**CDM-SSCWG45-A13**

# Draft Small-scale Methodology

# AMS-III.BF: Reduction of $N_2O$ emissions from use of Nitrogen Use Efficient (NUE) seeds that require less fertilizer application

Version 02.0 - Draft

Sectoral scope(s): 15

# COVER NOTE

## 1. Procedural background

1. Following the approval of the methodological tool "Project emissions from cultivation of biomass" at the seventy-fifth meeting of the Executive Board (hereinafter referred as the Board) of the clean development mechanism (CDM), the Small-Scale Working Group (SSC WG) requested a mandate from the Board to integrate this tool into SSC methodologies. Consequently, the Board mandated this task at its seventy-sixth meeting (EB 76, para 53).

## 2. Purpose

2. The draft revision streamlines the sources and calculations of default emission factors, replacing a calculation procedure.

## 3. Key issues and proposed solutions

3. None.

## 4. Impacts

4. Simplified and streamlined procedures.

## 5. Subsequent work and timelines

5. The SSC WG, at its 45th meeting, agreed on the draft revised methodology. After receiving public inputs on the document, the SSC WG will continue working on the methodology, at its 46th meeting, for recommendation to the Board at a future meeting of the Board.

## 6. Recommendations to the Board

6. Not applicable (call for public input).

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# 1. Introduction

1. The following table describes the key elements of the methodology:

**Table 1. Methodology key elements**

| | |
|---|---|
| **Typical projects** | Use of a genetically distinct type of seed for crops that will utilize nitrogen more efficiently, hereafter called "Nitrogen Use Efficiency (NUE) seed" |
| **Type of GHG emissions mitigation action** | Avoidance of $N_2O$ emissions from agricultural activity<br>Reduction in amount of fertilizer used by the crop |

# 2. Scope, applicability, and entry into force

## 2.1. Scope

2. The technology/measure comprises use of a genetically distinct type of seed for crops that will utilize nitrogen more efficiently, hereafter called "Nitrogen Use Efficiency (NUE) seed", and therefore requires less fertilizer than conventional seeds.[1] The result of this reduced fertilizer use will be lower Nitrous Oxide emissions that occur as a result of nitrification and denitrification in the soil. This methodology will enable project proponents to calculate reductions in greenhouse gas (GHG) emissions from the use of NUE seed to achieve the same crop yield with significantly less fertilizer input than conventional seed. By reducing the amount of fertilizer required to sustain yields, $N_2O$ emissions are also reduced.



## 2.2. Applicability

3. This methodology will be applicable if the following conditions are met:

(a) The project activity is applicable to NUE seed, according to the definition as contained in paragraph 6(a) below. The containers of NUE seed must be clearly marked as such and always remain segregated from other seed;

(b) No NUE seeds have been used previously in the proposed project area. In addition, the NUE seed must replace the same crop (i.e. NUE rice replacing traditional rice varieties). Project participants shall clearly define the project area prior to validation. Project participants may use precise GPS coordinates or local documentation (i.e. zoning maps, deeds, etc.) that clearly delineates the boundaries of the land owned or leased by farmer using the NUE seed;

(c) With the exception of the use of NUE seed, and associated reductions in nitrogen fertilizer applications, project proponents should undertake the same management practices before and after the project. The methodology only

[1] The NUE seeds are based on patented technology that has also been published in peer reviewed journals (e.g. Sharwat, A.K. et. al. 2008. Sept 6(7):722-32 and Good, A.G., et. al. 2007. Can. J. Bot. 85:2522-262).

accounts for reduction in emissions resulting from NUE seed. This methodology does not cover other changes in management practices;[2]

(d) The methodology is not applicable to technology/measure where the savings in synthetic nitrogen fertilizer applications are attributable in total or in part to enhanced biological fixation (e.g. by rhizobia activity, as in AMS-III.A). Only changes in the nitrogen assimilation efficiency of the modified seeds are eligible under this methodology;

(e) If rice is used as an NUE crop, project proponent needs to demonstrate that NUE varieties have physiological plant characteristics compared to the varieties they replace such as not to increase $CH_4$ emissions. This should be demonstrated ex ante or during the first verification by comparison of key characteristics of plants cultivated with project and baseline seeds like total root biomass, root to shoot ratio and number of tillers. Furthermore, project proponents needs to demonstrate that there is no increase in $CH_4$ emissions due to increasing the area/time fields are flooded;

(f) To avoid double-counting, the emission reductions generated by the project activity are owned by the project proponent. Farmers that take part in the project activity, if they are not themselves the project proponent, sign an agreement with the project proponent that specifies that they will not claim emissions reductions for using NUE seed on their land;

(g) For each farmer taking part in the project activity, reliable and verifiable data on the amount of synthetic nitrogen fertilizer used shall be recorded and provided;



(h) The project can only be eligible on land that has been used for the same crop as in the project activity for the last three years;

(i) There are no national or regional regulations that require the use of NUE seeds or otherwise forbid the use of conventional seed varieties;

(j) In all countries where this bioengineered crop technology is introduced the local regulations related to biosafety are complied, including testing and field evaluation of crops to demonstrate environmental and human health safety. In countries where new crop varieties are subject to government variety registration procedures, these procedures are also complied;

(k) Aggregated annual emission reductions of all fields included under one project activity shall be less than or equal to 60 kt $CO_2$ equivalent.

### 2.3. Entry into force

4. Not applicable (call for public input).

[2] Examples of changes in management practices that are not eligible include what is commonly known as the "4Rs", specifically changes in practices to apply the right fertilizer at the right time, right rate and right place.

# 3. Normative references

5. Project participants shall apply the “General guidelines for SSC CDM methodologies” and the “Guidelines on the demonstration of additionality of small-scale project activities” (previously known as Attachment A to Appendix B) provided at <https://cdm.unfccc.int/Reference/Guidclarif/index.html> mutatis mutandis.

# 4. Definitions

6. For the purpose of this methodology the following definitions apply:

   (a) **NUE seeds** - are defined as seeds for crop varieties that have been genetically engineered to modify genes in nitrogen assimilation and metabolic pathways in ways that significantly increase the quantity of crop output, measured as grain, biomass, or other elements of economic value, per unit of nitrogen available for plant use;

   (b) **The DNDC model** - is a process-based model developed by the University of New Hampshire and can be used to determine baseline and project emissions of carbon and nitrogen biogeochemistry in agricultural ecosystems.[3] The model can be used for predicting emissions of trace gases including nitrous oxide ($N_2O$), nitric oxide (NO), nitrogen ($N_2$), ammonia ($NH_3$), methane ($CH_4$), and carbon dioxide ($CO_2$) among others.

# 5. Baseline methodology



## 5.1. Project boundary

7. The spatial extent of the project boundary includes all fields that use NUE seeds in the context of the project activity.

## 5.2. Baseline emissions

8. The baseline is the continued use of traditional seeds and nitrogen fertilizer rates as prior to the project, in order to achieve the same crop output as in the project scenario.

## 5.3. Emission reduction

9. The emission reductions in any *y* of the crediting period are calculated as:

$$ER_y = P_{pj,y} \times \left( \frac{EF_{NF,BL}}{NUE_{bl,y}} - \frac{EF_{NF,PJ}}{NUE_{pj,y}} \right) \times UF \quad \text{Equation (1)}$$

Where:

| | | |
|---|---|---|
| $ER_y$ | = | Emission reductions in year *y* (t $CO_2$) |
| $P_{pj,y}$ | = | Amount of crop produced by project activity in year *y* (t) |

[3] The most recent version of the DNDC model and user guide can be downloaded from the University of New Hampshire website at <http://www.dndc.sr.unh.edu/>.

