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Methodology for Quantifying Nitrous Oxide (N₂O) Emissions Reductions from Reduced Use of Nitrogen Fertilizer on Agricultural Crops

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MICHIGAN STATE
UNIVERSITY

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1. SOURCES, DEFINITIONS AND APPLICABILITY

1.1 Sources

This methodology is based upon, and is consistent with elements from the following documents:

- 2006 IPCC Guidelines for National Greenhouse Gas Inventories (revised Aug. 2011)¹.
- VCS Methodology Element “Quantifying N₂O Emissions Reductions in US Agricultural Crops through N Fertilizer Rate Reduction” – Version 1.4².
- N Millar, GP Robertson, PR Grace, RJ Gehl, and JP Hoben (2010). *Mitigation and Adaptation Strategies for Global Change* 15:185–204³.
- JP Hoben, RJ Gehl, N Millar, PR Grace, and GP Robertson (2011). *Global Change Biology* 17:1140–1152⁴.

1.2 Definitions

For the purpose of this methodology, the following definitions apply.

Agricultural Crops

Crops where the product is harvested for food, livestock fodder, or for another economic purpose, and that typically receive external input of N fertilizer

Synthetic nitrogen fertilizer

Any N-containing synthetic fertilizer (solid, liquid, gas) - this may be a single nutrient product (only including N), or other N-containing synthetic fertilizer, such as multi-nutrient fertilizers (e.g., N–P–K) or ‘enhanced–efficiency’ N fertilizers (e.g., slow release, controlled release and stabilized N).

Organic nitrogen fertilizer

Any N-containing organic material including animal manure, compost, and sewage sludge.

Direct N₂O emissions

Those emitted from the project site to which N fertilizer N is applied.

Indirect N₂O emissions

Those emitted beyond the project site but resulting from N fertilizer applied to the project site.

North Central Region (NCR)

Area of the US encompassing the twelve Midwestern states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin.

1.3 Applicability and Scope

The methodology is applicable to the Agriculture, Forestry and Other Land Use (AFOLU) sector, and is specific to Agricultural Land Management (ALM) project activities. The scope of this methodology is

¹ http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

² <http://www.v-c-s.org/sites/v-c-s.org/files/VCS%20N2O%20Reduction%20Methodology%20and%20Annexes%20v1%204.pdf>

³ <http://www.springerlink.com/content/12n3gh1370p5h656>

⁴ <http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2010.02349.x/abstract>

limited to on-farm reductions in N fertilizer rate associated with the management of N-containing synthetic and organic fertilizers that reduce net N₂O emissions from annual or perennial cropping systems. Emissions reductions and crediting for project activities occur by reducing the N fertilizer rate during the crediting period, when compared to the baseline (pre-project) period.

A reduction in N rate during the project period will not significantly reduce crop yield (section 7). Greenhouse gas reductions associated with carbon sequestration in the soil (section 4), fossil fuel use on-site, and emissions reductions off-site caused by production and distribution of N fertilizers are excluded.

To the best of our knowledge, implementation of project activities associated with this methodology, with or without registration as an AFOLU project, shall not lead to violation of any applicable law even if the law is not enforced.

2. PROJECT ELIGIBILITY

Proposed projects will be at sites on which eligible crops as defined in section 2.5 have been cultivated for at least five years (e.g., equivalent of five annual cropping seasons) prior to the project start date.

2.1 Fertilizer Nitrogen Sources

Eligible N sources:

- Synthetic N fertilizers;
- Organic N fertilizers.

All eligible N inputs are considered equal on a nitrogen mass basis irrespective of source.

2.2 Fertilizer Nitrogen Management

Nitrogen fertilizer addition during the baseline and project crediting period must be compared using the same crop type(s) grown on the same land area (section 2.6).

Nitrogen fertilizer addition to a project site during growth of a single crop (or double or multiple crops) during a growing season is eligible for determination of ‘yearly’ N fertilizer rate irrespective of when N fertilizer is applied during the calendar year or whether N fertilizer applied is split between calendar years to the same crop.

2.2.1 Best Management Practice

During a project-crediting period, adherence to Best Management Practices (BMPs) as they relate to the application of synthetic and organic N fertilizer at the cropping site is required. These BMPs are related to N fertilizer formulation (or N content of organic additions) and dates and methods of application.

Details of fertilizer BMPs are readily available for each US state via state departments of agriculture and from US federal agencies such as the Natural Resources Conservation Service (NRCS)⁵ and the USDA Farm Service Agency⁶. These BMPs are also described in the Global 4R Nutrient (Fertilizer) Stewardship Framework, published by the International Plant Nutrition Institute (IPNI)⁷.

⁵ <http://www.nrcs.usda.gov>

⁶ www.fsa.usda.gov

⁷ <http://www.ipni.net/4r>

Project Proponents shall describe and justify in the GHG Project Plan how relevant BMPs have been adhered to.

2.3 Nitrous Oxide Emissions

Both direct and indirect pathways of N₂O emissions are eligible.

Indirect N₂O emissions occur through two pathways:

- Following volatilization of the gases ammonia (NH₃) and nitrogen oxides (NO and NO₂ collectively termed NO_x) produced as a result of N applied to a project site, and the subsequent re-deposition of these gases and their products ammonium (NH₄⁺) and nitrate (NO₃⁻) to soils and waters beyond a project boundary;
- After leaching and runoff of N (mainly as NO₃⁻) applied to a project site enters receiving waters or soils beyond the site – this is only applicable to regions where leaching and runoff occurs (see **Annex A**).

2.4 Geographic Location

Projects are eligible in all countries, and are divided into three Categories (section 2.5).

2.4.1 Projects in the United States of America

Project Categories 1, 2, and 3 are eligible.

2.4.2 Projects outside the United States of America

Project Categories 2 and 3 are eligible.

2.5 Project Categories

- *Category 1:* Proposed projects located in the NCR (section 1.2) of the US that involve corn in row-crop systems such as continuous corn and rotations of corn-soybean or corn-soybean-wheat will use Method 1 to calculate N₂O emissions reductions. Only the corn component of a rotation is eligible in this category.
- *Category 2:* Proposed projects located worldwide that include fertilized agricultural crops will use Method 2 to calculate N₂O emissions reductions so long as proponents can demonstrate using empirical data published (or accepted to be published) in peer-reviewed scientific journals that the use of the Tier 1 emission factor (EF₁ = 1.0% [0.01]; IPCC 2006) is conservative for calculating N₂O emissions at the project site(s). ACR will engage experts to review the data.
- *Category 3:* Proposed projects located worldwide that include fertilized agricultural crops will use new project-specific emissions factors to calculate emissions reductions so long as proponents can demonstrate using empirical data published (or accepted to be published) in peer-reviewed scientific journals that the use of a new Tier 2 emissions factor is conservative for calculating N₂O emissions at the project site(s). ACR will engage experts to review the data.

Projects located within the NCR boundary (section 1.2) that involve crops other than corn (eligible under Category 1), including crops in rotation with corn, are eligible under Categories 2 and 3.

During a project crediting period, projects initially accepted for inclusion in Category 2 can be re-assigned to Category 3, should new data become available. See section 9.1 for retroactive crediting for projects in Categories 2 and 3.

2.6 Cropping Area

The parcel of land on which the baseline crop is grown must be the same parcel of land on which the project crop is grown.

2.6.1 Soil Type

Proposed projects on sites with organic soils (Histosols), as defined by the World Reference Base for Soil Resources (FAO 2006)⁸, are ineligible.

Histosols comprise soils formed in organic material. These vary from soils developed in predominantly moss peat in boreal, arctic and subarctic regions, via moss peat, reeds/sedge peat (fen) and forest peat in temperate regions to mangrove peat and swamp forest peat in the humid tropics.

Histosols are found at all altitudes, but the vast majority occurs in lowlands. Common names are peat soils, muck soils, bog soils and organic soils.

Histosols are soils having organic material, either 1) 10 cm or more thick starting at the soil surface and immediately overlying ice, continuous rock, or fragmental materials, the interstices of which are filled with organic material; or 2) cumulatively within 100 cm of the soil surface either 60 cm or more thick if 75 percent (by volume) or more of the material consists of moss fibres or 40 cm or more thick in other materials and starting within 40 cm of the soil surface.

Soils maps for individual fields can be used to determine whether a field is underlain by a soil series in the Histosol Order.

3. PROJECT BOUNDARY

Consistent with ACR Standard (v. 2.1) requirements, the project boundary includes a spatial boundary, a temporal boundary, and a greenhouse gas (GHG) and carbon (C) pool assessment boundary.

3.1 Spatial Boundary

The spatial boundary encompasses the results of actions that are under the project proponent's control. This includes direct and indirect emissions of N₂O (section 1.2) resulting from a reduction of N fertilizer rate at the project site (Figure 1). The spatial boundary includes the project site and indirect emissions from beyond the site of N fertilizer addition.

⁸ <ftp://ftp.fao.org/agl/agll/docs/wsrr103e.pdf>

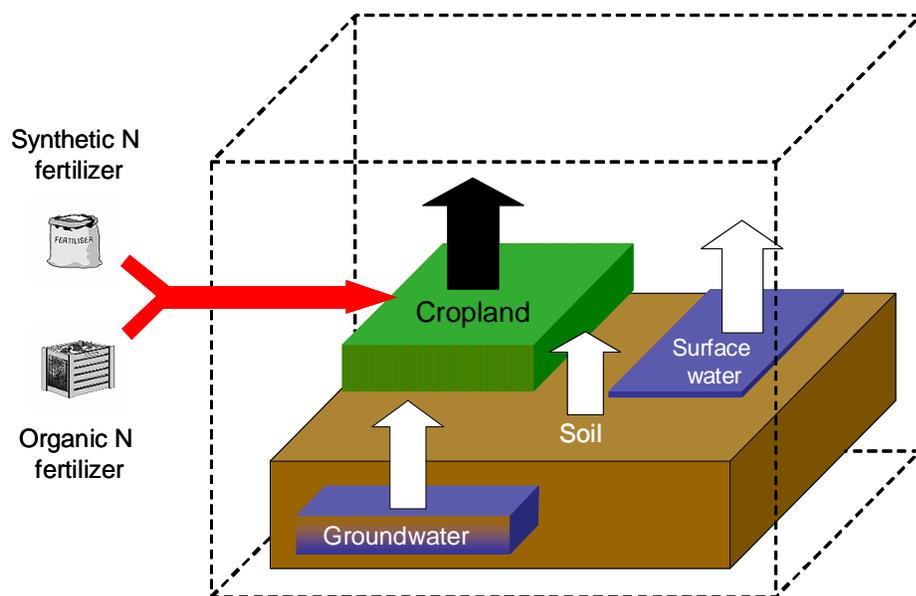


Figure 1. Schematic depicting the project spatial boundary for N₂O emissions (dotted line). Direct N₂O emissions from the site of N fertilizer addition (black arrow), and indirect emissions from beyond the site of N fertilizer addition (white arrows) are shown. Arrow sizes do not reflect the magnitude of N fertilizer addition or N₂O emissions.

3.2 Temporal Boundary

The ACR Standard (v. 2.1) stipulates that ACR sector standards specify the required minimum project duration and project crediting period for particular project types. No current ACR sector standard currently exists for methodologies reducing GHG (N₂O) emissions due to altered N rate management. This methodology therefore uses the accepted *ACR Methodology for N₂O Emission Reductions through Changes in Fertilizer Management (November 2010)* as guidance for temporal boundary demarcation.

Project activities that lead to a reduction in N fertilizer rate may be implemented for one year or longer. The crediting period for which the project is valid and during which time it can generate offsets against a baseline scenario is seven (7) years, equal to the current crediting period for non-AFOLU projects. If the project complies with ACR requirements in place at the time of a crediting period renewal then in accordance with ACR Standard (v 2.1) there is no limit to the allowed number of project crediting period renewals.

