independent assessment by qualified third-party auditors to validate the accuracy and credibility of monitoring data and ensure compliance with established methodologies. These auditors review project documentation, field data, and monitoring reports to confirm the reported reductions in nitrous oxide (N_2O) emissions. By relying on impartial and experienced professionals in agricultural carbon offset projects and greenhouse gas accounting, the verification process upholds transparency and credibility in the generation of carbon credits.

In line with the Core Carbon Principles set by the Integrity Council for the Voluntary Carbon Market (ICVCM), our monitoring and verification framework is designed to ensure transparency, additionality, permanence, and high-integrity environmental outcomes.By integrating robust monitoring practices with third-party verification, this methodology ensures that projects deliver measurable and verifiable climate benefits. This iterative process fosters continuous improvement, supports innovation in fertilizer management, and reinforces our commitment to impactful and trustworthy participation in the carbon market.

3. Quantification of Estimated Reductions

This chapter outlines the methodology for quantifying the estimated reductions in greenhouse gas (GHG) emissions resulting from sustainable agricultural practices, with a particular focus on the reduction of N_2O emissions. The primary sources of N_2O emissions in these projects are categorized as follows:

- **Direct N_2O Emissions**: These emissions arise from the nitrification and denitrification processes of nitrogen in fertilizers applied to the soil. Synthetic fertilizers increase the amount of nitrogen available in the soil, which can be converted into N_2O, a potent greenhouse gas.
- **Indirect N_2O Emissions**: Emissions from the volatilization of nitrogen from fertilizers, followed by its deposition onto soils or water bodies, contribute to N_2O emissions. Nitrogen lost through volatilization adds to the overall N_2O emissions, even if the nitrogen does not remain in the soil.
- **Emissions from Leaching and Runoff**: Nitrogen can be lost through leaching into groundwater or runoff into nearby water bodies. This nitrogen, once in aquatic systems, can be converted to N_2O, further contributing to GHG emissions.

The calculations presented here follow a structured approach to assess the various sources of N_2O emissions within agricultural systems. The chapter begins with an overview of the overall equation that forms the foundation for calculating emission reductions, followed by a detailed explanation of each component.

3.1 Process Flow

Accurately quantifying forest coverage and estimating N_2O sequestration potential is crucial for understanding the role of forests in mitigating climate change. Carbontribe leverages computer vision models and remote sensing technologies to classify cropland and non-cropland areas, monitor critical forest parameters, and estimate annual carbon sequestration rates. This methodology integrates high-resolution satellite imagery, machine learning algorithms, and ecological equations to provide a comprehensive, scalable solution for forest monitoring and carbon accounting.

Step 1: Data Acquisition and Preprocessing

- Satellite imagery is collected from various sources such as remote sensing platforms.
- The collected data undergo preprocessing, including noise reduction, radiometric correction, cloud detection and removal, and geographic alignment, to ensure compatibility with the computer vision models.

Step 2: Cropland Classification Using Computer Vision

- A computer vision model is trained to classify regions as cropland or non-cropland. Training data includes labeled examples of both categories.
- The model processes high-resolution images to identify forested areas based on spectral, textural, and structural features.
- The output is a classified map highlighting forest and non-forest regions with pixel-level accuracy.

Step 3: Monitoring Key Forest Parameters

- For areas classified as cropland, the monitoring process aligns with IPCC guidelines to estimate nitrogen flow and N_2O accurately. More detailed information what parameters and how exactly we conduct the monitoring can be found in the following chapters
- Wherever possible, further literature reviews will be conducted to obtain detailed information such as country-specific factors, fertiliser type-specific allometric equations, and regional emission factors. This ensures that monitoring results are both scientifically robust and tailored to local ecological contexts.
- These parameters are monitored over time at the specified frequency to track changes and trends in forest health and growth.

Step 4: N_2O Sequestration Estimation

- Using the monitored parameters, relevant equations or estimation models are applied to infer N_2O reduction.

Step 5: Blockchain Storage

- All relevant data, including forest classification outputs, monitored parameters, and N_2O reduction estimates, are securely stored on a decentralized blockchain platform.
- Data links, metadata, and timestamps are recorded to ensure traceability and tamper-proof documentation.

Step 6: Digital Asset Creation:

- A digital asset in the form of a Non-Fungible Token (NFT) is created to represent the carbon sequestration results for a specific geographic area and time period.
- The NFT includes embedded data or links to external datasets, including:
    - Detected cropland areas
    - Parameter estimates and methods
    - Scientific equations and values used in the calculations
    - Documentation on compliance with IPCC methodologies and any country-specific factors
- The blockchain-stored data and NFT serve as a transparent and auditable foundation for issuing carbon credits.
- This process ensures that credits are backed by scientifically verified data, reducing the risk of fraudulent claims

3.2 Total Emission Reduction

The reduction in greenhouse gas (GHG) emissions for our agricultural projects is determined by calculating the difference between the baseline emissions and the project emissions. The total GHG emission reduction is expressed as:

$$ER = E_{baseline} - E_{Project}$$

Where ER represents the total emissions reductions (-t CO_2e/ha). $E_{baseline}$ refers to emissions under the baseline scenario, and $E_{Project}$ refers to emissions after project implementation.