| | | |
|---|---|---|
| $NUE_{bl,y}$ | = | Nitrogen utilization efficiency of the crop cultivation in the baseline scenario, in tonnes of crop output per tonne of nitrogen fertilizer application (t/t-N) |
| $NUE_{pj,y}$ | = | Nitrogen utilization efficiency of the crop cultivation in the project scenario, in tonnes of crop output per tonne of nitrogen fertilizer application (t/t-N) |
| $EF_{NF,BL}$ | = | Emission factor for the nitrogen fertilizer application in baseline, in tonnes of $CO_2$ equivalent emitted per tonne of nitrogen in the fertilizers (t $CO_2$/t-N) |
| $EF_{NF,PJ}$ | = | Emission factor for the nitrogen fertilizer application in project, in tonnes of $CO_2$ equivalent emitted per tonne of nitrogen in the fertilizers |
| $UF$ | = | Uncertainty factor[4]<br>For Option 1 IPCC default value, value of 0.82 is used for UF, based on FCCC/SBSTA/2003/10/Add.2, page 25.<br>For option 2DNDC model and Option 3 Direct measurementotherwise, value of 1.0 is used |

### 5.3.1. Crop production ($P_{pj,y}$)

10. The yearly crop produced by the project participant farms using the NUE technology will be determined by direct measurements at participant farms or at a representative sample thereof, based on the area cultivation efficiency.



$$P_{pj,y} = \sum_{i} P_{i,y} = AUE_{pj,y} \times \sum_{i} A_{i,y}$$ Equation (2)

Where:

| | | |
|---|---|---|
| $P_{i,y}$ | = | Crop production of the individual farm/field *i* in the year *y* (t) |
| $AUE_{pj,y}$ | = | Area cultivation efficiency (productivity) in project scenario, in tonnes of crop produced per unit cultivated area (t/ha) |
| $A_{i,y}$ | = | Cultivated area at the individual participant field/farm *i* (ha) |
| $i$ | = | 1, 2, 3 indices for the participant fields/farms |

11. The total crop production using NUE technology ($P_{i,y}$) may be measured individually in all participant farms each year. Alternatively, the yearly area cultivation efficiency in project scenario ($AUE_{pj,y}$) will be determined by measuring the crop output at representative farms. The monitoring will be carried out through direct measurement of the product delivered by the farm/field and its cultivated area. The basis for the measurement of product output (e.g. in mass of grains at a given condition of processing, moisture, etc.) will be described in the project design document (PDD). In case of sampling, the

4 An uncertainty factor is applied, taking into account the uncertainty related to the external data that are not necessarily representative of the project specific static and dynamic conditions.

selected farms/fields for representative measurements at each year will be provided by an independent third party[5] entity based in the participants' database and sample stratification. The entity will communicate to the project participant the selected farms not before one month in advance of the earliest time expected for start harvesting in the project region/country.

### 5.3.2. Nitrogen utilization efficiencies ($NUE_{bl,y}$ and $NUE_{pj,y}$)

12. The yearly nitrogen utilization efficiencies for crop cultivation at project and baseline cultivation practices will be determined by direct measurements at participant farms in project scenario and in a control group for baseline scenario. The control group for baseline consists of a number of farms/fields selected among the participants that at the year *y* will utilize seeds and nitrogen fertilizer types and amounts as per the baseline technology. The efficiencies are determined as:

$$NUE_{bl,y} = \frac{\sum_j P_{j,y}}{\sum_j Q_{NF,j,y}} \quad \text{Equation (3)}$$

$$NUE_{pj,y} = \frac{\sum_j P_{j,y}}{\sum_i Q_{NF,i,y}} = \frac{AUE_{pj,y}}{q_{NF,pj,y}} \quad \text{Equation (4)}$$



Where:

| | | |
|---|---|---|
| $P_{j,y}$ | = | Crop production of the farms/fields *i* cultivated using the baseline technology, measured in tonnes of output (t) |
| $Q_{NF,j,y}$ | = | Total quantity of nitrogen fertilizers utilized by the farms/fields utilizing the baseline technology, in tonnes of nitrogen (t-N) |
| $j$ | = | 1, 2, 3 indices for the fields/farms selected to compose the baseline control group, where the crop cultivation utilizes the baseline seeds and nitrogen application rates |
| $Q_{NF,i,y}$ | = | Total quantity of nitrogen fertilizers utilized by the farms/fields utilizing the project technology, in tonnes of nitrogen (t-N) |
| $q_{NF,pi,y}$ | = | Rate of nitrogen fertilizers application per unit crop cultivation area at the farms/fields utilizing the project technology in the year *y (*t-N/ha) |

13. To determine the baseline nitrogen utilization efficiency ($NUE_{bl,y}$) a control group is composed yearly, consisting of a number of farms *i* selected among the project participant farms *i*. In this control group the crop cultivation will utilize the baseline seeds

[5] The independent third party may be a national or international accredited entity for certification of quality management or environmental management systems, or a governmental body.

and nitrogen fertilizer application rates. The total number of farms of the control group for each sampling stratus should represent at least 5 per cent of the participant farms or five farms/fields for each stratus (the stratus is the set of farms/fields with similar dynamic and static conditions),[6] whichever is larger. The selection will be provided by the independent third party entity based in the participants' database and sample stratification, at least one month in advance of the time for sowing start in the project region/country. The total crop production ($P_{j,y}$) and the total nitrogen fertilizer application ($QNF_{,j,y}$) will be measured at each farm composing the control group.

14. Baseline fertilizer nitrogen application rates to be followed in the control group are described in the PDD, and shall be obtained from historical records of each individual farmer or at representative samples of farms included in the project. The project proponents will collect the amount of fertilizer used and nitrogen content (t-N/t) of fertilizer for three years before the project begins (x, x-1, x-2). The project proponents will collect fertilizer purchase or use from each farmer, which can be provided to the DOE upon validation. Synthetic and organic fertilizer nitrogen content (t-N/t) and amount of fertilizer used for each farm can be determined from the historical data. For organic fertilizer only inputs imported from outside the field can be included, i.e. the reapplication of crop residues from the same cultivated area cannot be accounted, even after being digested by animals or treated in anaerobic reactors or composting. Average synthetic and organic nitrogen fertilizer use for each farm or for each farm stratus (a set of farms with similar dynamic and static characteristics) can be determined, and by taking the cultivated areas in the previous three years the application rate (t-N/ha) may also be determined. This average application rates from the historical data will be utilized in the baseline control group.



15. To determine the project nitrogen utilization efficiency ($NUE_{pj,y}$) the nitrogen utilization and the crop output will be monitored at participant farms *i* or at representative sample thereof. The total crop production ($P_{i,y}$) is measured individually in all participant farms each year, as well as the total nitrogen fertilizer applied ($Q_{NF,i,y}$) (using the amount of fertilizer applied and nitrogen content of the fertilizer). Alternatively, the yearly area cultivation efficiency in project scenario ($AUE_{pj,y}$) determined as per paragraph 11 is used, and the rate of nitrogen fertilizer application at the participant farms/fields *i* in tonnes of fertilizer-N per unit cultivation area (t-N/ha).

### 5.3.3. Emission factor for nitrogen fertilizer application ($EF_{NF}$)

16. The emissions associated with the utilization of nitrogen fertilizers are calculated as:

$$EF_{NF,BL} = EF_{CO2,P} + EF_{N2O,BL} \quad \text{Equation (5)}$$

$$EF_{NF,PJ} = EF_{CO2,P} + EF_{N2O,PJ} \quad \text{Equation (6)}$$

[6] Dynamic conditions are those that are connected to the management practice of a field, thus can change over time (no matter whether intended by the project activity or due to other reasons) and shall be monitored in the project fields. Static conditions are site-specific parameters that characterize a soil and do not (relevantly) change over time and thus do in principle only have to be determined once for a project and the corresponding fields.

Where:

| | | |
|---|---|---|
| $EF_{CO2,P}$ | = | Emission factor for $CO_2$ emissions in the production of synthetic nitrogen fertilizer (t $CO_2$/t-N) |
| $EF_{N2O,BL}$ | = | Emission factor for $N_2O$ emissions due to direct $N_2O$ emissions at the baseline crop cultivation area and indirect $N_2O$ emissions from nitrogen fertilizer application (t $CO_2$/t-N) |
| $EF_{N2O,PJ}$ | = | Emission factor for $N_2O$ emissions due to direct $N_2O$ emissions at the project crop cultivation area and indirect $N_2O$ emissions from nitrogen fertilizer application (t $CO_2$/t-N) |

17. Project proponents may claim $CO_2$ emission reductions for the production of synthetic fertilizers ($EF_{CO2,P}$) for the share of synthetic fertilizer to the total nitrogen fertilizers shown to have historically been used on the participant farms *i*. The emission factor provided in “AMS-III.A: Offsetting of synthetic nitrogen fertilizers by inoculant application in legumes-grass rotations on acidic soils on existing cropland” for urea may be used, taking into account the nitrogen content of urea. annex 2 of AMS-III.A provides default data for calculating the t $CO_2$ emitted per metric ton of other fertilizers consumed.