In accordance with ACR Standard (v 2.1), the desired frequency of credit (Emission Reduction Tons [ERTs]) issuance dictates the frequency of verification. Project proponents shall apply this or a revised version of this methodology for each reporting year since the previous verification. Prior to issuance, all emissions reductions attributable to the project activity must be verified. At each request for issuance of new ERTs, the project proponent must submit a verification statement from an approved verifier based on a desk audit. No less than once every five years project proponents must submit a verification statement based on a full verification including a field visit to the project site(s). Within the five-year period, the project proponent has flexibility to balance the costs of verification against accrued ERTs.

3.3 Greenhouse Gases

The greenhouse gases included in calculations of baseline emissions and project emissions are shown in Table 1.

Table 1. Greenhouse gases and sources, along with explanation for inclusion or exclusion of quantification.

Period	Source	Gas	Included?	Justification / Explanation
Baseline	Direct Emissions due to N fertilizer addition	CO ₂	No	Exclusion is conservative.
		CH ₄	No	Exclusion is conservative.
		N ₂ O	Yes	N ₂ O is major emissions source from fertilizer N addition
	Indirect Emissions due to N fertilizer addition	CO ₂	No	Exclusion is conservative.
		CH ₄	No	Exclusion is conservative.
		N ₂ O	Yes	N ₂ O is major emissions source from fertilizer N addition
Project	Direct Emissions due to N fertilizer addition	CO ₂	No	Exclusion is conservative.
		CH ₄	No	Exclusion is conservative.
		N ₂ O	Yes	N ₂ O is major emissions source from fertilizer N addition
	Indirect Emissions due to N fertilizer addition	CO ₂	No	Exclusion is conservative.
		CH ₄	No	Exclusion is conservative.
		N ₂ O	Yes	N ₂ O is major emissions source from fertilizer N addition

Projects shall state and justify *ex-ante* in the Project Document which Category the project is being submitted under (section 2.5). The same Category will be applied for baseline and project scenarios, and used for the assessment of additionality. Projects may switch categories or emission factors under the rules of section 9.1 (retroactive crediting).

3.4 Carbon Pools

Soil carbon (C) is the primary pool of concern for ALM methodologies. In accordance with ACR Standard (v. 2.1), any pool whose exclusion is conservative can be omitted from accounting. With this methodology reductions in N fertilizer rate resulting from project implementation will not result in soil C stock change. Therefore, soil C pools do not require monitoring. **Annex B** provides further justification for this exclusion.

4. SELECTION OF BASELINE SCENARIO

Projects will be eligible on land where eligible crops as defined in section 2.5 have been cultivated for at least five years prior to the project start date (section 2). As stipulated in section 2.2, N fertilizer addition during the baseline and project crediting period must be compared using the same crop(s) grown on the same land area (section 2.6). In the absence of the ALM project activity, the continuation of these cropping practices using ‘business-as-usual’ (BAU) N rate management practices is the most realistic and credible baseline scenario.

The baseline scenario is the situation where in the absence of the project activity, N fertilizer is applied at a BAU rate to the crop. This results in higher emissions of N₂O when compared to a project scenario where a lower N fertilizer rate is applied to this same crop on the same parcel of land. The baseline scenario is equivalent to BAU for the project developer.

The determination of baseline N fertilizer application rates and associated N₂O emissions is carried out using one of two Approaches. Both Approach 1 and Approach 2 are eligible for use in the US, and Approach 1 is eligible for use outside the US. Both Approaches use a yield-goal calculation method to generate a baseline fertilizer N application rate, from which emissions of N₂O are calculated. Approach 1 derives the baseline N rate from producer-specific management records, and Approach 2 derives the baseline N rate from US county-level records aggregated by the USDA National Agricultural Statistics Service, i.e., USDA crop yield data in conjunction with standard, state-specific, university-recommended, yield-goal based equations for calculating N rates from these yields for the period in question.

Approach 1 is used preferentially in the US. Approach 2 (US county scale data) is used if relevant site-specific records are insufficient to establish a baseline N rate.

4.1 Approach 1

The baseline N fertilizer rate is determined from the project proponents' management records that cover at least five years (e.g., continuous monoculture) or six years (e.g., three cycles of a two crop rotation, or two cycles of a three crop rotation) prior to the proposed project implementation year. Determination of the baseline N₂O emissions will be calculated from the average of the previous N rate applications to the same crop(s) as the proposed project crop(s) on the same parcel of land. A worked example of a baseline N rate calculation using Approach 1 is given in **Annex C**.

Records from which the baseline N fertilizer rate can be determined will be required. Examples of these include synthetic fertilizer purchase and application rate records, manure application rate and manure N content data.

4.2 Approach 2

In the US, if the baseline N fertilizer rate for the specific crop(s) cannot be established from project proponent records (Approach 1), then Approach 2 is used. With Approach 2, baseline N fertilizer rate is calculated from crop yield data at the county level, available from United States Department of Agriculture – National Agricultural Statistics Service (USDA – NASS), and equations for determining N fertilizer rate recommendations based on yield goal estimates (e.g., found in state department of agriculture and land grant university agriculture department documents). Approach 2 is not applicable for the calculation of baseline organic N fertilizer rate; this N input is given a value of 0 (zero) by default. This approach is conservative, as any non-verifiable, organic N input during the baseline period will not be accounted for, thereby lowering the baseline value from which N rate reductions can be made. The use of crop yield data from USDA – NASS must be consistent with the crop rotation history of the proposed project site(s). For example, a project field in which corn has been grown in alternate years with soybean for the last six years (2006 – 2011; starting with corn) must use USDA – NASS data for corn yield for the relevant county from 2006, 2008 and 2010 for a project start date of 2012. This requirement reduces the uncertainty in baseline calculation, as county crop yield records for an individual year reflect the prevailing environmental and economic conditions at that time. This requirement also reduces the potential for 'gaming' as project proponents cannot select historical data that might have the effect of artificially increasing the baseline. Moreover, if data demonstrating the crop rotation history on the project site cannot be verified, then the proposed project is ineligible to generate N₂O emissions reductions under this protocol. **Annex C** outlines further information and a worked example of a baseline N rate calculation using Approach 2.

5. ASSESSMENT OF ADDITIONALITY

As recognized by ACR Standard (v. 2.1) to qualify as additional every project must either exceed an approved performance standard, as defined in the relevant methodology, and a regulatory additionality test, or pass the ACR's three-prong test of additionality.

In the US additionality is assessed through a performance standard approach, and 'is demonstrated by showing that a proposed project activity is (1) surplus to regulations, and (2) exceeds a performance standard as defined in an approved methodology.' The relevant performance standard approach for projects in the US is defined in sections 5.1 and 5.2.

Outside the US, the project will be tested for additionality using the three-pronged ACR additionality test as described in the ACR Standard (v. 2.1). The application of an additionality tool⁹ is recommended.

5.1 Regulatory Surplus Test

Consistent with ACR Standard (v. 2.1), project developers pass the Regulatory Surplus Test if there are no 'existing laws, regulations, statutes, legal rulings, or other regulatory frameworks that directly or indirectly affect GHG emissions associated with a project action or its baseline, and which require technical, performance, or management actions.' For proposed projects using this methodology, developers must investigate whether there are regulations in place encompassing project land that require the landowner to reduce the N fertilizer rate below that of the baseline BAU scenario. In determining whether an action is surplus to regulations, ACR does not consider voluntary agreements without an enforcement mechanism, proposed laws or regulations, optional guidelines, or general government policies. Projects that are deemed regulatory surplus are considered surplus for the duration of the crediting period.

Annex D provides more information and presents a non-exhaustive list of regulations dealing with practices that relate to N fertilizer management. Project developers must consider and evaluate the applicability of all such regulations in the context of proposed project activities to satisfy the Regulatory Surplus Test.

5.2 Performance Standard Test

As per ACR Standard (v. 2.1) guidelines, 'under the performance standard approach projects are required to achieve a level of performance that, with respect to emission reductions or removals, or technologies or practices, is significantly better than average compared with similar recently undertaken practices or activities in a relevant geographic area.'

In using this methodology, project proponents in the US must pass a Practice-Based Performance Standard Test. This standard equates the BAU baseline scenario for N fertilizer application with the common practice of producers to apply N fertilizer rates based upon recommendations derived from yield goal calculations known to overestimate crop N needs.

Evidence for the wide-scale historic and continued adoption of this yield goal approach, and therefore its legitimacy as a Performance Standard for testing additionality in US crop-based agriculture is given in **Annex E**. Project developers pass the Performance Standard Test by reducing their N fertilizer rate below the BAU rate, which is also the baseline value for N fertilizer rate for the proposed project. Reductions in N fertilizer rate and therefore N₂O emissions below the BAU rate at the project site (Approach 1), or below the BAU value in the US county where the project is to be conducted (Approach 2), will result in project additionality.

⁹ e.g., <http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-01-v5.2.pdf>

If Approach 2 is to be used then the crop rotation history for the project site must be verifiable (section 4.2). “Gaming” by this avenue is highly unlikely: Producers applying N fertilizer at rates below the calculated county average are likely not maximizing agronomic yields and would be better advised to apply more fertilizer (to achieve higher crop yields) than to apply fertilizer at their historic low rates in order to achieve unwarranted offset credits.

6. EMISSION MEASUREMENTS

All emissions of N₂O (baseline and project, direct and indirect) are reported in units of Megagram of carbon dioxide equivalents (Mg CO₂e). One (1) Mg is equivalent to 1 × 10⁶g or one (1) metric Ton or one (1) tonne.

Emissions for baseline and project period are calculated on a per hectare (ha) of land basis.

Year **t** is the 12-month period following the first input of N fertilizer dedicated to the project crop(s).

Subscripts **B** (e.g., F_{B SN, t}) and **P** (e.g., F_{P SN, t}) distinguish baseline and project terms, respectively.

In calculating direct and indirect emissions of N₂O, the methodology utilizes terminology and rationale presented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (revised Aug. 2011).

6.1 Baseline Emissions

Equation (1) calculates overall baseline emissions:

$$N_2O_{B \text{ total}, t} = N_2O_{B \text{ direct}, t} + N_2O_{B \text{ indirect}, t} + \quad (1)$$

Where:

$N_2O_{B \text{ total}, t}$ Total baseline N₂O emissions, Mg CO₂e ha⁻¹ in year t;

$N_2O_{B \text{ direct}, t}$ Direct baseline N₂O emissions from the project site, Mg CO₂e ha⁻¹ in year t;

$N_2O_{B \text{ indirect}, t}$ Indirect baseline N₂O emissions beyond the project site, Mg CO₂e ha⁻¹ in year t;

6.1.1 Direct Emissions

Method 1

A regionally derived (North Central Region [NCR]) emission factor (EF_{BDM1}) is used in calculations of direct emissions of N₂O for baseline and project scenarios - see **Annex G**.

Equations (2) through (5) calculate direct, baseline N₂O emissions from N fertilization for Method 1:

$$N_2O_{B \text{ direct}, t} = (F_{B \text{ SN}, t} + F_{B \text{ ON}, t}) * EF_{BDM1} * N_2O_{MW} * N_2O_{GWP} \quad (2)$$

$$F_{B \text{ SN}, t} = M_{B \text{ SF}, t} * NC_{B \text{ SF}} \quad (3)$$

$$F_{B \text{ ON}, t} = M_{B \text{ OF}, t} * NC_{B \text{ OF}} \quad (4)$$

$$EF_{BDM1} = 6.7 * 10^{-4} * (\exp [6.7 * (F_{B\ SN,t} + F_{B\ ON,t})] - 1) / (F_{B\ SN,t} + F_{B\ ON,t}) \quad (5)$$

Where:

$F_{B\ SN,t}$	Baseline synthetic N fertilizer applied, Mg N ha ⁻¹ in year t;
$F_{B\ ON,t}$	Baseline organic N fertilizer applied, Mg N ha ⁻¹ in year t;
$M_{B\ SF,t}$	Mass of baseline N-containing synthetic fertilizer applied, Mg ha ⁻¹ in year t;
$M_{B\ OF,t}$	Mass of baseline N-containing organic fertilizer applied, Mg ha ⁻¹ in year t;
$NC_{B\ SF}$	N content of baseline synthetic fertilizer applied, g N (100g fertilizer) ⁻¹ ;
$NC_{B\ OF}$	N content of baseline organic fertilizer applied g N (100g fertilizer) ⁻¹ ;
EF_{BDM1}	Emission factor for baseline direct N ₂ O emissions from N inputs Mg N ₂ O–N (Mg N input) ⁻¹ . See Annex G for full description of emission factor calculation;
N_2O_{MW}	Ratio of molecular weights of N ₂ O to N (44/28), Mg N ₂ O (Mg N) ⁻¹ ;
N_2O_{GWP}	Global Warming Potential for N ₂ O, Mg CO ₂ e (Mg N ₂ O) ⁻¹ (IPCC default = 310. See Annex F).

