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The American Carbon Registry® Methodology for N_2O Emission Reductions through Changes in Fertilizer Management

Version 2.0
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WINROCK INTERNATIONAL

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2 ACRONYM LIST

See latest version of *ACR Standard* for a full list of acronyms. The following additional acronyms are used in this methodology.

AFOLU Guidelines	Agriculture, Forestry and Other Land Uses section of IPCC Guidelines for National Greenhouse Gas Inventories 2006
ALM	Agricultural Land Management
ALM ACR project activity	Agricultural Land Management activity implemented per ACR requirements
DNDC	DeNitrification-DeComposition, a simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems
GPG LULUCF	IPCC Good Practice Guidance for Land-Use Land Use Change and Forestry
N	Nitrogen
N_2	Dinitrogen
N_2O	Nitrous oxide
NASS	USDA - National Agricultural Statistics Service
NCV	Net Calorific Value
NH_3	Ammonia
NO	Nitric oxide
NO_3^-	Nitrate
NRCS	Natural Resources Conservation Service of the U.S. Department of Agriculture
PDF	Probability Distribution Function
PRA	Participatory Rural Appraisal

SOC	Soil organic carbon
SSURGO	Soil Survey Geographic Database of the NRCS National Cartography and Geospatial Center
UAN	Urea Ammonium Nitrate
WFPS	Water Filled Pore Space

3 PURPOSE, SOURCES, DEFINITIONS, APPLICABILITY

3.1 Purpose

This methodology is applicable to Agricultural Land Management (ALM) ACR Project Activities that involve a change in fertilizer management. This may include changes in fertilizer application rate, type (synthetic or organic fertilizers), placement, timing, use of timed-release fertilizers, use of nitrification inhibitors, and other technologies and/or practices. Project Activities must meet all applicability conditions in Section 1.5 to use this methodology.

The methodology uses DNDC – a peer-reviewed, tested and highly parameterized model – to estimate, for baseline and project scenarios, direct N_2O emissions from fertilizer use and indirect emissions from leaching and ammonia volatilization.

Projects using this methodology must comply with all requirements of the *ACR Standard*, submit a GHG Project Plan for certification by ACR, and secure independent validation and verification by an ACR-approved third-party verifier of the GHG Project Plan and GHG assertions.

3.2 Sources

This methodology is based on elements from the following methodologies:

- Approved CDM methodology AR-ACM0001 “Afforestation and reforestation of degraded land”
- CDM “Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities”
- ACR methodology for Voluntary Emission Reductions in Rice Management Systems, v1.0

3.3 Selected Baseline Approach

Field-specific historical emissions, or common practice, as applicable. Three approaches are distinguished:

1. **Baseline Approach 1**: projects that propose to reduce fertilizer application rate, without changing any other aspect of fertilizer management such as the implementation of Variable Rate Technology, timing, placement, or composition, must use a Field Specific Historical Baseline.
2. **Baseline Approach 2**: projects that propose to change fertilizer management by adjusting more than just application rate, and for which the Project Activity has a current adoption rate less than

or equal to 5% within the Reference Region around the project[1] must use a Common Practice Baseline.

3. **Baseline Approach 3**: projects that propose to change fertilizer management by adjusting more than just application rate, and for which the Project Activity has a current adoption rate greater than 5% within the Reference Region must use a Field Specific Historical Baseline.

Project Proponents have two options to determine the current adoption rate of a specific practice: using survey data, or using expert opinion.

- **Survey data**. The current adoption must be determined using a statistically valid survey of producers within the Reference Region where the project is located. The survey must be designed to achieve a relative precision that is better than ±25% with 90% confidence, i.e. 90% of the time. In addition, procedures must be in place to minimize digitization errors. It is acceptable that the survey ultimately has a smaller precision on the condition that Project Proponents can demonstrate that this smaller precision was not impacted by systematic errors.. The average of all available survey data must be used to calculate the current adoption rate (including those published in validated GHG Project Plans). For initial validation, 1 data point in the past 5 years suffices to quantify the baseline adoption rate. However, upon renewal of a project's Crediting Period, the current adoption rate must be based on the average of at least 2 time points in the 5 years preceding the Crediting Period.
- **Expert opinion**. If 3 independent experts assert that the current adoption rate of a given practice is less than 2% of the acres within the Reference Region, no survey has to be conducted, and projects using the practice may use a Common Practice Baseline. The independent experts must have at least 10 years of relevant experience in agronomy and must be associated with an academic institution, government institution, or must be a certified crop advisor with experience in the Reference Region. The validity of the independent experts shall be evaluated during validation of a GHG Project Plan.