18. Emission factor for $N_2O$ comprises of emission factor due to direct $N_2O$ emissions at the baseline and/or project crop cultivation areas and indirect $N_2O$ emissions due to nitrogen fertilizer application. Project proponents will have following options for calculation of emission factor for $N_2O$ emissions.



### 5.3.4. Option 1: using IPCC default value

19. Option 1 is a simple default to convert *N* of the applied fertilizers into $N_2O$ emissions at the baseline and project crop areas. It does not require any direct monitoring and ~~shall be~~is based on the most conservative estimate of emissions from the range provided by IPCC 2006 Guidelines.[7] This default, which is the sum of both direct and indirect emissions, shall be taken from the following table.

**Table 2. Default values**

| t CO2/t-N | Organic fertilizer | Synthetic fertilizer |
|---|---|---|
| Other crops | 6.20 | 6.67 |
| Rice | 2.93 | 3.40 |

~~The emission factors for baseline and project emissions are equivalent, and are the sum of the emission factors for direct and indirect emissions.~~

~~$$EF_{N2O,BL} = EF_{N2O,PJ} = EF_{N2O,direct,IPCC} + EF_{N2O,indirect,IPCC}$$~~ ~~Equation (7)~~

[7] Volume 4, Chapter 11, Table 11.1. and equations 11.1, 11.9, 11.10.

Where:

| | | |
|---|---|---|
| $EF_{N2O,direct,IPCC}$ | = | Emission factor due to $N_2O$ emissions at the crop cultivation area (t $CO_2$/t-N) |
| $EF_{N2O,indirect,IPCC}$ | = | Emission factor due to indirect $N_2O$ emissions from nitrogen fertilizer application (t $CO_2$/t-N) |

### 5.3.4.1. Emission factor for direct $N_2O$ emissions ($EF_{N2O,\ direct,\ IPCC}$)

$$EF_{N2O,direct,IPCC} = EF_{IPCC1} \times MW_{N2O} \times GWP_{N2O} \quad \text{Equation (8)}$$

Where:

| | | |
|---|---|---|
| $EF_{IPCC1}$ | = | IPCC conversion factor for direct $N_2O$ emissions from nitrogen fertilizer application, a value of 0.01 is used for all crops, except flooded rice fields, where the value 0.003 is used (t-$N_2O$-N/t-N) |
| $MW_{N2O}$ | = | Ratio of molecular weights of $N_2O$ and *N* (44/28) (t-$N_2O$/t-N) |
| $GWP_{N2O}$ | = | Global Warming Potential for $N_2O$ |

### 5.3.4.2. Emission factor for indirect $N_2O$ emissions ($EF_{N2O,\ indirect,\ IPCC}$)

20. Indirect $N_2O$ emissions occur outside the project boundary, which are attributable to the nitrogen fertilizers applied. By saving nitrogen fertilizers application, the project activity may claim for the avoided indirect emissions, which is strictly a leakage effect. The emission reduction is taken into account by applying the emission factor derived from the conversion rates for indirect $N_2O$ emissions as per the IPCC approach

$$EF_{N2O,indirect,IPCC} = \left(FRAC_{gas} \times EF_{IPCC2} + FRAC_{leach} \times EF_{IPCC3}\right) \times MW_{N2O} \times GWP_{N2O} \quad \text{Equation (9)}$$

Where:

| | | |
|---|---|---|
| $FRAC_{gas}$ | = | Fraction of fertilizer N that volatilizes as $NH_3$ and $NO_X$. A default value of 0.15 is used by taking the average rates for synthetic fertilizers (0.10) and organic fertilizers (0.20) as per IPCC 2006 Guidelines[8] (kg N volatilized/kg N applied) |
| $FRAC_{leach}$ | = | Fraction of *N* added (synthetic or organic) to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs. A default value of 0.30 is used according to IPCC 2006 Guidelines[9] (kg N leached/kg N applied) |

[8] Volume 4, Chapter 11, Table 11.3

[9] Volume 4, Chapter 11, Table 11.3

| | | |
|---|---|---|
| $EF_{IPCC2}$ | = | Emission factor for $N_2O$ emissions from atmospheric deposition of N on soils and water surfaces. A default value of 0.01 is used according to IPCC 2006 Guidelines[10] (kg $N_2O$ -N/kg$NH_3$-N+$NO_X$-N) |
| $EF_{IPCC3}$ | | Emission factor for $N_2O$ emissions from N leaching and runoff. A default value of 0.0075 is used according to IPCC 2006 Guidelines[11](kg $N_2O$ -N/kgN leached) |

### 5.3.5. Option 2: using the DNDC model

20. Project proponents can also have the option of estimating direct and indirect $N_2O$ emissions for baseline and project crop cultivation areas ($EF_{N2O,BL}$ and $EF_{N2O,PJ}$) by applying the DNDC model as described in appendix 3 of this methodology. In this case the emission factor resulting from the DNDC for baseline crop cultivation areas shall be capped[12] to 51.15 t $CO_2$e/t-N (till December 2012) and 49.17 t $CO_2$e/t-N (onward January 2013) for all crops except rice and for rice the factor will be capped at 39.45 t $CO_2$/t-N (till December 2012) and 37.93 t $CO_2$/t-N (onward January 2013).

21. The DNDC model shall be validated to the specific crop and region of project implementation. This requires the most infrastructure and cost but is likely to provide a more accurate calculation of actual emissions. Refer to appendix 3 for reference. Project proponents may refer to existing literature on model validation for the specific project area and crops used in baseline as well as project scenarios. Model validation through literature reference is only applicable if project proponents are able to demonstrate that the studies referred to have used the updated version of the model and have validated application for the same set of conditions/parameters of where crop is grown in the project activity. A literature review of DNDC model validations is provided in appendix 2 for reference. Alternatively, project proponents may wish to undertake a model validation study prior to project implementation. Model validation must be carried out for the baseline crop and area parameters as well as the NUE crop and parameters in the project scenario. Project proponents can follow methodologies provided in model validation studies available from the University of New Hampshire website <http://www.dndc.sr.unh.edu/>. The DNDC model requires inputs of various soil characteristics like texture, density and soil organic carbon content as well as inputs of crop characteristics like tillage, fertilization and irrigation. These input data are required for the project site. Since the project activity is based on the use of NUE seed the only parameters that could change are the fertilizer requirements and crop characteristics of the alternative seed.

22. Input parameters for the DNDC model can be divided into two types:

    (a) Static input parameters: the parameters of climate and soil that remain the same for baseline as well as project scenarios;



[10] Volume 4, Chapter 11, Table 11.3

[11] Volume 4, Chapter 11, Table 11.3

[12] This was obtained by multiplying the sum of highest value with uncertainty range for IPCC conversion factors for direct and indirect $N_2O$ emissions from nitrogen fertilizer application by the ratio of molecular weight of *N* to $N_2O$ i.e. 44/28 multiplied by the GWP of $N_2O$ as applicable during the crediting period.

(b) Management input parameters: the parameters of cropping characteristics, tillage, fertilization and irrigation.

A list of all input parameters and data sources is available in appendix 1.