Method 2

Equations (3), (4), and (6) calculate direct, baseline N₂O emissions from N fertilization for Method 2:

$$N_2O_{B\ direct,t} = (F_{B\ SN,t} + F_{B\ ON,t}) * EF_{BDM2} * N_2O_{MW} * N_2O_{GWP} \quad (6)$$

$$F_{B\ SN,t} = M_{B\ SF,t} * NC_{B\ SF} \quad (3)$$

$$F_{B\ ON,t} = M_{B\ OF,t} * NC_{B\ OF} \quad (4)$$

Where:

$F_{B\ SN,t}$	Baseline synthetic N fertilizer applied, Mg N ha ⁻¹ in year t;
$F_{B\ ON,t}$	Baseline organic N fertilizer applied, Mg N ha ⁻¹ in year t;
$M_{B\ SF,t}$	Mass of baseline N-containing synthetic fertilizer applied, Mg ha ⁻¹ in year t;
$M_{B\ OF,t}$	Mass of baseline N-containing organic fertilizer applied, Mg ha ⁻¹ in year t;
$NC_{B\ SF}$	N content of baseline synthetic fertilizer applied, g N (100g fertilizer) ⁻¹ ;
$NC_{B\ OF}$	N content of baseline organic fertilizer applied g N (100g fertilizer) ⁻¹ ;

EF_{BDM2}	Emission factor for baseline direct N ₂ O emissions from N inputs Mg N ₂ O–N (Mg N input) ⁻¹ (IPCC default Tier 1 = 0.01. See Annex F);
N_2O_{MW}	Ratio of molecular weights of N ₂ O to N (44/28), Mg N ₂ O (Mg N) ⁻¹ ;
N_2O_{GWP}	Global Warming Potential for N ₂ O, Mg CO ₂ e (Mg N ₂ O) ⁻¹ (IPCC default = 310. See Annex F).

After application to soil, the amounts of applied synthetic N fertilizer ($F_{B\ SN, t}$) and of applied organic N fertilizer ($F_{B\ ON, t}$) are not adjusted for NH₃ and NO_x volatilization for method 1 or method 2. This is in accordance with 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Chapter 11, Note 11, revised Aug. 2011).

Using Approach 2 (section 6.2), the calculated baseline N fertilizer rate represents the product of the mass and the N content of the synthetic N containing fertilizer ($M_{B\ SF, t} * NC_{B\ SF}$). As such, it can be substituted into equation 3 to calculate $F_{B\ SN, t}$. Approach 2 is not applicable for the calculation of the baseline organic fertilizer N rate. The value of $F_{B\ ON, t}$ is 0 (zero) by default.

6.1.2 Indirect Emissions

Equations (7) through (9) calculate baseline indirect N₂O emissions from N fertilization:

$$N_2O_{B\ indirect, t} = N_2O_{B\ volatil, t} + N_2O_{B\ leach, t} \quad (7)$$

$$N_2O_{B\ volatil, t} = [(F_{B\ SN, t} * \text{Frac}_{GASF}) + (F_{B\ ON, t} * \text{Frac}_{GASM})] * EF_{BIV} * N_2O_{MW} * N_2O_{GWP} \quad (8)$$

$$N_2O_{B\ leach, t} = (F_{B\ SN, t} + F_{B\ ON, t}) * \text{Frac}_{LEACH} * EF_{BIL} * N_2O_{MW} * N_2O_{GWP} \quad (9)$$

Where:

$N_2O_{B\ indirect, t}$ Indirect baseline N₂O emissions beyond the project site, Mg CO₂e ha⁻¹ in year t;

$N_2O_{B\ volatil, t}$ Indirect baseline N₂O emissions produced from atmospheric deposition of N volatilized as a result of N application at the project site, Mg CO₂e ha⁻¹ in year t;

$N_2O_{B\ leach, t}$ Indirect baseline N₂O emissions produced from leaching and runoff of N in regions where leaching and runoff occurs, as a result of N application at the project site, Mg CO₂e ha⁻¹ in year t;

$F_{B\ SN, t}$ Baseline synthetic N fertilizer applied, Mg N ha⁻¹ in year t;

$F_{B\ ON, t}$ Baseline organic N fertilizer applied, Mg N ha⁻¹ in year t;

Frac_{GASF} Fraction of all synthetic N added to baseline soils that volatilizes as NH₃ and NO_x, dimensionless (IPCC default Tier 1 = 0.10. See Annex F);

Frac_{GASM} Fraction of all organic N added to baseline soils that volatilizes as NH₃ and NO_x, dimensionless (IPCC default Tier 1 = 0.20. See Annex F);

Frac _{LEACH}	Fraction of N added (synthetic or organic) to baseline soils that is lost through leaching and runoff, in regions where leaching and runoff occurs, dimensionless (IPCC default Tier 1 = 0.30. See Annex A and F);
EF _{BIV}	Emission factor for baseline N ₂ O emissions from atmospheric deposition of N on soils and water surfaces, [Mg N ₂ O–N (Mg NH ₃ –N + NO _x –N volatilized) ⁻¹] (IPCC default Tier 1 = 0.01. See Annex F);
EF _{BIL}	Emission factor for baseline N ₂ O emissions from N leaching and runoff, Mg N ₂ O–N (Mg N leached and runoff) ⁻¹ (IPCC default Tier 1 = 0.0075. See Annex F);
N ₂ O _{MW}	Ratio of molecular weights of N ₂ O to N (44/28), Mg N ₂ O (Mg N) ⁻¹ ;
N ₂ O _{GWP}	Global Warming Potential for N ₂ O, Mg CO ₂ e (Mg N ₂ O) ⁻¹ (IPCC default = 310. See Annex F).

At project sites where leaching and runoff do not occur (see **Annex A**), indirect N₂O emissions are calculated by removing the factor N₂O_{B leach, t} from equation (7).

6.2 Project Activity Emissions

Equation (10) calculates overall project emissions:

$$N_2O_{P \text{ total}, t} = N_2O_{P \text{ direct}, t} + N_2O_{P \text{ indirect}, t} \quad (10)$$

Where:

N₂O_{P total, t} Total project N₂O emissions, Mg CO₂e ha⁻¹ in year t;

N₂O_{P direct, t} Direct project N₂O emissions from the project site, Mg CO₂e ha⁻¹ in year t;

N₂O_{P indirect, t} Indirect project N₂O emissions beyond the project site, Mg CO₂e ha⁻¹ in year t;

6.2.1 Direct Emissions

Method 1

A regionally derived (North Central Region [NCR]) equation is used to calculate direct emissions of N₂O for baseline and project scenarios - see **Annex G**.

Equations (11) through (14) calculate direct, project N₂O emissions from N fertilization:

$$N_2O_{P \text{ direct}, t} = (F_{P \text{ SN}, t} + F_{P \text{ ON}, t}) * EF_{PDM1} * N_2O_{MW} * N_2O_{GWP} \quad (11)$$

$$F_{P \text{ SN}, t} = M_{P \text{ SF}, t} * NC_{P \text{ SF}} \quad (12)$$

$$F_{P \text{ ON}, t} = M_{P \text{ OF}, t} * NC_{P \text{ OF}} \quad (13)$$

$$EF_{PDM1} = 6.7 * 10^{-4} * (\exp [6.7 * (F_{P\,SN,t} + F_{P\,ON,t})] - 1) / (F_{P\,SN,t} + F_{P\,ON,t}) \quad (14)$$

Where:

$F_{P\,SN,t}$	Project synthetic N fertilizer applied, Mg N ha ⁻¹ in year t;
$F_{P\,ON,t}$	Project organic N fertilizer applied, Mg N ha ⁻¹ in year t;
$M_{P\,SF,t}$	Mass of project N-containing synthetic fertilizer applied, Mg ha ⁻¹ in year t;
$M_{P\,OF,t}$	Mass of project N-containing organic fertilizer applied, Mg ha ⁻¹ in year t;
$NC_{P\,SF}$	N content of project synthetic fertilizer applied g N (100g fertilizer) ⁻¹ ;
$NC_{P\,OF}$	N content of project organic fertilizer applied g N (100g fertilizer) ⁻¹ ;
EF_{PDM1}	Emission factor for project direct N ₂ O emissions from N inputs, Mg N ₂ O–N (Mg N input) ⁻¹ . See Annex G for full description of emission factor calculation
N_2O_{MW}	Ratio of molecular weights of N ₂ O to N (44/28), Mg N ₂ O (Mg N) ⁻¹ ;
N_2O_{GWP}	Global Warming Potential for N ₂ O, Mg CO ₂ e (Mg N ₂ O) ⁻¹ (IPCC default = 310. See Annex F).

Method 2

Equations (12), (13), and (15) calculate direct, project N₂O emissions from N fertilization for Method 2:

$$N_2O_{P\,direct,t} = (F_{P\,SN,t} + F_{P\,ON,t}) * EF_{PDM2} * N_2O_{MW} * N_2O_{GWP} \quad (15)$$

$$F_{P\,SN,t} = M_{P\,SF,t} * NC_{P\,SF} \quad (12)$$

$$F_{P\,ON,t} = M_{P\,OF,t} * NC_{P\,OF} \quad (13)$$

Where:

$F_{P\,SN,t}$	Project synthetic N fertilizer applied, Mg N ha ⁻¹ in year t;
$F_{P\,ON,t}$	Project organic N fertilizer applied, Mg N ha ⁻¹ in year t;
$M_{P\,SF,t}$	Mass of project N-containing synthetic fertilizer applied, Mg ha ⁻¹ in year t;
$M_{P\,OF,t}$	Mass of project N-containing organic fertilizer applied, Mg ha ⁻¹ in year t;
$NC_{P\,SF}$	N content of project synthetic fertilizer applied g N (100g fertilizer) ⁻¹ ;
$NC_{P\,OF}$	N content of project organic fertilizer applied g N (100g fertilizer) ⁻¹ ;

EF_{PDM2}	Emission factor for project N ₂ O emissions from N inputs, Mg N ₂ O–N (Mg N input) ⁻¹ (IPCC default = 0.01. See Annex F)
N_2O_{MW}	Ratio of molecular weights of N ₂ O to N (44/28), Mg N ₂ O (Mg N) ⁻¹ ;
N_2O_{GWP}	Global Warming Potential for N ₂ O, Mg CO ₂ e (Mg N ₂ O) ⁻¹ (IPCC default = 310. See Annex F).

After application to soil, the amounts of applied synthetic N fertilizer ($F_{B\ SN, t}$) and of applied organic N fertilizer ($F_{B\ ON, t}$), are not adjusted for NH₃ and NO_x volatilization for method 1 or method 2. This is in accordance with 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Chapter 11, Note 11, revised Aug. 2011).