3.3 Baseline Emissions Calculation

This section outlines the methodology for calculating baseline emissions, based on historical data related to synthetic fertilizer use. The formula used is shown below and entails project-specific data, such as the type and quantity of fertilizer applied, alongside default emission values for estimating associated emissions. Table 1 provides a description of the parameters used in the formula. This methodology establishes the baseline emissions, which serves as the reference point for measuring future emission reductions resulting from the project.

Baseline Emissions Formula:

$$E_{baseline} = \sum_{n=i} (N_{base,\,a,i} \times EF_{base,d,i} + N_{base,v,i} \times EF_{base,v,i} + N_{base,l,i} \times EF_{base,l,i}) \times N\ to\ N_2O \times N_2O\ to\ CO_2$$

Where:

- i: Type of synthetic fertilizer

Table 1: Parameters for Baseline Emissions Calculation

Parameter	Description	(Default) Value	Source
$N_{base,a,i}$	Amount of synthetic fertilizer applied in the baseline year (t N/ha)	Variable (project-specific)	Farm records, receipts
$EF_{base,d,i}$	Direct emission factor for synthetic fertilizers	Derive from Table 11.1	IPCC Volume 4, Chapter 11 (2006, updated 2019)

$N_{base,v,i}$	Amount of nitrogen volatilized (fraction of applied nitrogen)	Variable (project-specific)	IPCC Volume 4, Chapter 11 (2006, updated 2019)
$EF_{base,v,i}$	Emission factor for volatilized nitrogen	Derive from Table 11.3	IPCC Volume 4, Chapter 11 (2006, updated 2019)
$N_{base,l,i}$	Amount of nitrogen leached (fraction of applied nitrogen)	Variable (project-specific)	IPCC Volume 4, Chapter 11 (2006, updated 2019)
$EF_{base,l,i}$	Emission factor for leached nitrogen	Derive from Table 11.3	IPCC Volume 4, Chapter 11 (2006, updated 2019)
$N\ to\ N_2O$	Molecular weight ratio to convert N_2O-N to N_2O	1.57	IPCC Volume 4, Chapter 11 (2006)
N_2O to CO_2	N_2O to CO_2 conversion factor	310	IPCC Volume 4, Chapter 11 (2006)

3.4 Project Emissions Calculation

This section outlines the methodology for calculating project emissions, which are based on the reduced or alternative fertilizer use in the project compared to baseline levels. The same formula used for baseline emissions is applied, but with adjustments to reflect the actual amount of synthetic fertilizers used in the project, or alternative fertilizers. The description of the parameters is given in table 2.

This section outlines the methodology for calculating project emissions, which are based on the reduced or alternative fertilizer use in the project compared to baseline levels. The same formula used for baseline emissions is applied, but with adjustments to reflect the actual amount of synthetic fertilizers used in the project or alternative fertilizers. The methodology follows a tiered approach based on IPCC guidelines.

Tier 1 Approach: Tier 1 calculations rely on IPCC default values, such as global averages or standard emission factors for synthetic fertilizers.

Refined Approaches (Tier 2 or 3): When possible, project-specific measurements or species-specific values from peer-reviewed literature should be applied. For example, studies on utilizing nitrogen-fixing rhizobia may provide more accurate data on N_2O reduction.

The description of the parameters is given in Table 2.

Project Emissions Formula:

$$E_{project} = \sum_{n=i} (N_{proj,a,i} \times EF_{proj,d,i} + N_{proj,v,i} \times EF_{proj,v,i} + N_{proj,l,i} \times EF_{proj,l,i}) \times N\ to\ N_2O \times N_2O\ to\ CO_2$$

Where:

- i: Type of synthetic fertilizer

Table 2: Parameters for Project Emissions Calculation

Parameter	Description	(Default) Value	Source
$N_{proj,a,i}$	Amount of synthetic fertilizer applied in the project year (t N/ha)	Variable (project-specific)	Farm records, receipts
$EF_{proj,d,i}$	Direct emission factor for synthetic fertilizers in the project	Derive from Table 11.1	Tier 1: IPCC Volume 4, Chapter 11 (2006, updated 2019) Tier 2: Field-specific emission studies
$N_{proj,v,i}$	Amount of nitrogen volatilized in the project (fraction of applied nitrogen)	Variable (project-specific)	Tier 1: IPCC Volume 4, Chapter 11 (2006, updated 2019) Tier 2: Region-specific measurements or models
$EF_{proj,v,i}$	Emission factor for volatilized nitrogen in the project	Derive from Table 11.30.01 t N_2O-N per t N volatilized	Tier 1: IPCC Volume 4, Chapter 11 (2006, updated 2019) Tier 2: Context-specific emission factors (e.g., biologically enhanced nitrogen cycling)
$N_{proj,l,i}$	Amount of nitrogen leached/runoff in the project (fraction of applied nitrogen)	Variable (project-specific)	Tier 1: IPCC Volume 4, Chapter 11 (2006, updated 2019) Tier 2: Measured local leaching data and