23. The calculated emissions from the DNDC model will be converted into emission factor by taking into account the monitored quantity of nitrogen fertilizers applied in the monitored farms/fields ($Q_{NF,y}$).

$$EF_{N2O,BL} = \frac{\sum_i EF_{N2O,BL,\text{modeled},y,i}}{\sum_i Q_{NF,BL,y,i}} \quad \text{Equation (10)}$$

$$EF_{N2O,PJ} = \frac{\sum_i EF_{N2O,PJ,\text{modeled},y,i}}{\sum_i Q_{NF,PJ,y,i}} \quad \text{Equation (11)}$$

Where:

| | | |
|---|---|---|
| $EF_{N20,BL,modeled,y,i}$ | = | Total $N_2O$ emissions (direct and indirect, in $CO_2$ equivalent) from the crop area *i* modeled at the baseline cultivation conditions during the year *y* (t $CO_2$) |
| $EF_{N20,PJ,modeled,y,i}$ | = | Total $N_2O$ emissions (direct and indirect, in $CO_2$ equivalent) from the crop area *i* modeled at the project cultivation conditions during the year *y* (t $CO_2$) |
| $Q_{NF,BL,y,i}$ | = | Amount of nitrogen fertilizers applied on the crop area *i* cultivated with the baseline conditions during the year *y* (t-N) |
| $Q_{NF,PJ,y,i}$ | = | Amount of nitrogen fertilizers applied on the crop area *i* cultivated with the project cultivation conditions during the year *y* (t-N) |



### 5.3.6. Option 3: Direct monitoring

#### 5.3.6.1. Emission factor for direct $N_2O$ emissions ($EF_{N2O,\ direct,\ measured}$)

24. Project proponents can also have the option of doing direct $N_2O$ emission measurements on crop fields cultivated with the project seeds and nitrogen application rates. This requires the most infrastructure and cost, but is likely to provide the most accurate calculation of actual emissions. The process for testing follows appendix 5. The direct measurements will be at a control group of selected representative fields *k* for each year. For each monitoring strata (a set of farms/fields with similar static and dynamic conditions) a minimum of three fields is selected. The measured fluxes of $N_2O$ to the atmosphere during the crop cultivation will be converted into emission factor, by taking into account the monitored quantity of nitrogen fertilizers applied in the monitored

farms/fields ($Q_{NF,k,y}$). By applying this option, it may be assumed that the project and baseline fields will have the same $N_2O$ emission factor per unit mass of nitrogen fertilizer applied. Emission factor for indirect $N_2O$ emissions are calculated as per the IPCC default method (Option 1).

$$EF_{N2O,BL} = EF_{N2O,PJ} = EF_{N2O,direct,measured} + EF_{N2O,IPCC,indirect} \quad \text{Equation (12)}$$

$$EF_{N2O,direct,measured} = \frac{\sum_k EF_{N2O,k,measured,y}}{\sum_k Q_{NF,k,y}} \times GWP_{N2O} \quad \text{Equation (13)}$$

Where:

| | | |
|---|---|---|
| $EF_{N2O,k,measured,y}$ | = | Measured total nitrous oxide emitted to the atmosphere as $N_2O$ from the directly monitored field $k$ in the year $y$ (t-$N_2O$) |
| $Q_{NF,k,y}$ | = | Amount of nitrogen in the fertilizers applied on the monitored field $k$ during the year $y$ (t-N) |
| $k$ | = | 1, 2, 3 indices for the fields/farms selected to direct measurements of $N_2O$ emissions |

### 5.4. Leakage

25. No leakage calculation is required.



## 6. Monitoring methodology

26. The monitoring plan will be described in the project design document for determination of each parameter of Equation (1), based on sampling and measurements or in default values. The ex post monitoring will be done at control groups (participant farms that are selected to determine the yearly NUE at project and baseline conditions). For that purpose, project proponents shall set up a database which holds data and information that allow an unambiguous identification of participating farms, including name and address of the farmer, size of the cultivated field and additional information regarding the dynamic and static conditions. Dynamic conditions are those connected to the management practice (e.g. the type and conditions for nitrogen fertilizer applications). Static conditions are site-specific parameters that characterize the soil. The PDD should use the different dynamic and static conditions to describe a stratified sampling design, for example the farms with similar soil and management practices will be set as strata for representative sampling. The yearly farms selected to compose the control groups for project and baseline conditions will be set up by an intervening independent third party,[13] based on the stratified sampling design described in the PDD.

27. For each farm *i* taking part in the project activity, the appropriate historic data for synthetic nitrogen fertilizer, crop yield, and management practices shall be established. It

[13] The independent third party may be a DOE, a national or international accredited entity for certification of quality management or environmental management systems, or a governmental body.

shall be verified that no change of agricultural practices occurred during the time period selected. Farmers shall sign statement of review forms to confirm project applicability conditions.

28. Relevant parameters shall be monitored as indicated in section 6.1 below. The applicable requirements specified in the “General guidelines for SSC CDM methodologies” shall be taken into account by the project proponents. When measurements are made, tools will be calibrated to manufacturer specifications.

29. Farmer records shall be cross-checked with records from seed suppliers and synthetic nitrogen fertilizer suppliers. In case of discrepancies between farmer records and those from the respective suppliers, the most conservative value shall be taken.

## 6.1. Data and parameters monitored

**Data / Parameter table 1.**

| **Data / Parameter:** | $P_{pj,y}$ |
|---|---|
| Data unit: | T |
| Description: | Amount of crop produced by project activity in year *y* |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |



**Data / Parameter table 2.**

| **Data / Parameter:** | $P_{i,y}$ |
|---|---|
| Data unit: | T |
| Description: | Amount of crop produced by the individual farm/field *i* in the year *y* |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 3.**

| **Data / Parameter:** | $P_{j,y}$ |
|---|---|
| Data unit: | T |
| Description: | Crop production of the farms/fields *i* cultivated using the baseline technology, measured in tonnes of output |
| Source of data: | Farmer records |

| | |
|---|---|
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 4.**

| **Data / Parameter:** | $Q_{NF,j,y}$ |
|---|---|
| Data unit: | t-N |
| Description: | Total quantity of nitrogen fertilizers utilized by the farms/fields utilizing the baseline technology |
| Source of data: | Farmer records[14] |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 5.**

| **Data / Parameter:** | $Q_{NF,i,y}$ |
|---|---|
| Data unit: | t-N |
| Description: | Total quantity of nitrogen fertilizers utilized by the farms/fields utilizing the project technology |
| Source of data: | Farmer records[15] |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |



**Data / Parameter table 6.**

| **Data / Parameter:** | $A_{i,y}$ |
|---|---|
| Data unit: | ha |
| Description: | Cultivated area at the individual participant field/farm *i* |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |

[14] Total nitrogen applied is calculated using total fertilizer applied and nitrogen content of the fertilizer.

[15] Total nitrogen applied is calculated using total fertilizer applied and nitrogen content of the fertilizer.

| | |
|---|---|
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 7.**

| **Data / Parameter:** | $AUE_{pj,y}$ |
|---|---|
| Data unit: | t/ha |
| Description: | Area cultivation efficiency (productivity) in project scenario |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 8.**

| **Data / Parameter:** | **Crop type** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |



**Data / Parameter table 9.**

| **Data / Parameter:** | **Planting date** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 10.**

| **Data / Parameter:** | **Harvest date** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |

| | |
|---|---|
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 11.**

| **Data / Parameter:** | **Fraction of leaves and stems left in field after harvest** |
|---|---|
| Data unit: | % |
| Description: | – |
| Source of data: | Default value or farmers records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 12.**

| **Data / Parameter:** | **Maximum achievable crop yield for the region** |
|---|---|
| Data unit: | kg dry matter/ha |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |



**Data / Parameter table 13.**

| **Data / Parameter:** | **Number of tillage events** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 14.**

| **Data / Parameter:** | **Date of each tillage event** |
|---|---|
| Data unit: | N/A |

| | |
|---|---|
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 15.**

| **Data / Parameter:** | **Depth of each tillage event** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 16.**



| **Data / Parameter:** | **Number of fertilizer applications** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 17.**

| **Data / Parameter:** | **Date of each fertilizer event** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 18.**

| **Data / Parameter:** | **Fertilizer application method** |
|---|---|
| Data unit: | N/A |
| Description: | either surface or injection |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 19.**

| **Data / Parameter:** | **Fertilizer type** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |



**Data / Parameter table 20.**

| **Data / Parameter:** | **Fertilizer application rate** |
|---|---|
| Data unit: | kg N/ha |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 21.**

| **Data / Parameter:** | **Number of organic amendment applications per year** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |

| | |
|---|---|
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 22.**

| **Data / Parameter:** | **Date of application** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 23.**

| **Data / Parameter:** | **Type of organic amendment** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |



**Data / Parameter table 24.**

| **Data / Parameter:** | **Application rate** |
|---|---|
| Data unit: | kg C/ha |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 25.**

| **Data / Parameter:** | **Ratio of C/N in the organic amendment** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Field measurements |

| | |
|---|---|
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 26.**

| **Data / Parameter:** | **Number of irrigation events** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 27.**

| **Data / Parameter:** | **Date of irrigation events** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |



**Data / Parameter table 28.**

| **Data / Parameter:** | **Irrigation type** |
|---|---|
| Data unit: | N/A |
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 29.**

| **Data / Parameter:** | **Irrigation application rate** |
|---|---|
| Data unit: | Mm |

| | |
|---|---|
| Description: | – |
| Source of data: | Farmer records |
| Measurement procedures (if any): | – |
| Monitoring frequency: | Annual |
| QA/QC procedures: | – |
| Any comment: | – |

**Data / Parameter table 30.**

| **Data / Parameter:** | $A_i$ |
|---|---|
| Data unit: | Ha |
| Description: | Area of field/farm *i* |
| Source of data: | – |
| Measurement procedures (if any): | Strata area must be delineated ex-ante through use of GPS coordinates and/or legal parcel records and shall not change during the duration of the project |
| Monitoring frequency: | Once prior to validation |
| QA/QC procedures: | – |
| Any comment: | – |

# 7. Project activity under a programme of activities



30. No specific measures for consideration of leakage in case of programs of activities apply. ~~Farmer records shall be cross-checked with records from seed suppliers and synthetic nitrogen fertilizer suppliers. In case of discrepancies between farmer records and those from the respective suppliers, the most conservative value shall be taken.~~

# Appendix 1. Inputs to the DNDC model

1. The table below summarizes the inputs to the DNDC model.

**Table 1. DNDC input parameters and data sources**

| Input Category | Input | Units | Data source | | | |
|---|---|---|---|---|---|---|
| | | | Project records/ baseline plot | Measured | Lookup[(b)] | Default |
| Location | GPS location of stratum | decimal° | | X | | |
| Climate | Atmospheric background $NH_3$ concentration | µg N/m$^3$ | | | X | X |
| | Atmospheric background $CO_2$ concentration | ppm | | | X | X |
| | N concentration of rainfall | mg N/l or ppm | | X | X | |
| | Daily precipitation | Cm | | | X | |
| | Daily max temp | $^0$C | | | X | |
| | Daily min temp | $^0$C | | | X | |
| Soils[(a)] | Land-use type | type | | X | X | |
| | Clay content | 0-1 | | X | X | |
| | Bulk density | g/cm$^3$ | | X | X | |
| | Soil pH | value | | X | X | |
| | SOC at surface soil | kg C/kg | | X | X | |

| **Input Category** | **Input** | **Units** | **Data source** | | | |
|---|---|---|---|---|---|---|
| | Soil texture | type | | X | X | |
| | Slope | % | | X | | |
| | Depth of water retention layer | cm | | X | X | |
| | High groundwater table | cm | | X | X | |
| | Field capacity | 0-1 | | X | | X |
| | Wilting point | 0-1 | | X | | X |
| Cropping System | Crop type | type | X | | | |
| | Planting date | date | X | | | |
| | Harvest date | date | X | | | |
| | C/N ratio of the grain | ratio | | X | X | X |
| | C/N ratio of the leaf + stem tissue | ratio | | X | X | X |
| | C/N ratio of the root tissue | ratio | | X | X | X |
| | Fraction of leaves and stem left in field after harvest | 0-1 | | X | | |
| | Maximum yield | kg dry matter/ha | X | | | |
| Tillage System | Number of tillage events | number | X | | | |
| | Date of tillage events | date | X | | | |
| | Depth of tillage events | 6 depths[a] | X | | | |
| Synthetic N Fertilizer | Number of fertilizer applications | number | X | | | |
| | Date of each fertilizer application | date | X | | | |
| | Application method | surface / injection | X | | | |
| | Type of fertilizer | type[b] | X | | | |

| Input Category | Input | Units | Data source | | | |
|---|---|---|---|---|---|---|
| | Fertilizer application rate | kg N/ha | X | | | |
| | Time-release fertilizer (if used) | # days for full release | X | | | |
| | Nitrification inhibitors (if used) | | X | | | |
| Organic Fertilizer | Number of organic applications per year | number | X | | | |
| | Date of application | date | X | | | |
| | Type of organic amendment | type | X | | | |
| | Application rate | kg C/ha | X | | | |
| | Amendment C/N ratio | ratio | | | | X |
| Irrigation System | Number of irrigation events | number | X | | | |
| | Date of irrigation | date | X | | | |
| | Irrigation type | 3 types[c] | X | | | |
| | Irrigation application rate | Mm | X | | | |



[(a)] Soil parameters for DNDC are for the properties of the top layer of the soil profile;

[(b)] Values can be referenced from appropriate national or regional databases. Climate parameters can be obtained from the nearest weather station.

i. 0, 5, 10, 20, 30, 50 cm;
ii. DNDC accepts seven types of fertilizers: Urea, Anhydrous Ammonia, Ammonium Nitrate, Nitrate, Ammonium Bicarbonate, Ammonium Sulfate and Ammonium Phosphate;
iii. Flood, sprinkler, or surface drip tape.

# Appendix 2. Validation studies comparing DNDC predictions against experimental measurement[(a)]

**Table 1. Validation studies comparing DNDC predictions against experimental measurement**

| Reference | Systems modelled | Predicted properties | Countries | Version (if stated) |
|---|---|---|---|---|
| Babu et al. (2005) | Rice | Grain yield; $CH_4$ emission | India | |
| Babu et al. (2006) | Rice, Rice-Wheat | $N_2O$, $CH_4$ | India | |
| Beheydt et al. (2007) | Grassland; Crops | Soil $NH_4^+$, $NO_3^-$, WFPS, $N_2O$ | Belgium | DNDC 8.3P |
| Beheydt et al. (2008) | Crops | Soil $NH_4^+$, $NO_3^-$, WFPS, $N_2O$ | Belgium | DNDC 8.3 P |
| Brown et al. (2002) | Grassland; Winter wheat | $N_2O$ | UK | UK-DNDC |
| Cui et al. (2005a) | Forested wetland | $CH_4$; $N_2O$; Net ecosystem carbon exchange | USA | Wetland-DNDC |
| Cui et al. (2005b) | Forested wetland | $CH_4$, $CO_2$, SOC, gross photosynthesis | USA | Wetland-DNDC |
| Cui et al. (2005) | Forested wetland | $CH_4$, net ecosystem carbon exchange | USA | Wetland-DNDC + MIKE SHE |
| Frolking et al. (1998) | Grazed rangeland; Grass ley; Crop rotations | $N_2O$, soil WFPS; soil $NO_3^-$, soil $NH_4^+$ | USA; Scotland; Germany | |
| Grant et al. (2004) | | | | |
| Hsieh et al. (2005) | Grazed grassland | $N_2O$ | Ireland | |
| Kesik et al. (2005) | Forest | $N_2O$, NO | Multiple sites across Europe | PnET-N-DNDC |
| Kiese et al. (2005) | Tropical rainforest | $N_2O$ | Australia; Costa Rica | PnET-N-DNDC |
| Lamers et al. (2007a) | Forest | $N_2O$ | Germany | Forest-DNDC 3.7W |
| Lamers et al. (2007b) | Forest | $N_2O$ | Germany | Wetland-DNDC |
| Li et al. (1992b) | Native shortgrass prairie; Fallow (organic soil); Cut ryegrass; Grassland; Winter wheat | $N_2O$; ($N_2 + N_2O$); $CO_2$ | USA; England; Germany | |
| Li et al. (1994a) | Wheat straw on bare soil; Grassland; Winter wheat; Crop rotations | % Undecomposed residue; $CO_2$ emission; long-term SOC | Costa Rica; Germany; USA; England | |
| Li et al. (1994b) | Bare soil; St Augustine grass; Sugarcane | $N_2O$; soil $NO_3^-$ | USA | |
| Li et al. (1997) | Grass; Crop rotations | SOC | England; Australia; Germany; Czech Republic | |
| Li (2000) | Winter wheat; Maize; Rice | NO; $N_2O$; $CH_4$; $NH_3$ | China; Costa Rica; USA | |
| Lu et al. (2008) | Forest (*Abies fabric*) | Soil $CO_2$ | China | Forest-DNDC |
| Miehle et al. (2006a) | Eucalyptus | Above ground C | Australia | Forest-DNDC |
| Pathak et al. (2005) | Rice | Grain yield, total biomass, crop N uptake, $CH_4$, $N_2O$ | India | |
| Saggar et al. (2004) | Dairy-grazed pasture | $N_2O$, soil WFPS | New Zealand | NZ-DNDC |
| Saggar et al. (2007b) | Sheep-grazed pasture | $N_2O$, $CH_4$ | New Zealand | NZ-DNDC |
| Smith et al. (2002) | Crops | $N_2O$ | Canada | DNDC 7.1 |
| Smith et al. (2008) | Crops | Soil temperature, $NO_3^-$, $NH_4^+$, moisture content, $N_2O$ | Canada | |
| Stange et al. (2000) | Temperate forest | $N_2O$, NO, soil WFPS | USA, Austria, Denmark, Germany | PnET-N-DNDC |
| Wang et al. (1997) | Pasture | $N_2O$, $CO_2$ | Australia | Modified DNDC |
| Xu-Ri et al. (2003a) | Semi-arid grassland | $N_2O$; soil T; WFPS | China (Inner Mongolia) | |
| Zhang et al. (2002a) | Winter wheat; Rice; Corn | Soil water, LAI, above ground biomass, biomass of each organ; plant N | China; USA | Crop-DNDC |