6.2.2 Indirect Emissions

Equations (16) through (18) calculate indirect, project N₂O emissions from N fertilization:

$$N_2O_{P\ indirect, t} = N_2O_{P\ volatil, t} + N_2O_{P\ leach, t} \quad (16)$$

$$N_2O_{P\ volatil, t} = [(F_{P\ SN, t} * Frac_{GASF}) + (F_{P\ ON, t} * Frac_{GASM})] * EF_{PIV} * N_2O_{MW} * N_2O_{GWP} \quad (17)$$

$$N_2O_{P\ leach, t} = (F_{P\ SN, t} + F_{P\ ON, t}) * Frac_{LEACH} * EF_{PIL} * N_2O_{MW} * N_2O_{GWP} \quad (18)$$

Where:

$N_2O_{P\ indirect, t}$	Indirect project N ₂ O emissions beyond the project site, Mg CO ₂ e ha ⁻¹ in year t;
$N_2O_{P\ volatil, t}$	Indirect project N ₂ O emissions produced from atmospheric deposition of N volatilized as a result of N application at the project site, Mg CO ₂ e ha ⁻¹ in year t;
$N_2O_{P\ leach, t}$	Indirect project N ₂ O emissions produced from leaching and runoff of N in regions where leaching and runoff occurs, as a result of N application at the project site, Mg CO ₂ e ha ⁻¹ in year t;
$F_{P\ SN, t}$	Project synthetic N fertilizer applied, Mg N ha ⁻¹ in year t;
$F_{P\ ON, t}$	Project organic N fertilizer applied, Mg N ha ⁻¹ in year t;
$Frac_{GASF}$	Fraction of all synthetic N added to project soils that volatilizes as NH ₃ and NO _x , dimensionless (IPCC default Tier 1 = 0.10. See Annex F);
$Frac_{GASM}$	Fraction of all organic N added to project soils that volatilizes as NH ₃ and NO _x , dimensionless (IPCC default Tier 1 = 0.20. See Annex F);
$Frac_{LEACH}$	Fraction of N added (synthetic or organic) to project soils that is lost through leaching and runoff, in regions where leaching and runoff occurs, dimensionless (IPCC default Tier 1 = 0.30. See Annex A and F);

EF _{PIV}	Emission factor for project N ₂ O emissions from atmospheric deposition of N on soils and water surfaces, [Mg N ₂ O–N (Mg NH ₃ –N + NO _x –N volatilized) ⁻¹] (IPCC default Tier 1 = 0.01. See Annex F);
EF _{PIL}	Emission factor for project N ₂ O emissions from N leaching and runoff, Mg N ₂ O–N (Mg N leached and runoff) ⁻¹ (IPCC default Tier 1 = 0.0075. See Annex F);
N ₂ O _{MW}	Ratio of molecular weights of N ₂ O to N (44/28), Mg N ₂ O (Mg N) ⁻¹ ;
N ₂ O _{GWP}	Global Warming Potential for N ₂ O, Mg CO ₂ e (Mg N ₂ O) ⁻¹ (IPCC default = 310. See Annex F).

At project sites where leaching and runoff do not occur (see **Annex A**), project indirect N₂O emissions are calculated by removing the factor N₂O_{P_{leach, t}} from equation (18).

7. LEAKAGE AND PERMANENCE

As defined by ACR Standard (v. 2.1) ‘leakage is an increase in GHG emissions or decrease in sequestration outside the project boundaries that occurs because of the project action.’

As the project site is being actively maintained for commodity production during the project-crediting period, leakage risks are negligible for ALM projects involving cropland management activities. Crop producers are highly risk averse and so are unlikely to intentionally suffer reduced crop yields in exchange for marginally increased revenue associated with ERTs from reducing N fertilization rates in a manner that affects expected crop yields.

Reducing N rates by adopting N rates based on economic optimization will not result in a significant reduction in average crop yield. Using extensive historical and current data from seven Midwestern states at typical crop-to-fertilizer price ratios, the largest average reduction in corn yield brought about by lowering N fertilizer rate to the economic optimum from the agronomic optimum is expected to be 0-3% (Iowa State University Agronomy Extension). Consequently, with no or negligible reduction in productivity within the project boundary, there will be no associated incentive or requirement for a shift of activity or increased production outside of the project boundary, which might then result in increased N fertilizer use and N₂O emissions. The leakage potential is therefore negligible.

Moreover, although accounting for ‘positive leakage’ is not eligible, less available N in the soil will result in a reduction in other gaseous and hydrologic N pollutants (e.g., NH₃, NO_x, and NO₃⁻). In the same manner, any increases in yield will lead to positive leakage, but these benefits are also not quantified or credited.

Nitrous oxide emission reductions associated with reducing N fertilizer rate are permanent and cannot be reversed. Therefore, use of this methodology does not require any buffer or other risk mitigation mechanism to be used (section 9).

8. UNCERTAINTY ASSESSMENT

In accordance with ACR Standard (v. 2.1), methodologies submitted to ACR should include information and procedures for estimating uncertainty relevant to the project and baseline scenario.

Annex F (Table FI) provides information on uncertainty ranges for IPCC Tier 1 emissions factors for direct and indirect N₂O emissions and other factors used in the methodology. Use of these IPCC emissions factors is universally accepted as a mechanism for calculating N₂O emissions – they are science driven and used in many currently accepted AFOLU methodologies for calculating N₂O emissions. Further details on these factors, their derivation and their robustness for use in N₂O emissions calculations can be found in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Revision Aug. 2011 - Chapter 11: N₂O Emissions from Managed Soils, and CO₂ Emissions from Lime and Urea Application.

The uncertainty associated with a reduction in direct N₂O emissions brought about by a reduction in N rate between the baseline period and the project period using Method 1 is calculated using equation (19):

$$N_2O \text{ Emissions}_{(RED UNC)} = [1 - \{0.63 * \exp(-40 * [N_{Proj}]^2)\}] * 100 \quad (19)$$

Where:

$N_2O \text{ Emissions}_{(RED UNC)}$ = Uncertainty in N₂O emissions reductions associated with a reduction in N rate, %;

N_{Proj} = $F_{P SN,t} + F_{P ON,t}$ (project N input), Mg N ha⁻¹ yr⁻¹.

Equation (19) is applicable to projects that determine their baseline N rate (and therefore baseline direct N₂O emissions) using either Approach 1 or Approach 2 (section 4). Further details of how emissions uncertainty is derived are given in Annex G.

Project proponents will use equation (19) to calculate emissions reductions uncertainty (%) for a project.

Credit award deductions as a result of uncertainty will be derived from the conservativeness factors specified in the Clean Development Mechanism (CDM) Methodology Panel guidance on addressing uncertainty in its Thirty Second Meeting Report, Annex 14 (Table 2 below).

Table 2. Conservativeness factors and uncertainty deduction for N₂O emissions reductions based upon uncertainty at 95% confidence level.

Uncertainty range at 95% confidence level of project emissions reductions [#]	Conservativeness factor	Uncertainty deduction*
< ± 15%	1.000	0.000
> ± 15% ≤ ± 30%	0.943	0.057
> ± 30% ≤ ± 50%	0.893	0.107
> ± 50% ≤ ± 100%	0.836	0.164

[#] Where uncertainty in emissions reductions is < ± 15%, no deductions will be applied. Uncertainty in emissions reductions does not exceed 100% (see Annex G). * Uncertainty deduction (UNC) = (1 – Conservativeness factor). See equation (20) in section 9.

Activity data: With Approach 1, the data used to calculate the synthetic and organic fertilizer N input (i.e., the terms $M_{SF,t}$, $M_{OF,t}$, NC_{SF} , and NC_{OF}) will be derived and verified using project proponent, site-specific management records (section 11.1). There is therefore negligible uncertainty in determining the baseline and project activity data from which N₂O emissions are calculated; no uncertainty deductions for activity data are made when using Approach 1. Using Approach 2 for baseline N rate determination increases activity data uncertainty; baseline N rate is generated from county level not site specific data.

However, as detailed in sections 4.2 and 5.2, Approach 2 is conservative by design, and its use will likely lead to the generation of baseline N rates that are lower than those from site-specific records. A lower baseline N rate limits the potential for substantial N rate reductions without a crop productivity decline (a major disincentive for altering N management practice and project adoption; section 7), thereby greatly reducing the benefit from potential ‘gaming’ (section 5.2).

Management practices: Project proponents will be required to provide specific information for on-farm practices relating to N fertilizer management, which will adhere to BMPs (section 2.2.1). These will be verified prior to and during the project crediting period, therefore uncertainty will be negligible.

9. EMISSION REDUCTIONS AND CALCULATION OF ERTs

Equation (20) calculates the N₂O emission reductions brought about by project implementation:

$$N_{2O_{PR,t}} = [(N_{2O_{B\ total,t}} - N_{2O_{P\ total,t}}) * A_p] * (1 - LK) * (1 - UNC) \quad (20)$$

Where:

$N_{2O_{PR,t}}$ Reduction in total N₂O emissions brought about by project implementation, Mg CO₂e in year t;

$N_{2O_{B\ total,t}}$ Total baseline N₂O emissions within the project spatial boundary as a result of N application at the project site, Mg CO₂e ha⁻¹ in year t;

$N_{2O_{P\ total,t}}$ Total project N₂O emissions within the project spatial boundary as a result of N application at the project site, Mg CO₂e ha⁻¹ in year t;

A_p Project area, ha

LK Leakage deduction (here set = 0 as described in section 7)

UNC Uncertainty deduction (set as in Table 2 [right hand column] in this methodology).

Equation (21) calculates the amount of ERTs that can be issued:

$$ERT_t = N_{2O_{PR,t}} * (1 - BUF) \quad (21)$$

Where:

ERT_t Emission Reduction Tonnes (ERTs) at time t, Mg CO₂e;

BUF Buffer deduction (here set = 0 as described in section 7).

9.1 Retroactive Crediting

To incentivize the collection of N₂O emissions data and the development of emissions factors compatible with IPCC Tier 2 methodologies (IPCC 2006), ACR will allow the option of retroactive crediting for projects initially credited under Categories 2 and 3.

Projects eligible under Category 2 will initially receive credits based upon the IPCC Tier 1 emissions factor (0.01 (1%)). If through field experimentation and data collection during the project crediting period, project developers can show that the emissions factor is >1% for the project site(s), then upon publication of the results in a peer-reviewed journal (or notice of accepted publication) and positive review by ACR reviewers, the higher emissions factor would be used to 1) award credits at the higher rate for the remainder of the project crediting period, and 2) retroactively award credits based upon the difference between the emissions factors for years in which the 1% value was used. The project would be re-assigned to Category 3.

Projects initially assigned under Category 3 may also submit revised emissions factors for their project site(s).

During the project crediting period, a project developer may submit revised emissions factors for verification no more than once per cropping season (for an individual crop), per project site.

10. DATA AND PARAMETERS

10.1 Data and Parameters Not Monitored

Parameter:	$M_{B\ SF, t}$
Data unit:	$Mg\ ha^{-1}\ yr^{-1}$
Description:	Mass of baseline synthetic N containing fertilizer applied
Source of data:	Project proponent records (Approach 1)
Measurement procedures:	
Any comment:	Approach 2 calculates baseline fertilizer N rate = $(M_{B\ SF, t} * NC_{B\ SF})$, and is substituted into equation 3 to calculate $F_{B\ SN, t}$.

Parameter:	$M_{B\ OF, t}$
Data unit:	$Mg\ ha^{-1}\ yr^{-1}$
Description:	Mass of baseline organic N containing fertilizer applied
Source of data:	Project proponent records (Approach 1)
Measurement procedures:	
Any comment:	Approach 2 is not applicable for the calculation of $M_{B\ OF, t}$.

Parameter:	$NC_{B\ SF}$
Data unit:	$g\ N\ (100g\ fertilizer)^{-1}$
Description:	Nitrogen content of baseline synthetic fertilizer applied
Source of data:	Project proponent records (Approach 1)
Measurement procedures:	

Any comment:	Approach 2 calculates baseline fertilizer N rate = $(M_{B\ SF, t} * NC_{B\ SF})$, and is substituted into equation 3 to calculate $F_{B\ SN, t}$.
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Parameter:	$NC_{B\ OF}$
Data unit:	g N (100g fertilizer) ⁻¹
Description:	Nitrogen content of baseline organic fertilizer applied
Source of data:	Project proponent records (Approach 1)
Measurement procedures:	
Any comment:	Approach 2 is not applicable for the calculation of $N_{CB\ OF}$.