			context-specific emission factors (e.g., biologically enhanced nitrogen cycling)
$EF_{proj,l,i}$	Emission factor for leached nitrogen in the project	0.0075 t N_2O-N per t N leached	Tier 1: IPCC Volume 4, Chapter 11 (2006, updated 2019) Tier 2: Site-specific leaching studies
$N\ to\ N_2O$	Molecular weight ratio to convert N_2O-N to N_2O	1.57	IPCC Volume 4, Chapter 11 (2006)
N_2O to CO_2	N_2O to CO_2 conversion factor	310	IPCC Volume 4, Chapter 11 (2006)

3.5 Estimation of Amount of Nitrogen Volatilized and leached in the Project

In cases where detailed project-specific data is unavailable or when a simplified estimation is preferred, a fraction-based approach is used to calculate emissions from fertilizer use. This method relies on default fractions for nitrogen volatilization and leaching, as outlined in the IPCC guidelines (Volume 4, Chapter 11). Specifically, it assumes that a set percentage of the applied nitrogen is volatilized or leached, with associated emission factors for each pathway. By applying these default fractions to the total nitrogen applied, the emissions from volatilization and leaching can be estimated without the need for detailed field measurements.

The fraction-based estimation method provides a streamlined and efficient way to calculate project emissions, especially in cases where more specific data is not available or when a less granular approach is deemed sufficient for the purpose of carbon crediting. This methodology is consistent with Tier 1 IPCC guidelines for emissions estimation and ensures transparency and comparability across projects.

Amount of Volatilisation

$N_v = N_a \times Frac_v$

Where:

- $Frac_v$: Fraction of nitrogen volatilized

Table 3: Amount of Nitrogen Volatilized in the project

Parameter	Description	(Default) Value	Source
$Frac_v$	Volatilisation compared to synthetic fertiliser applied (t NH3–N + NOx–N) (t N applied)	Derive from Table 11.3	IPCC Volume 4, Chapter 11 (2006, updated 2019)

Amount of losses by leaching/runoff

$N_l = N_a \times Frac_l$

Where:

- $Frac_l$: Fraction of nitrogen leaching

Table 4: Amount of Nitrogen leached/runoff in the project

Parameter	Description	(Default) Value	Source
$Frac_l$	N losses by leaching/runoff compared to synthetic fertiliser applied (t NH3–N + NOx–N) (t N applied)	Derive from Table 11.3	IPCC Volume 4, Chapter 11 (2006, updated 2019)

3.6 Monitoring Parameters

Table 5: Monitoring parameters

Parameter	Description	Monitoring Method	Frequency
$N_{applied}$	Amount of nitrogen fertilizer applied	For the year prior to the project start date, include as-applied maps, purchase and application records for synthetic fertilizer, and other grower records that demonstrate fertilizer application amounts per fertilizer type.	Annual
Fertilizer type	Type of synthetic or alternative fertilizer	Fertilizer purchase receipts, Agricultural service provider labels	Annual
EF & $Frac$ values	Emission, volatilisation and leaching factors for fertilizers	IPCC defaults EF_d: Table 11.1 Volume 4, Chapter 11, IPCC 2019 Other EF & $Frac$: Table 11.3 Volume 4, Chapter 11, the IPCC 2019 Refinement Field Studies	Annual

References

Hoben, J.P., Gehl, R.J., Millar, N., Grace, P.R., and Robertson, G.P. (2011). Non-linear nitrous oxide (N2O) response to nitrogen fertilizer in on-farm corn crops of the US Midwest. Global Change Biology 17:1140–1152.

Integrity Council for the Voluntary Carbon Market (ICVCM). (2023). *Core Carbon Principles and Assessment Framework*. https://icvcm.org/core-carbon-principles/

Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Intergovernmental Panel on Climate Change (IPCC). (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Nasiro, K., & Mohammednur, T. (2024). Precision nutrient management amid climate change challenges: A review. *Science Forum*, 2024(5), 1-13. https://doi.org/10.11648/j.sf.20240503.12

United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. https://sdgs.un.org/2030agenda

Zhao, Y., Lu, Y., Zhang, S., Li, Z., & Liu, Y. (2017). Effects of nitrogen fertilizer reduction on crop yield and soil environmental quality: A review. *Science of The Total Environment, 616*, 1328-1335. https://doi.org/10.1016/j.scitotenv.2017.10.197