[(a)] Source: Giltrap, Donna L., Changsheng Li, Surinder Saggar. 2010. *DNDC: A process-based model of greenhouse gas fluxes from agricultural soils, Agriculture Ecosystems and Environment.* 136 292-300.

# Appendix 3. Overview of DNDC modelling and guidance on DNDC implementation

1. A separate model run must be performed for each individual field or farm included in the project area using separate input parameter files (*.dnd) $EF_{NF,BL}$ for baseline control group and $EF_{NF,PJ}$ for project farms/fields can be calculated separately following the below steps outlined for DNDC modelling.

## 1. Calibration for crop yield

2. Prior to modelling, parameterization of soil physical conditions (which drive soil moisture dynamics) and crop simulation is crucial to calibrating the modelling of *C* and *N* biogeochemistry and $N_2O$ emissions. Through transpiration and *N* uptake, as well as depositing litter into soil, plant growth regulates soil water, *C* and *N* regimes, which in turn determine a series of biogeochemical reactions impacting soil carbon dynamics, $CH_4$, and $N_2O$ emissions. The DNDC crop model must be calibrated for cropping systems to be included in the project. In the DNDC model, crops are defined by the following parameters:

    (a) **Maximum biomass (kg C per ha)** - the maximum biomass productions for grain, leaves + stems (non-harvest above ground biomass), and roots under optimum growing conditions (namely, maximum biomass assuming no N, water or growing degree day limitations). The unit is kg C/ha (1 kg dry matter contains 0.4 kg C). If local data are not available, then literature values can be used;

    (b) **Biomass fraction** - the grain, leaves + stem, and root fractions of total biomass at maturity;

    (c) **Biomass C/N ratio** - Ratio of C/N for grain, leaves + stems, and roots at maturity;

    (d) **Total N demand (kg N per ha**) - Amount of the total N demanded by the crop to reach the maximum production;

    (e) **Thermal degree days (°C)** - cumulative air temperature from seeding till maturity of the crop;

    (f) **Water demand (g water/g dry matter)** - Amount of water needed for the crop to produce a unit of dry matter of biomass;

    (g) **N fixation index** - the default number is 1 for non-legume crops. For legume crops, the N fixation index is equal to the ratio (total N content in the plant)/(plant N taken from soil).

3. All crops to be included in the project must be calibrated in DNDC. The following steps are used for calibration:

    (a) Adjust maximum biomass parameter:

        (i) Enter observed maximum biomass and fraction for grain, leaves + stems and root. Provide more than adequate fertilization (i.e. use the autofertilization option in DNDC). Provide more than adequate irrigation (i.e. use the irrigation index mode and set the index to 1). Run the year with the actual local climate/soil conditions. Check the modelled grain yield – the difference between the modelled and observed grain yield should be less than 10 per cent:

a. If the difference is greater than 10 per cent and the modelled grain yield is less than the actual yield, increase the maximum biomass parameter;

b. If the difference is greater than 10 per cent and the modelled grain yield is greater than the actual yield, decrease the maximum biomass parameter;

(b) Adjust cumulative thermal degree days (TDD):

(i) Check the modelled maturity date which can be found in the Day_FieldCrop.csv file. The last column of this file shows daily grain weight (kg C/ha). The maturity date can be inferred by checking the last day where there is an increase in grain weight (i.e. the first day where the grain weight levels off):

a. If the modelled maturity date is later than the harvest date, reduce the TDD value;

b. If the modelled maturity date is earlier than the harvest date, increase the TDD value;



(c) Adjust water requirement:

(i) Change irrigation practices back to actual management practices while maintaining the high fertilizer application rate and run the model again:

a. If the modelled yield/biomass is lower than observed yield/biomass, decrease the water requirement value;

b. If the modelled yield/biomass is higher than observed yield/biomass, increase the water requirement value.

4. If the mean absolute deviation does not decrease below 10 per cent as crop parameters (optimal yield, TDD and crop water requirements) are refined, then choose the parameters set that provides the minimum mean absolute deviation and record the value of the minimum absolute deviation. Parameters shall be chosen using the literature and expert knowledge.

## 2. Uncertainty ranges for soil input parameters

5. Soil physical and chemical properties have a significant impact on $N_2O$ production, consumption, and emissions. Project proponents have the choice of estimating soil conditions based on field samples or available soil databases. If field measurements are used, then the target precision level for each soil parameter shall be +/-10 per cent of the mean at a 90 per cent confidence level. The distribution of the field values shall be assumed to be normally distributed. If soil survey data from available databases are

used, then default uncertainty estimates shall be set based on uncertainty estimates and probability distribution functions provided by the database.

6. Soil measurement data must not be older than 10 years prior to the project start date and official laboratory statements must be available for verification. DNDC requires that soil input parameters are obtained from the top 10 cm of soil depth. The following procedures must be followed for soil sampling:

   (a) Samples must be collected at two depth increments: 0-5 cm and 0-10 cm;

   (b) Samples must be collected using a core method;

   (c) 20 samples must be collected for one field/farm per stratum (derived based on a 90 per cent confidence level and 10 per cent acceptable error); 16 samples at 0-5 cm depth and 4 samples at 0-10 cm depth;

   (d) To ensure spatial independence of soil properties, a random sampling pattern must be used;

   (e) Samples should be combined together by depth;

   (f) The GPS coordinates and depth at each sampling location must be recorded;

   (g) The combined 0-5 cm samples must be tested for all parameters;

   (h) The combined 0-10 cm samples must be tested for soil bulk density, pH, and clay fraction;

   (i) Soil samples must be analyzed by a certified soil laboratory.



7. For each sampling event, a log must be developed including the following information:

   (a) Date of sampling event;

   (b) Description of the core method and compositing procedure;

   (c) GPS coordinates of each sampling location;

   (d) Core depth of each sample;

   (e) Name/address of third-party soil sampling contractor (if applicable);

   (f) Name/address of the certified soil laboratory used for analysis.