Parameter:	Baseline Crop yield
Data unit:	Mg ha ⁻¹ yr ⁻¹
Description:	Crop yield (standard reporting method for particular crop, e.g., dry grain yield)
Source of data:	County level data (Approach 2)
Measurement procedures:	
Any comment:	

Parameter:	Baseline Crop area
Data unit:	Hectare (ha)
Description:	Area of crop(s) planted, from which baseline fertilizer N rate determined
Source of data:	Project proponent records (Approach 1 and 2)
Measurement procedures:	
Any comment:	

Parameter:	Frac _{GASF}
Data unit:	dimensionless
Description:	Fraction of all synthetic N added to project soils that volatilizes as NH ₃ and NO _x
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.10)
Measurement procedures:	
Any comment:	

Parameter:	Frac _{GASM}
Data unit:	dimensionless
Description:	Fraction of all organic N added to project soils that volatilizes as NH ₃ and NO _x
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.20)
Measurement procedures:	
Any comment:	

Parameter:	Frac _{LEACH}
Data unit:	dimensionless

Description:	Fraction of N added (synthetic or organic) to project soils that is lost through leaching and runoff, in regions where leaching and runoff occurs
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.30)
Measurement procedures:	
Any comment:	

Parameter:	EF _{BDM1}
Data unit:	Mg N ₂ O–N (Mg N input) ⁻¹
Description:	Emission factor for baseline direct N ₂ O emissions from N inputs (Method 1)
Source of data:	Empirical research on producer fields throughout Michigan
Measurement procedures:	
Any comment:	Parameter only valid in North Central Region of the US (Annex G; Hoben et al. 2011).

Parameter:	EF _{BDM2}
Data unit:	Mg N ₂ O–N (Mg N input) ⁻¹
Description:	Emission factor for baseline direct N ₂ O emissions from N inputs (Method 2)
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.01)
Measurement procedures:	
Any comment:	

Parameter:	EF _{BIV}
Data unit:	Mg N ₂ O–N (Mg NH ₃ –N + NO _x –N volatilized) ⁻¹
Description:	Emission factor for baseline N ₂ O emissions from atmospheric deposition of N on soils and water surfaces
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.01)
Measurement procedures:	
Any comment:	

Parameter:	EF _{BIL}
Data unit:	Mg N ₂ O–N (Mg N leached and runoff) ⁻¹
Description:	Emission factor for baseline N ₂ O emissions from N leaching and runoff,
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.0075)
Measurement procedures:	
Any comment:	

Parameter:	EF _{PDMI}
Data unit:	Mg N ₂ O–N (Mg N input) ⁻¹

Description:	Emission factor for project direct N ₂ O emissions from N inputs (Method 1)
Source of data:	Empirical research on producer fields throughout Michigan
Measurement procedures:	
Any comment:	Parameter only valid in North Central Region of the US (Annex G; Hoben et al. 2011).

Parameter:	EF _{PDM2}
Data unit:	Mg N ₂ O-N (Mg N input) ⁻¹
Description:	Emission factor for project direct N ₂ O emissions from N inputs (Method 2)
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.01)
Measurement procedures:	
Any comment:	

Parameter:	EF _{PIV}
Data unit:	Mg N ₂ O-N (Mg NH ₃ -N + NO _x -N volatilized) ⁻¹
Description:	Emission factor for project N ₂ O emissions from atmospheric deposition of N on soils and water surfaces
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.01)
Measurement procedures:	
Any comment:	

Parameter:	EF _{PIL}
Data unit:	Mg N ₂ O-N (Mg N leached and runoff) ⁻¹
Description:	Emission factor for project N ₂ O emissions from N leaching and runoff,
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories (default Tier 1 = 0.0075)
Measurement procedures:	
Any comment:	

11. MONITORING PROCEDURE

The Project Proponent must provide sufficient geographic and physical information in the Project Document to allow for the unique identification and delineation of the extent of the project site(s). This can be achieved by field survey (e.g., using GPS), or by using geo-referenced spatial data (e.g., maps, GIS datasets, orthorectified aerial photography, or geo-referenced remote sensing images).

11.1 Data and Parameters Monitored

The following parameters must be monitored during the project activity.

Parameter:	$M_{P_{SF,t}}$
Data unit:	$Mg\ N\ yr^{-1}$
Description:	Mass of project synthetic N containing fertilizer applied
Source of data:	Project proponent records
Measurement procedures:	Generally accepted field application methods using calibrated applicators of known capacity for fertilizer mass or volume determination
Any comment:	

Parameter:	$M_{P_{OF,t}}$
Data unit:	$Mg\ N\ yr^{-1}$
Description:	Mass of project organic N containing fertilizer applied
Source of data:	Project proponent records
Measurement procedures:	Generally accepted methods using calibrated applicators of known weight/volume for liquid and solid organic material application
Any comment:	

Parameter:	$NC_{P_{SF}}$
Data unit:	$g\ N\ (100g\ fertilizer)^{-1}$
Description:	Nitrogen content of project synthetic fertilizer applied
Source of data:	Project proponent records
Measurement procedures:	Generally accepted procedures for sampling, handling and analysis of bulk fertilizer
Any comment:	Verify fertilizer is from accredited source*

Parameter:	$NC_{P_{OF}}$
Data unit:	$g\ N\ (100g\ fertilizer)^{-1}$
Description:	Nitrogen content of project organic fertilizer applied
Source of data:	Project proponent records
Measurement procedures:	Generally accepted sampling and handling procedures for organic materials. Laboratory analysis for total N using total Kjeldahl Nitrogen [TKN] or total N by combustion
Any comment:	

Parameter:	Project Crop area
Data unit:	Hectare (ha)
Description:	Area of crop(s) planted, from which project fertilizer N rate determined
Source of data:	Project proponent records
Measurement procedures:	
Any comment:	

* The formulation of the synthetic N containing fertilizer will also be verified. From this, the N content (% of mass) can be determined. Farmers' records will be crosschecked with records from synthetic and organic N fertilizer suppliers. In case of discrepancies between the records of the farmers and those from suppliers of synthetic and organic N containing fertilizers, the most conservative value(s) will be taken.

ANNEX A: EQUATIONS FOR DETERMINING IF LEACHING AND RUNOFF OCCUR AT PROJECT SITE

The approach uses default (Tier 1) values for leaching and run-off from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Revised August 2011), and the ratio of growing season values of precipitation to potential evapotranspiration.

A project site is considered to have a $\text{Frac}_{\text{LEACH}}$ default value of $0.30 \text{ kg N (kg N additions)}^{-1}$ when:

$$\text{Precip}_{\text{GS}} / \text{PET}_{\text{GS}} \geq 1.00 \quad (\text{A1})$$

A project site is considered to have a $\text{Frac}_{\text{LEACH}}$ default value of $0.00 \text{ kg N (kg N additions)}^{-1}$ when:

$$\text{Precip}_{\text{GS}} / \text{PET}_{\text{GS}} < 1.00 \quad (\text{A2})$$

Where:

$\text{Precip}_{\text{GS}}$ = Precipitation during the growing season, mm;

PET_{GS} = Potential evapotranspiration during the growing season, mm.

The growing season is considered to occur from May – September inclusive, unless otherwise verifiable. Planting and harvesting or frost records can be used to verify that the growing season is other than May – September. While this period is appropriate for corn over most of the NCR, in southern parts of the US corn can be planted a number of weeks prior to the beginning of May. Also, for example, if winter annual crops such as winter wheat and fall canola are grown, the appropriate growing season may be October – July.

Where crop irrigation is employed, irrigation water is considered equivalent to rainfall, and as such, project proponents will add irrigation water input to precipitation data to calculate total precipitation during the growing season. Water from drip irrigation is excluded.

Average values for precipitation and irrigation water and potential evapotranspiration for baseline determination are calculated from the same time period used to determine baseline fertilizer N rate, i.e., consistent with project proponents' records (Approach 1) or county level data (Approach 2).

Information sources for determining if leaching and runoff occur at project site

If site-specific data for precipitation and potential evapotranspiration are not readily available, data from local meteorological stations can be used. A centralized information source to identify these stations in the US can be found at the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) station information webpage: <http://www.weather.gov/tg/siteloc.shtml>. Archived data for all US meteorological sites is at the National Climatic Data Center (NCDC): <http://lwf.ncdc.noaa.gov/oa/climate/stationlocator.html>.

Individual US states may also have meteorological data available through academic or other institutions. In Michigan for example, annual precipitation and potential evapotranspiration data can be obtained from Enviro-weather (formerly MAWN) <http://www.agweather.geo.msu.edu/mawn>.

Potential Evapotranspiration (PET) at project sites may also be calculated using the FAO Penman–Monteith equation. More information can be found in Allen et al. (1998).

ANNEX B: EVIDENCE FOR EXCLUDING SOIL C IN METHODOLOGY ACCOUNTING

In this methodology, reductions in fertilizer N rate resulting from project implementation are not considered to result in significant (>3% of the total CO₂e benefits from reduction in N₂O emissions) decreases in soil C stock. Evidence from the literature presented below justifies exclusion of this C pool.

N fertilizer can increase soil C stocks by increasing crop growth and associated rates of crop residue production. Because this protocol will not result in significant crop growth (yield) declines and therefore no declines in residue inputs, there can be no associated decline in soil C stocks. In fact available evidence suggests that excess N can speed decomposition (Parton et al. 2007) and thereby lower (Khan et al. 2007) or maintain (Russell et al. 2009) C stocks that might otherwise increase, suggesting that this protocol may, if anything, promote soil C sequestration. We nevertheless make no such claim.

Therefore, soil C pools are not monitored, as their exclusion will lead to a conservative estimate of the number of ERTs generated by a project.

ANNEX C: CALCULATING BASELINE N FERTILIZER RATE

Approach 1

The baseline fertilizer N rate is determined from the project proponent's management records for at least the previous five years (monoculture) or six years (e.g., three cycles of a two crop rotation, or two cycles of a three crop rotation) prior to the proposed project implementation year.

Baseline N₂O emissions are calculated from an average of the previous N rate applications to the crop(s).

Worked example

Calculating baseline fertilizer N rate for corn in a corn–soybean rotation

For a proposed project beginning in 2012, a producer (project proponent) has applied the following N fertilizer rates to a corn–soybean rotation in the previous 6 years (3 rotations, Table C1).

Table C1. Fertilizer N rates applied to a corn (C) – soybean (S) rotation (2006 – 2011).

Year	Crop	Synthetic Fertilizer N rate (kg N ha ⁻¹ yr ⁻¹)	Organic Fertilizer N rate (kg N ha ⁻¹ yr ⁻¹)	Total Fertilizer N rate (kg N ha ⁻¹ yr ⁻¹)
2006	C	180	20	200
2007	S	0	10	10
2008	C	160	30	190
2009	S	20	0	20
2010	C	190	20	210
2011	S	0	0	0
2006–2011 Average	S	(0+20+0)/3 ≈ 6.7	(10+0+0)/3 ≈ 3.3	(10+20+0)/3 ≈ 10
2006–2011 Average	C	(180+160+190)/3 ≈ 177	(20+30+20)/3 ≈ 23	(200+190+210)/3 = 200
2006–2011 Average	C–S	(180+0+160+20+190+0)/6 ≈ 92	(20+10+30+0+20+0)/6 ≈ 13	(200+10+190+20+210+0)/6 = 105

The baseline fertilizer N rate for a corn crop in the proposed project to be planted in 2012 is calculated from the average of the total fertilizer N rate applied to the previous 3 corn crops during the previous 6 years, i.e., = (200 + 190 + 210)/3 = 200 kg N ha⁻¹ yr⁻¹. Reductions from this baseline rate are considered additional and are credited.

N.B. The baseline synthetic and organic fertilizer N rate (Table C1) in each year (t) is calculated from: (M_{BSF,t} * NC_{BSF}) and (M_{BOF,t} * NC_{BOF}), respectively,

Where:

M_{BSF,t} Mass of baseline N containing synthetic fertilizer applied, Mg ha⁻¹ in year t;

$M_{B\ OF, t}$	Mass of baseline N containing organic fertilizer applied, Mg ha ⁻¹ in year t;
$NC_{B\ SF}$	Nitrogen content of baseline synthetic fertilizer applied g N (100g fertilizer) ⁻¹ ;
$NC_{B\ OF}$	Nitrogen content of baseline organic fertilizer applied g N (100g fertilizer) ⁻¹ ;

Approach 2

If the baseline fertilizer N rate cannot be determined from project proponent records (Approach 1), then Approach 2 is used. With Approach 2, the baseline fertilizer N rate is calculated from crop yield data at the county level (available from the United States Department of Agriculture – National Agricultural Statistics Service (USDA – NASS)) and equations for determining fertilizer N rate recommendations based on yield goal estimates (found in e.g., state department of agriculture and university agricultural extension documents). The baseline fertilizer N rate value calculated using Approach 2 represents the product of the mass and the N content of the synthetic N containing fertilizer, i.e., $M_{B\ SF, t} * NC_{B\ SF}$. Approach 2 is not applicable for the calculation of the baseline organic fertilizer N rate. This value of $F_{B\ ON, t}$ is taken as 0 (zero).

Worked example

Calculating baseline N fertilizer rate for corn in a corn–soybean rotation in Tuscola County, Michigan.

From the methodology eligibility conditions, section 2.2.1, “During a project-crediting period, adherence to Best Management Practices (BMPs) as they relate to the application of synthetic and organic N fertilizer at the cropping site is required.”

For a project developer based in Michigan, the Michigan Department of Agriculture publication Generally Accepted Agricultural Management Practices (GAAMP) for Nutrient Utilization, (2012) is consulted. This publication recommends the Michigan State University (MSU) Extension Bulletin E–2904 – Nutrient Recommendations for Field Crops in Michigan (Warncke et al. 2004), for selecting the appropriate rate of N fertilizer for corn.

From Extension Bulletin E–2904 the equation for calculating the N rate (lb N acre⁻¹) recommendation for a corn (grain) crop planted in rotation with soybean in mineral soil is given by:

$$N\ rate = (1.36 * YG_t) - 27 - NC \quad (C1)$$

Where:

YG_t Yield goal of crop in year t, to which recommended N rate will be applied, bushel acre⁻¹;

NC Nitrogen credit from previous soybean crop, lb N acre⁻¹.

In Extension Bulletin E–2904 soybean is given an N credit of 30 lb N acre⁻¹.

To calculate the predicted future corn yield the following equation is used:

$$YG_t = 1.05 * [(Y_{t-2} + Y_{t-4} + Y_{t-6}) / 3] \quad (C2)$$

Where:

Y_t = Project start date (year)

Y_{t-n} = Average county yield of crop in years 2, 4, and 6 (3 individual years of yield data) prior to project adoption.

The approach of taking previous year’s yield data and multiplying by 105% (1.05) in order to calculate the yield goal for the forthcoming crop is a common and conservative practice for producers. The approach is consistent with typical recommendations from university extension and agronomic organizations. Documentation outlining this approach is found for example in Fertilizer Suggestions for Corn – G174, University of Nebraska, Lincoln (Shapiro et al. 2003), and The Illinois Council on Best Management Practices (2001).

For Approach 2, the previous year’s yield data is determined from interrogation of the USDA NASS web pages (Figures C1 and C2, <http://www.nass.usda.gov>).

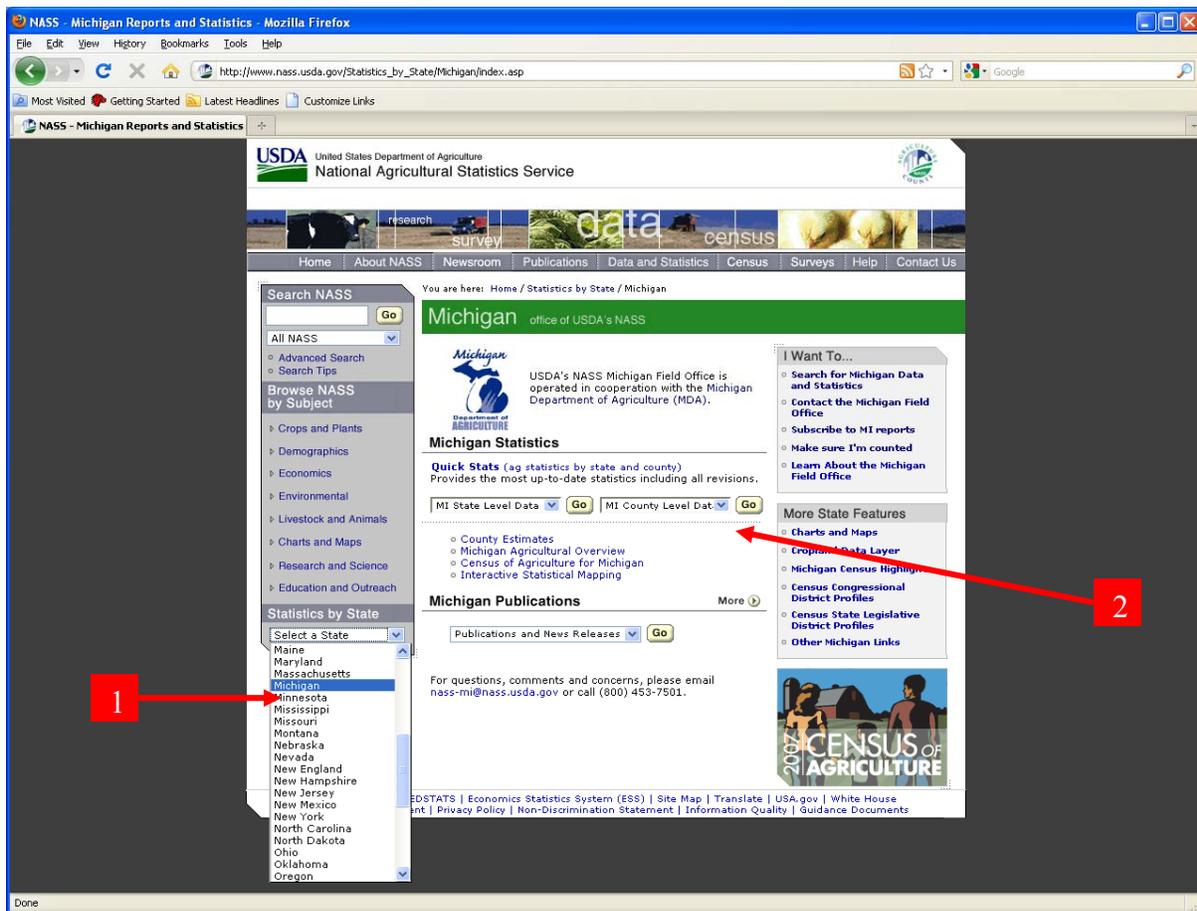


Figure C1. USDA NASS web screen showing selection menus for State (1), and County (2) level data inquiry.

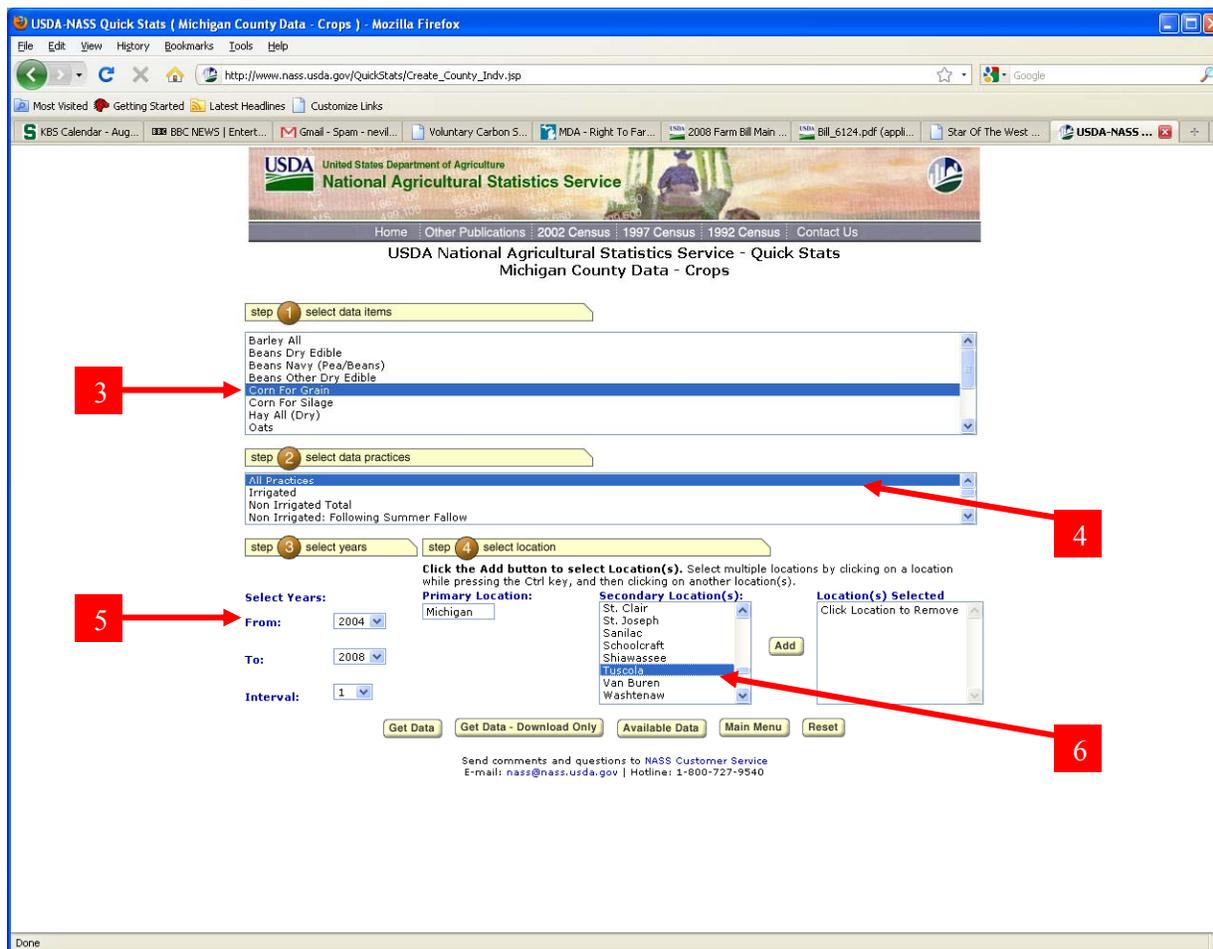


Figure C2. USDA NASS web screen showing selection menus for crop (3), practice (4), years (5) and County (6).

Data is downloaded as .csv files from which average yield data can be calculated (Table C2).

Table C2. County yield data for corn (grain) in Tuscola county Michigan, for years 2005 through 2010.

	2005	2006	2007	2008	2009	2010
Yield (bushel acre⁻¹)	148	154	134	174	164	148

From section 4.2, the use of crop yield data from USDA – NASS must be consistent with the crop rotation history of the proposed project site(s). In this example a project field has had corn grown in rotation with soybean for at least the last six years (2005 – 2010, starting with corn). The calculation therefore must use USDA – NASS data for corn yield from 2005, 2007 and 2009 for a project start date of 2011. Using equation C2, we can calculate the yield goal for corn in 2011 (year t) as follows:

$$\begin{aligned}
 YG_t &= 1.05 * [(148 + 134 + 164) / (3)] \\
 &= 156.1 \text{ bushel acre}^{-1}
 \end{aligned}$$

From equation C1 the fertilizer N rate recommendation for corn (grain) in Michigan:

$$\begin{aligned} &= (1.36 * 156.1) - 27 - 30 \\ &= 155.3 \text{ lb N acre}^{-1} \end{aligned}$$

For conversion from non SI (lb N acre⁻¹) to SI (kg N ha⁻¹) units, the value is multiplied by 1.12 (a conversion factor accepted by the American Society of Agronomy (ASA), the Crop Science Society of America (CSSA), and the Soil Science Society of America (SSSA) – <http://www.soils.org/files/publications/journals-sitable-coverions.pdf>).

The fertilizer N rate recommendation for corn (grain) is then:

$$= 174.0 \text{ kg N ha}^{-1}$$

This value is considered the baseline fertilizer N rate for corn (grain) in a corn–soybean rotation for any proposed project site situated in the county of Tuscola, Michigan that had a project start date in 2011.