## 3. Model run

8. $N_2O$ emissions factor is determined by performing Monte Carlo simulation with 2000 DNDC simulations using input parameters. Due to the uncertainty of input soil parameters, DNDC must be run through a Monte Carlo analysis for emissions calculations. The duration of each Monte Carlo run should be the same as the duration of the cultivation cycle for the field. Once the Monte Carlo run is complete, results are recorded in a CSV file in the C:\DNDC\Result\Record\MonteCarlo folder. The name of the file is the site name as entered into DNDC. From the CSV file extract the direct $N_2O$ emissions, nitrate leaching, $NH_3$ and NO emissions for Monte Carlo run *j* for each field/farm *i* as follows:

| | | |
|---|---|---|
| $NL_{DIRECT,j,i}$ | = | Direct annual $N_2O$ emissions in field/farm *i* from Monte Carlo run *j* (kg $N_2O$ -N/ha) |
| $NL_{LEACH,j,i}$ | = | Annual nitrate leaching loss in field/farm *i* from Monte Carlo run *j* (kg $NO_3$-N/ha) |
| $NL_{VOLAT,j,i}$ | = | Annual ammonia volatilization and nitric oxide emissions in field/farm *i* from Monte Carlo run *j* (kg $NH_3$-N/ha + $NO_X$-N/ha volatilized) |

9. Total direct and indirect $N_2O$ emissions ($EF_{N20,j,i}$) in t $CO_2$e/ha in field/farm *i* for Monte Carlo run *j* are calculated as follows:

$$EF_{N20,j,i} = \left(NL_{,DIRECT\ j,i} + \left(NL_{VOLAT,j,i} \times EF_2\right) + \left(NL_{LEACH,j,i} \times EF_3\right)\right) \times MW_{N2O} \times GWP_{N2O}$$

Equation (1)

Where:

| | | |
|---|---|---|
| $EF_{N20,j,i}$ | = | $N_2O$ emissions for Monte Carlo run *j* in field/farm *i* within the project boundary (t $CO_2$-e/ha) |
| $NL_{,DIRECT\ j,i}$ | = | Direct annual $N_2O$ emissions in field/farm *i* from Monte Carlo run *j* (kg $N_2O$ -N/ha) |
| $NL_{LEACH,j,i}$ | = | Annual nitrate leaching loss in field/farm *i* from Monte Carlo run *j* (kg $NO_3$-N/ha) |
| $NL_{VOLAT,j,i}$ | = | Annual ammonia volatilization and nitric oxide emissions in field/farm *i* from Monte Carlo run *j* (kg $NH_3$-N/ha + $NO_X$-N/ha volatilized) |
| $EF_2$ | = | Emission factor for $N_2O$ emission from atmospheric deposition of *N* on soils and water surfaces and subsequent volatilization (default = 0.01; IPCC AFOLU Guidelines 2006[1]) (kg $N_2O$ -N/(kg $NH_3$-N + $NO_X$-N volatilized) |
| $EF_3$ | = | Emission factor for $N_2O$ emission from N leaching and runoff (default = 0.0075; IPCC AFOLU Guidelines 2006[2]) (kg $N_2O$ -N/kg N leaching/runoff)) |
| $MW_{N2O}$ | = | Ratio of molecular weights of $N_2O$ and N (44/28) (t $N_2O$/t-N) |
| $GWP_{N2O}$ | = | Global Warming Potential for $N_2O$ |
| $j$ | = | 1, 2, 3 ... N Monte Carlo runs |
| $i$ | = | 1, 2, 3 … M fields/farms |

10. Total average emissions in t $CO_2$e/ha in field/farm *i* for all Monte Carlo runs are calculated as follows:



[1] Volume 4 Chapter 11 Table 11.3

[2] Volume 4 Chapter 11 Table 11.3

$$EF_i = \frac{\sum_{j=1}^{N}\left(EF_{N2O,j,i}\right)}{N} \qquad \text{Equation (2)}$$

Where:

| | | |
|---|---|---|
| $EF_i$ | = | $N_2O$ emissions within the project boundary for field/farm *i* for all Monte Carlo runs (t $CO_2$e/ha) |
| $EF_{N2O,j,i}$ | = | $N_2O$ emissions for Monte Carlo run *j* in field/farm *i* within the project boundary (t $CO_2$e/ha) |
| $j$ | = | 1, 2, 3 ... N Monte Carlo runs |
| $i$ | = | 1, 2, 3 … M fields/farms |

11. The total $N_2O$ emissions in within the project boundary can be estimated as the sum of emissions for all fields/farms.

$$EF_y = \left(\sum_{i=1}^{M}(EF_i \times A_i)\right) \qquad \text{Equation (3)}$$

Where:

| | | |
|---|---|---|
| $EF_y$ | = | $N_2O$ emissions within the project boundary (t $CO_2$e/yr) |
| $A_i$ | = | Area of field/farm *I* (ha) |
| $i$ | = | 1, 2, 3 … M fields/farms |



## 4. Model uncertainty

12. Under the DNDC modelling approach, the project proponent has the option of replacing standard default input values with project-specific measurements. Project-specific measurements will decrease the model uncertainty, thereby decreasing the uncertainty and required discounting. Derivation of model uncertainty is described in appendix 4.

# Appendix 4. Estimation of uncertainty modelled emissions

1. Model uncertainty shall be derived from the set of 2000 Monte Carlo runs for both the baseline control group and project farms/fields simulations separately. Model uncertainty at 90 per cent confidence level shall be calculated on a per field/farm basis as follows:

$$Uncertainty_{BSL,i} = \frac{\left(\frac{S_{BSL,i}}{\sqrt{4096}}\right) \times 1.645}{BE_i}$$ Equation (1)

$$Uncertainty_{P,i} = \frac{\left(\frac{S_{P,i}}{\sqrt{4096}}\right) \times 1.645}{PE_i}$$ Equation (2)

Where:

| | | |
|---|---|---|
| $Uncertainty_{BSL,i}$ | = | Total uncertainty in field/farm *i* in baseline scenario (%) |
| $Uncertainty_{P,i}$ | = | Total uncertainty in field/farm *i* in project scenario (%) |
| $S_{BSL,i}$ | = | Standard deviation of the modeled baseline GHG emissions in field/farm *i* derived from the Monte Carlo runs |
| $S_{P,i}$ | = | Standard deviation of project GHG emissions in field/farm *i* derived from the Monte Carlo runs |
| $BE_i$ | = | $N_2O$ emissions within the project boundary in the baseline scenario for field/farm *i* for all Monte Carlo runs (t $CO_2$e/ha) |
| $PE_i$ | = | $N_2O$ emissions as a result of NUE seed use within the project boundary for field/farm *i* for all Monte Carlo runs (t $CO_2$e/ha) |
| $j$ | = | 1, 2, 3 … N Monte Carlo runs |
| $i$ | = | 1, 2, 3 … M fields/farms |

1. Standard deviations are calculated as below:

$$S_{BSL,i} = \sqrt{\frac{\sum_{j=1}^{N} \left(BE_{N20,j,i} - BE_i\right)^2}{4096 - 1}}$$ Equation (3)

$$S_{P,i} = \sqrt{\frac{\sum_{j=1}^{N} \left(PE_{N20,j,i} - PE_i\right)^2}{4096 - 1}}$$ Equation (4)

Where:

| | | |
|---|---|---|
| $BE_{N20,j,i}$ | = | $N_2O$ emissions within the project boundary in the baseline for Monte Carlo run *j* in field/farm *I* (t $CO_2$e/ha) |
| $PE_{N20,j,i}$ | = | $N_2O$ emissions within the project boundary in the project scenario for Monte Carlo run *j* in field/farm *I* (t $CO_2$e/ha) |

2. The total uncertainty for the project is calculated by propagating errors across strata and then between the error in baseline emissions and the error in project emissions:

$$Uncertainty_{BSL} = \sqrt{Uncertainty_{BSL,i1}^2 + Uncertainty_{BSL,i2}^2 + \cdots} + Uncertainty_{BSL,iM}^2$$ Equation (5)

$$Uncertainty_P = \sqrt{Uncertainty_{P,i1}^2 + Uncertainty_{P,i2}^2 +} \cdots + Uncertainty_{P,iM}^2$$ Equation (6)

$$ER_{Error} = \sqrt{Uncertainty_{BSL}^2 + Uncertainty_P^2}$$ Equation (7)



Where:

| | | |
|---|---|---|
| $ER_{Error}$ | = | Total uncertainty for project (%) |
| $Uncertainty_{BSL}$ | = | Total uncertainty in baseline scenario (%) |
| $Uncertainty_P$ | = | Total uncertainty in project scenario (%) |

3. Uncertainty deduction

If:

| | |
|---|---|
| $ER_{Error} \leq$ 10% of $ER_y$ | then no deduction for uncertainty is required |
| $ER_{Error} >$ 10% of $ER_{Error}$ | then, |

$$ER_y = ER_y - \left(ER_y \times (ER_{Error} - 10\%)\right)$$ Equation (8)

Where:

| | | |
|---|---|---|
| $ER_y$ | = | Total emission reductions due to the project activity (t $CO_2$e/yr) |
| $ER_{Error}$ | = | Total uncertainty for project (%) |

# Appendix 5. Guidelines for measuring nitrous oxide emissions from crop fields

1. The implementation of gas measurement in fields requires the involvement of experts in this field or at least experienced staff trained by experts (i.e. from research institutions). These guidelines cannot replace expertise in setting up chamber measurements. They rather set minimum requirements that serve for standardizing the conditions under which $N_2O$ emissions are measured for projects under this methodology.