Depending on the proposed project details, similar equations for crops in other States can be utilized.

Note, as with Approach 1 the BAU baseline N fertilizer rate initially calculated remains fixed for the crediting period.

ANNEX D: DEMONSTRATING ADDITIONALITY

To demonstrate additionality a project will need to pass a regulatory surplus test.

The following paragraphs present some information and examples of regulations that deal with fertilizers and their application. The following is not meant to be an exhaustive list of regulations. Project developers must conduct a complete evaluation of federal, state and local regulations applicable to fertilizer use in the selected project location as part of the additionality assessment.

There is no Federal fertilizer statute and fertilizers are regulated under the individual States' authority. The Federal government does not regulate fertilizer directly however, there are regulations concerning the production, use and disposal of hazardous materials, drinking and surface water contamination and air pollution that are indirectly relevant to the use of hazardous materials in fertilizers and the application of fertilizers to land.

Below is a list of regulations at the Federal and State (Michigan) level that deal in some part with practices relating to synthetic and organic N fertilizer management in the agricultural sector.

Federal Regulations

The Food, Conservation, and Energy Act (2008)

The Military Munitions Rule (1997)

The Water Quality Amendment Act (1987)

The Superfund Amendments and Reauthorization Act (SARA) (1986)

Resource Conservation and Recovery Act of 1976 (RCRA) Statute - Solid Waste Disposal, Title 42, Chap. 82, Subchapter III - Hazardous Waste Management

The Federal Water Pollution Control Act (1972)

Hazardous Waste Regulation, 40 CFR, Part 503, Standards for the Use or Disposal of Sewage Sludge

The Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200)

State Regulations

Each state in the US has its own fertilizer regulatory program. State regulations for fertilizers are generally developed and administered by State agriculture departments. Such regulations primarily address efficacy claims and composition statements of the active ingredients displayed on fertilizer labels. Most States have fertilizer regulations similar to that of the Association of American Plant Food Control Officials (AAPFCO) model Uniform State Fertilizer Bill.

The Uniform State Fertilizer Bill is a model bill providing the legal authority to regulate the registration, packaging, labeling, sale, storage, distribution, use and application of fertilizer and fertilizer materials. There are specific requirements for the accurate and meaningful labeling of fertilizers, including terms and definitions, and regulations for the storage requirements for bulk fluid and dry fertilizers.

Other AAPFCO Uniform Bills that may relate to fertilizer N application include the Uniform Soil Amendment Bill, the Model Agricultural Liming Materials Bill, the Model Chemigation Bill and the Uniform State Ammonia Bill.

Example: Michigan Regulations

Below are state level regulations indirectly relating to fertilizer N management as outlined in the Michigan Department of Agriculture Generally Accepted Agricultural and Management Practices (GAAMP) for Nutrient Utilization publication (2012).

These regulations apply to ‘a person applying, distributing, and storing fertilizer or organic materials in Michigan’ who ‘must comply with the relevant state and federal laws and regulations promulgated under these statutes, including but not limited to’:

Public Act 451: Natural Resources and Environmental Protection Act of 1994

Public Act 346: Commercial Drivers' License Law of 1988

Public Act 368: Michigan Public Health Code of 1978

Public Act 399: State of Michigan Safe Drinking Water Act of 1976

Public Act 154: Michigan Occupational Safety and Health Act (MIOSHA) of 1974

Public Act 162: Michigan Liming Materials Law of 1955

Further useful information regarding fertilizer regulations can be found at the Safe Fertilizer Information Institute (http://www.saffii.com/index.php/State_Fertilizer_Programs).

ANNEX E: COMMON PRACTICE FOR N FERTILIZER RATE APPLICATION

In using this methodology, project proponents must pass a Practice-Based Performance Standard Test. This standard equates the BAU baseline scenario for N fertilizer application with the common practice of producers to apply N fertilizer rates based upon recommendations derived from yield goal estimates. Project developers pass the Performance Standard Test by reducing their N fertilizer rate below the BAU rate, which is also the baseline value for N fertilizer rate for the proposed project. Reductions in N fertilizer rate and therefore N₂O emissions below the BAU rate at the project site (Approach 1), or below the BAU value in the county where the project is to be conducted (Approach 2), will result in project additionality.

Evidence for the wide-scale historic and continued use of the yield goal approach, and therefore its legitimacy as a Performance Standard for testing additionality in crop-based agriculture is given below.

Justification of the yield goal approach as a BAU baseline scenario

Both Approach 1 and 2, used to establish the project baseline, operate on the principle that a reduction in N fertilizer rate below the baseline results in a predictable, concomitant reduction in N₂O emissions. Project additionality is achieved through a reduction in N rate below the BAU baseline scenario, such that 'new' N₂O emissions are prevented from entering the atmosphere. These avoided emissions occur immediately, are irreversible, and are permanent.

Given that N₂O in agricultural soil is produced predominantly through the microbial transformations of inorganic N (Robertson and Groffman 2007), the potential to produce and emit N₂O increases with the increasing availability of N (Bouwman et al. 1993). Due to the strong influence of available soil N on N₂O emissions, some emissions of N₂O are an unavoidable consequence of maintaining highly productive cropland (Mosier 2002). However, any activity or process that acts to keep available soil N low will lead to smaller N₂O emissions. Anthropogenic activities that lower the input of N into cropland agriculture help to reduce emissions of N₂O (Robertson and Vitousek 2009).

To date the vast majority of evidence supports nitrogen input as the most robust and reliable default proxy for calculating N₂O emissions. It is consistent and straightforward to quantify as a metric and its use is substantiated by the IPCC, which uses annual N rate as the default method for calculating N₂O emissions from managed land in national greenhouse gas inventories. Moreover, its alteration is readily accessible to management intervention.

Altering N fertilizer management practices other than N rate, such as timing, placement, and fertilizer formulation can also alter N₂O emissions. However, to date there have been far fewer studies investigating their impact on N₂O responses as compared to the impact of fertilizer rate. Nevertheless, our protocol allows credit for these practices by crediting the degree to which they allow less fertilizer to be used – i.e. the degree to which they improve system-wide fertilizer use efficiency, which is often a stated goal of their use. Their direct impact on N₂O fluxes – irrespective of fertilizer amount – awaits further validation before their use can be incorporated with confidence into the present protocol.

Since the 1970s it has been common practice throughout the NCR and the conterminous US in general for producers to apply rates of N fertilizer based on recommendations derived from yield goal estimates (e.g., Fixen, 2006; Shapiro et al. 2003; Warncke et al. 2004). The agricultural departments of land grant universities and state agricultural organizations have typically endorsed yield-goal N fertilizer rate recommendations. These organizations are the most common source of external information and advice for producers, and this network serves as the foundation for producer BAU practice in the NCR and beyond, constituting a sector-wide approach for calculating baseline N fertilizer rates, and by extension, emissions of N₂O.

Despite concerns that yield goal-based recommendations are too liberal (Sawyer et al. 2006), the practice is still widely followed, and recommended, leading to application of N fertilizer in excess of crop requirements, principally as a result of unrealistic yield goal estimates (e.g., Vanotti and Bundy 1994). Furthermore, a producer's tendency is to hedge against a perceived insufficient supply of N from the soil or previous N inputs by applying N fertilizer in excess of the recommendations as compensation (e.g., Babcock 1992; Babcock and Blackmer 1994). Therefore, reductions in N rate below those determined by yield-goal based calculations (i.e., BAU baseline scenario) can be implemented to reduce the amount of excess N in cropland agriculture, thereby decreasing its N₂O burden without reducing crop productivity.

A regional approach to optimize crop yield has recently been developed that utilizes historical and current N fertilizer rate research data from field trials to determine economically profitable N inputs, expressed as a range of N rates around a maximum return to N (MRTN) at different N fertilizer and crop prices (Iowa State University Agronomy Extension 2004). The US Midwest states currently providing data for this approach are Iowa, Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin. Producers with relevant cropping systems in these states (and other states that may subsequently become involved) may wish to adopt a N fertilizer rate for the project within the economically profitable N rate range calculated, using this approach (Millar et al. 2010). Use of MRTN to reduce N rate use is not required, however – other methods may be used to reduce rates to better match crop needs, including the use of improved fertilizer application timing, fertilizer formulations, cover-crop N capture, or any of a number of other practices known to better match N fertilizer input to crop N needs than BAU approaches (Robertson and Vitousek 2009).

ANNEX F: DEFAULT FACTORS

Default (Tier 1) values used in the methodology for calculating direct and indirect emissions of N₂O from baseline and project scenarios are from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Revised Aug. 2011, Vol. 4, Ch. 11, IPCC 2006). The terms for the factors used in this methodology differ from that used in the IPCC guidelines, but the factors are equivalent in value and usage (Table F1).

Table F1. Default factors used to estimate direct and indirect emissions of N₂O in the methodology.

N ₂ O Emissions	Methodology factor	IPCC factor	Default value	Uncertainty range
Direct	EF _{BDM1} , EF _{PDM1}	EF ₁	0.010	0.003 - 0.03
Indirect	EF _{BIV} , EF _{PIV}	EF ₄	0.010	0.002 - 0.05
Indirect	EF _{BIL} , EF _{PIL}	EF ₅	0.0075	0.0005 - 0.025
Direct/Indirect	Frac _{GASF}	Frac _{GASF}	0.10	0.03 - 0.3
Direct/Indirect	Frac _{GASM}	Frac _{GASM}	0.20	0.05 - 0.5
Direct/Indirect	Frac _{LEACH}	Frac _{LEACH}	0.30	0.1 - 0.8

Tier 1 defaults are used at the coarse scale of national inventories; their values have been derived from numerous small-scale studies. For instance, the information from 1,008 N₂O emission measurements from peer reviewed agricultural field studies analyzed by Stehfest and Bouwman (2006) was a major driver for adopting the IPCC EF₁ value of 0.010. Further information on the peer reviewed studies and references used in the derivation of all the IPCC factors used in this methodology, and the unbiased and conservative approach used to determine them can be found in IPCC (2006).

Conversion of N₂O–N to N₂O

Conversion of N₂O–N (the mass of the nitrogen component of the nitrous oxide molecule) to N₂O for reporting emission reductions in units of CO₂e is performed by multiplication of the ratio of the molecular weight of N₂O to the atomic weight of the two N atoms in the N₂O molecule:

$$N_2O = N_2O-N * 44/28$$

Global Warming Potential of N₂O

The GWP value of 310 for N₂O used in the methodology is the 100-year value proposed in the Intergovernmental Panel on Climate Change Second Assessment Report (SAR).

The value of 310 is the direct GWP for one molecule of N₂O on a mass basis for a 100-year time horizon, relative to one molecule of CO₂, which is ascribed a value of 1 by convention. This means that a molecule of contemporary N₂O released to the atmosphere will have 310 times the radiative impact of a molecule of CO₂ released at the same time. The conversion can be represented as:

$$N_2O_{GWP} = 310, Mg CO_2e (Mg N_2O)^{-1}$$

ANNEX G: BACKGROUND RESEARCH AND EMISSIONS UNCERTAINTY ASSESSMENT

In the North Central Region (NCR), direct emissions of N₂O for baseline and project scenarios in corn-based, row-crop rotations can be calculated using Method 1. Method 1 uses an emission factor determined from multi-year field studies conducted in Michigan. This emission factor is consistent with IPCC Tier 2 methodological guidelines and in this methodology assigned the terms EF_{BDM1} and EF_{PDM1} for baseline and project emission calculations, respectively.

Full details of study sites, sampling, data analysis, results, and other information are in Hoben et al. (2011), and at <http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2010.02349.x/supinfo>.

Below we briefly overview this research and present details of the uncertainty assessment for emissions reductions, including the derivation of the Tier 2 emissions factor.

Overview

Previous research conducted by McSwiney and Robertson (2005), and more recently by Hoben et al. (2011) and Millar et al. (2012) show that N₂O emissions can increase exponentially with increasing N fertilizer rate, particularly at high rates that exceed the crop N uptake capacity.

These unique field studies in the North Central Region (NCR) specifically investigated long-term N₂O emission responses to a large number of N fertilizer rate treatments in row-crop agriculture. The large number of N rates and the small increments between them allow better resolution of the shape of the relationship between N rate and N₂O emissions.

The producer sites used in the development of the Tier 2 approach (Hoben et al. 2011) encompassed a wide range of soil type, texture, and grain yield that were comparable and broadly representative of commercial corn crop rotations and conditions throughout the NCR. During the study years, the sites experienced a wide range of environmental conditions throughout the growing season. In years with normal precipitation, crop yields at these sites are typical of the NCR as a whole (Smith et al. 2007). The N rates employed in Hoben et al. (2011) also are within the range commonly required for optimum corn-grain production and recommended for the US Midwest (Sawyer et al., 2006; Vitosh et al., 1995).

The non-linearity of N₂O emissions has significant consequences when comparing N₂O emissions reductions with the IPCC Tier 1 approach. An identical N fertilizer rate reduction will result in a significantly smaller reduction in N₂O emissions when the Tier 1 emission factor is used in calculations, when compared to the Tier 2 emission factor. The increasing divergence of N₂O emissions between Tier 1 and Tier 2 approaches, particularly at higher N rates, helps incentivize the reduction in N rate. Millar et al. (2010) show an example of this.

Uncertainty assessment

Methodologies and procedures adopted to calculate emissions of N₂O have been refined over many years, and are conservative in nature. Here we outline assumptions, parameters and procedures that relate to uncertainty in N₂O emissions in the methodology. We focus on the derivation of the regional NCR emissions factor used in equation (5) and (14) in sections 6.1.1 and 6.2.1, respectively. More detailed information on field-sampling and laboratory analytical techniques are given in Hoben et al. (2011).

Application of N fertilizer

The methodology monitors five parameters during the project period. Four of these relate directly to the calculation of N rate applied at the project site. These are detailed along with their measurement in section 11.1 of the methodology.

All of these parameters are assumed to have negligible uncertainty.

Derivation of regional (NCR) emissions factor

Daily N₂O emissions

Values for daily N₂O emissions have negligible uncertainty; field and laboratory sampling and analytical techniques have been refined over many years to standardize methodologies and minimize analytical uncertainty. We used standard methods to measure daily emissions as described in Hoben et al. (2011).

Annual N₂O emissions

We determined total annual emissions by interpolating daily emissions between sampling days. This was carried out using linear interpolation – a broadly accepted mechanism in the scientific peer reviewed literature. In brief, the sum of the rate of N₂O emissions on two successive sampling days was divided by two (averaged), and this average rate was multiplied by the period (in days) between the two measurements, then added to the previous cumulative emissions total. This can be represented by:

$$C_B = C_A + [(D_A + D_B) / 2] * (B-A) \quad (G1)$$

Where:

C_B = Cumulative N₂O emission as of day B (g N₂O-N ha⁻¹);

C_A = Cumulative N₂O emission as of day A (g N₂O-N ha⁻¹);

D_A = Daily gas flux on day A (g N₂O-N ha⁻¹ d⁻¹);

D_B = Daily gas flux on day B (g N₂O-N ha⁻¹ d⁻¹);

B = Day of latest emissions measurement (day of year);

A = Day of previous emissions measurement (day of year).

Annual emissions (g N₂O-N ha⁻¹ yr⁻¹) of N₂O for each field replicate were calculated from daily N₂O emissions (g N₂O-N ha⁻¹ d⁻¹) measured in each block (4) at each N rate (6, including zero) at each site during the year for all site years (8), to give a total of 192 cumulative annual N₂O emissions data points (4 * 8 * 6). These individual cumulative annual emissions, calculated directly from daily N₂O emissions with negligible uncertainty, are also assumed to have negligible uncertainty.

The best-fit line that defines the mathematical relationship between N rate (kg N ha⁻¹ yr⁻¹) and N₂O emissions (g N₂O-N ha⁻¹ yr⁻¹) for all 192 data points is:

$$\text{N}_2\text{O emissions} = 670 * \exp(0.0067 * \text{N rate}) \quad (G2)$$

Where:

N rate is the equivalent of F_{B SN, t} + F_{B ON, t} for baseline N input (equation [2] and [6]) and F_{P SN, t} + F_{P ON, t} for project N input (equation [11] and [15]).

The standard error (SE) associated with N₂O emissions, is:

$$\text{N}_2\text{O emissions}_{(SE)} = 58 * \exp(0.010 * \text{N rate}) \quad (G3)$$

Figure G1 (below) shows this relationship.

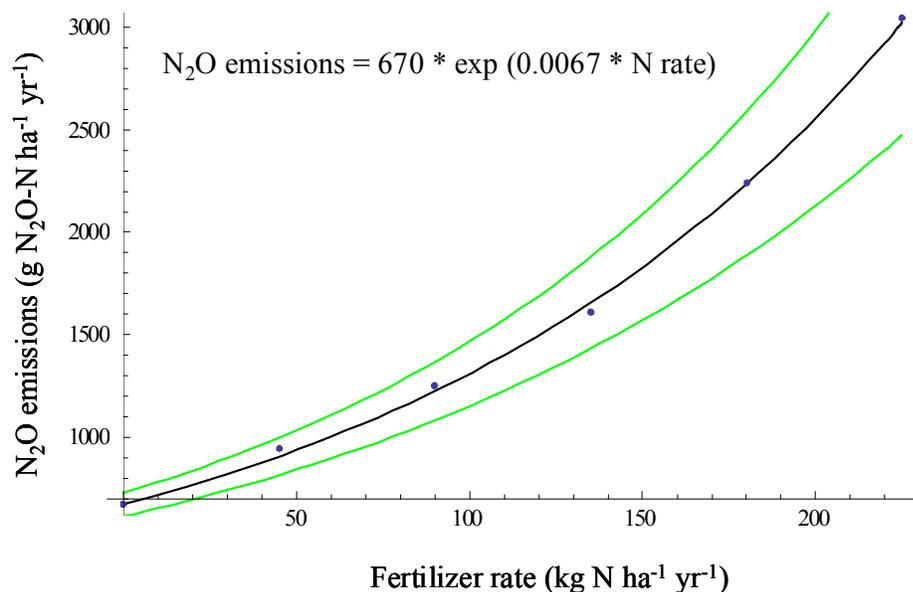


Figure G1. Relationship between N₂O emissions (g N₂O-N ha⁻¹ yr⁻¹) and N fertilizer rate (kg N ha⁻¹ yr⁻¹) for baseline and project N fertilizer rates (black line). Standard errors ($\pm 58 * \exp [0.010 * N \text{ rate}]$) are also shown (green lines). Calculated using Mathematica (v. 8, Wolfram Research Inc., 2011).

N₂O emissions reductions

Raw N₂O emissions reduction values were obtained by subtracting cumulative annual emissions of lower N application rates from cumulative annual emissions of higher N application rates (i.e., 0, 45, 90, 135, 180, and 225 kg N ha⁻¹ yr⁻¹) within the same block, site, and year. This emissions difference was then divided by the difference in rate between the N rate pairs. Thus, we obtained 32 values (4 blocks * 8 site years) for the emission reductions for each of the 15 pairs (e.g., 45 → 0, 90 → 0, 90 → 45, etc.).

To best define the interpolation of the empirical data for emissions reductions - N₂O emissions_(RED) - many types of function were tested, including linear and exponential functions with various parameter combinations. The function below (Equation [G4]) derived from equation [G2] above) was also tested.

$$N_2O \text{ emissions}_{(RED)} = 0.67 * \{ \exp(6.7 * N_{Base}) - \exp(6.7 * N_{Proj}) \} / (N_{Base} - N_{Proj}) \quad (G4)$$

Where:

$$N_2O \text{ emissions}_{(RED)} = N_2O \text{ emissions reductions, g N}_2\text{O-N ha}^{-1} \text{ yr}^{-1};$$

$$N_{Base} = F_{B_{SN,t}} + F_{B_{ON,t}} \text{ baseline N input, Mg N ha}^{-1} \text{ yr}^{-1};$$

$$N_{Proj} = F_{P_{SN,t}} + F_{P_{ON,t}} \text{ project N input, Mg N ha}^{-1} \text{ yr}^{-1}.$$

Equation (G4) outperformed all linear functions and works as effectively as more complex exponential functions.

Emissions factors

The emissions factor for N₂O is defined as the fraction of N applied that is released as nitrogen in N₂O (N₂O-N) at a non-zero N rate minus the N₂O-N emitted at zero N rate.

The emissions factors for baseline and project calculations were obtained by dividing the reduction function (equation G4) by $1 * 10^6$ (to convert g N₂O-N / Mg N rate to Mg N₂O-N / Mg N rate). We then formatted the equation to compare baseline and project N rates to zero N rate. Therefore, we have:

$$EF_{\text{Base}} = 6.7 * 10^{-4} * (\exp [6.7 * N_{\text{Base}}] - 1) / N_{\text{Base}} \quad (\text{G5})$$

$$EF_{\text{Proj}} = 6.7 * 10^{-4} * (\exp [6.7 * N_{\text{Proj}}] - 1) / N_{\text{Proj}} \quad (\text{G6})$$

Where:

EF_{Base} and EF_{Proj} are equivalent to EF_{BDMI} (Equation [5]) and EF_{PDMI} (equation [14]), respectively.

Emissions reduction uncertainty

The standard error equation (G3) is useful for describing uncertainty in annual emissions but cannot be used to accurately describe uncertainty for emissions reductions in the range of smaller N rate reductions (10 – 20 kg N ha⁻¹ yr⁻¹).

Instead the 32 values (4 blocks * 8 site years) for the emission reductions for each of the 15 pairs (e.g., 45 → 0, 90 → 0, 90 → 45, etc.) were used to obtain variability of the mean using the Bootstrap method (Monte Carlo algorithm with case re-sampling, Mathematica – v. 8, Wolfram Research Inc., 2011).

For each pair of N fertilizer rate reductions a random sample of 32 baseline values was taken and replaced with a random sample of 32 project values to compute a mean reduction. This process was repeated 100,000 times and the overall standard error of the means were calculated.

The standard error of the means was then multiplied by 1.645 (the critical value of normal one-sided test at 95% confidence), and divided by the average emissions reduction to give the fraction of the average that is within the 95% confidence interval. These values plotted against N rate are represented by Equation (G7), which calculates the uncertainty associated with a reduction in N rate during the project period:

$$N_2O \text{ Emissions}_{(\text{RED UNC})} = [1 - \{0.63 * \exp (-40 * [N_{\text{Proj}}]^2)\}] * 100 \quad (\text{G7})$$

Where:

$N_2O \text{ Emissions}_{(\text{RED UNC})}$ Uncertainty in N₂O emissions reductions, %;

N_{Proj} $F_{\text{P SN, t}} + F_{\text{P ON, t}}$ project N input, Mg N ha⁻¹ yr⁻¹.

Equation (G7) is identical to equation (19) in section 8 of this methodology.

Within the empirical N rate data range (0 – 225 kg N ha⁻¹ yr⁻¹), the highest uncertainty was ~90%. There is no evidence to suggest that higher N rates would generate uncertainties above 100%, therefore the Gaussian function was used to constrain uncertainty below 100%.

Project proponents will use equation (G7 / 19) to calculate emissions reductions uncertainties (%) for a project. Credit award deductions as a result of uncertainty will use the uncertainty deductions in Table G1 (below, and Table 2 – section 8).

Table G1. Conservativeness factors and uncertainty deduction for N₂O emissions reductions based upon uncertainty at 95% confidence level.

Uncertainty range at 95% confidence level of project emissions reductions [#]	Conservativeness factor	Uncertainty deduction*
< ± 15%	1.000	0.000
> ± 15% ≤ ± 30%	0.943	0.057

> ± 30% ≤ ± 50%	0.893	0.107
> ± 50% ≤ ± 100%	0.836	0.164

Where uncertainty in emissions reductions is $< \pm 15\%$, no deductions will be applied. Uncertainty in emissions reductions does not exceed 100% (see Annex G). * Uncertainty deduction (UNC) = $(1 - \text{Conservativeness factor})$. See equation (20) in section 9 of methodology.

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