2. Project proponents shall prepare a detailed plan for the $N_2O$ measurements before the start of the rice growing season. The plan shall include the schedule for the field and laboratory measurements, the logistics that are necessary to get the gas samples to the laboratory and a cropping calendar. The plan shall also include all reference field specific information regarding location and climate, soil, water management, plant characteristics, fertilizer treatment and organic amendments.

3. The following guidance is structured according to the steps from field measurement to emission factor calculation. Project proponents shall make sure that the measurements on project reference fields are carried out in an equal manner and simultaneously. This guidance is based on the United States Department of Agriculture's (USDA) publication.[1] This publication can be referenced for further information on trace gas measurements.



**Table 1. On the field - technical options for the chamber design**

| Feature | Conditions |
|---|---|
| **Chamber material** | Flux chambers should be fabricated of non-reactive materials (stainless steel, aluminum, PVC, polypropylene, polyethylene, or plexiglass)<br>Material should be white or coated with reflective material (mylar or painted) |
| **Chamber size** | Chambers should be large enough to cover at least 182 cm2 of the soil surface, and have a target height of 15 cm (height can be decreased to increase sensitivity or increased to accommodate plants) |
| **Auxiliaries of chamber** | Chambers should contain a vent tube, at least 10 cm long and 4.8 mm in diameter (e.g. 1/4"stainless steel tubing)<br>Chambers should have a sampling port to enable the removal of gas samples. Possible options include: butyl rubber septa or a nylon/polyethylene stopcock |

[1] Parking, T.B. and Venterea, R.T., 2010, Sampling Protocols, Chapter 3, Chamber-Based Trace Gas Flux Measurements, IN Sampling Protocols, R.F. Follett, editor, p.3-1 to 3-39, available at: <www.ars.usda.gov/research/GRACEnet>.

| Feature | Conditions |
|---|---|
| **Chamber anchor** | Anchors are fabricated so that they can accommodate the flux chamber during measurement phase.<br>Anchors can be made of 20 cm (or larger) diameter PVC. Alternatively, anchors can be made of thin-walled stainless steel or aluminium to minimize physical disturbance upon insertion |

**Table 2. On the field – air sampling**

| Feature | Conditions |
|---|---|
| **Anchors deployment** | Anchors should be installed at least 8 cm into the ground and extend no more than 5 cm above the surface. Permanent anchors should be installed at least 24 h prior to first flux measurement. In cultivated systems, chamber anchors are typically removed prior to cultivation, planting, or fertilizer application and then replaced |
| **Chamber placement** | In row-crop systems it is important that chambers be deployed to adequately represent the system. Chambers can be placed both between and within rows in row-crop agriculture. Inclusion of plants within chambers requires larger chambers while smaller chambers can be used between rows for higher sensitivity |
| **Frequency and timing of flux measurements** | To account for diurnal variability, measure flux at times of the day that more closely correspond to the daily average temperature (mid-morning, early evening). To account for perturbation-induced variations is recommended that fluxes be measured as soon as possible after the perturbation (such as rainfall, tillage, or fertility event), then daily for the next several days during and following the specific event. During the remainder of the year, gas flux measurements should be made at regular time intervals (every 1 or 2 weeks). It is highly recommended that fluxes be measured at least weekly and more frequently if resources allow |
| **Spatial variability** | Use chambers with larger footprint to minimize small scale variability. Use as many chambers as possible. It is recommended that ‘similar’ landscape elements be identified and a sampling design employed where chambers are stratified by landscape element, soil type, or vegetation |
| **Exposure time** | No more than 60 minutes |
| **Gas sampling** | Sampling is performed by inserting a polypropylene syringe into the chamber septa and slowly removing a gas sample with as little disturbance as possible. Typically, from 5 to 30 ml are removed |
| **Sample storage until analysis** | Storage < 24 h: air samples can remain in syringe<br>Storage > 24 h: transfer air samples into evacuated vial, store with slight overpressure |

**Table 3. Laboratory analysis**

| Feature | Conditions |
|---|---|
| **Method** | Gas Chromatograph with electron capture detector (ECD) |
| **Injection** | GC should be fit with a sample valve to minimize injection error and thus increase analytical precision |
| **Standards** | Several different standard concentrations should be run, as detector response may be nonlinear. The range of standards should bracket the concentrations found in samples (e.g. $N_2O$; 0.1, 1.0 and 10 ppm) |

## 1. Calculation of the emission rate for a plot (reference field)

4. For each gas analysis, calculate the mass of $N_2O$ emissions with the help of the following formula:

$$m_{N2O,t} = C_{N2O,t} \times V_{Chamber} \times M_{N2O} \times \frac{1_{atm}}{R \times T_t \times 1000} \quad \text{Equation (1)}$$

Where:

| | | |
|---|---|---|
| $m_{N2O,t}$ | = | Mass of $N_2O$ in chamber at time *t* (mg) |
| $t$ | = | Point of time of sample (e.g. 0, 15, 30 in case of three samples within 30 minutes) |
| $C_{N2O,t}$ | = | $N_2O$ concentration in chamber at time *t*, from gas analysis (ppm) |
| $V_{Chamber}$ | = | Chamber volume (L) |
| $M_{N2O}$ | = | Molar mass of $N_2O$: 44.0129 (g/mol) |
| $1_{atm}$ | = | Assume constant pressure of 1atm, unless pressure measurement is installed |
| $R$ | = | Universal gas constant: 0.08206 (L atm/K mol) |
| $T_t$ | = | Temperature at time *t* (K) |



5. Determine the slope of the line of best fit for the values of $M_{N2O}$ over time with the help of software (e.g. Excel):

$$s = \frac{\Delta m_{N2O}}{\Delta t} \quad \text{Equation (2)}$$

Where:

| | | |
|---|---|---|
| $s$ | = | Slope of line of best fit (mg/min) |

6. Calculate the emission rate per hour for one chamber measurement:

$$RE_{ch} = s \times \frac{60_{min}}{A_{chamber}} \quad \text{Equation (3)}$$

Where:

| | | |
|---|---|---|
| $RE_{ch}$ | = | Emission rate of chamber $ch$ (mg/h x m²) |
| $ch$ | = | Index for replicate chamber on a plot |
| $A_{chamber}$ | = | Chamber area (m²) |

7. Calculate the average emission rate of a chamber measurement per plot:

$$RE_{plot} = \frac{\sum_{ch=1}^{Ch} RE_{Ch}}{Ch}$$ Equation (4)

Where:

| | | |
|---|---|---|
| $RE_{plot}$ | = | Average emission rate of a plot (mg/h m²) |
| $Ch$ | = | Number of replicate chambers per plot |

8. Further procedure: From the average emission rates per plot of each chamber measurement, derive the seasonally integrated emission factor by integration of the measurement results over the season length. The simplest way of integration is multiplying the emission rate with the number of hours of the measurement interval (e.g. one week) and accumulating the results of every measurement interval over the season. Convert from mg/m² to kg/ha by multiplying with 0.01. The emission factor can then be multiplied by the total area of the farm/fields in order to calculate the total $N_2O$ emissions.



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## Document information

| Version | Date | Description |
|---|---|---|
| Draft 02.0 | 5 September 2014 | SSC WG 45, Annex 13<br>A call for public input will be issued on this draft revised methodology.<br>The revision streamlines the sources and calculations of default emission factors, replacing a calculation procedure. |
| 01.0 | 23 November 2012 | EB 70, Annex 26<br>Initial adoption. |

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