3.4 Definitions

Specifically defined terms are capitalized throughout this methodology. Definitions in the latest version of the *ACR Standard* apply. The following additional definitions are used in this methodology:

[1] A reference region is a wider region in which the broad climatic and soil conditions are relatively homogeneous. It is up to the Project Proponent to propose a valid reference region. However, the proposed reference region must be recognized by the USDA, extension service specialists, or agricultural commissioners.

Accuracy	The degree of closeness of repeated measurements under unchanged conditions to their true or actual value.
Calibration	The process of tuning the coefficients of Model Parameters, of a process-based model such as DNDC, to observations.
Common Practice Baseline	The Baseline used when the Project Activity implemented has a current adoption rate below or equal to 5% within the Reference Region.
Crediting Period	The finite length of time for which a GHG Project Plan is valid, and during which a project can generate offsets against its Baseline Scenario. The Baseline Scenario must be re-evaluated in order to renew the Crediting Period. The Crediting Period applies to the Project overall, rather than being field-specific.
Ex-ante	At validation of the GHG Project Plan; also refers to estimates made of GHG reductions prior to verification.
Ex-post	At verification; also refers to GHG reductions actually monitored and verified.
Field-Specific Historic Baseline	The Baseline used when the Project Activity implemented has a current adoption rate greater than 5%, and for projects that propose to reduce fertilizer application rate without changing any other aspect of fertilizer management.
Model Parameter	A data item that is supplied as input to a process-based model.
Model Validation	The process of evaluating calibrated model results using field-measured data and quantifying the residual (structural) uncertainty.
Parameterization	The selection of Model Parameters that a process-based model such as DNDC will use for simulation.
Precision	The degree to which repeated measurements under unchanged conditions show the same results.
Project	A group of fields on which Project Activities take place.
Project Activity	Change in fertilizer management that leads to a reduction in GHG emissions in comparison to the baseline management and GHG emissions. This may include changes in fertilizer application rate, type (synthetic or organic fertilizers), placement, timing, use of timed-release fertilizers, use of nitrification inhibitors, and other technologies and/or practices. Project Activities must meet all applicability conditions

	in Section 1.5 to use this methodology.
Project Participants	Individual farmers managing fields and taking part in the Project. Each Project Participant may enroll one or more fields on which Project Activities are implemented. Project Participants may work with a Project Proponent serving as aggregator.
Project Proponent	As defined in the *ACR Standard*, "an individual or entity that undertakes, develops, and/or owns a project. This may include the project investor, designer, and/or owner of the lands/facilities on which project activities are conducted. The Project Proponent and landowner/facility owner may be different entities." The Project Proponent may be an aggregator working with multiple Project Participants in a single Project. The Project Proponent holds the account on ACR.
Reference Region	A geographic region in which the broad climatic and soil conditions are relatively homogeneous. It is up to the Project Proponent to propose a valid Reference Region and justified this to the Validation/Verification Body. However, the proposed Reference Region must be recognized by the USDA, extension service specialists, or agricultural commissioners.
Structural Uncertainty	The inherent uncertainty of process-based models that remains even if all input data were error-free.
Uncertainty Deduction	Deduction, accounting for both uncertainty in input parameters and model Structural Uncertainty, applied to the emission reductions calculated by DNDC to ensure that credited emission reductions remain conservative.
Validation/ Verification Body	A competent and independent person, persons or firm responsible for performing the validation and/or verification process. To conduct validation and verification the VVB must be ACR-approved and accredited by the American National Standards Institute (ANSI), or be a Designated Operational Entity approved under Clean Development Mechanism or Accredited Independent Entity approved under Joint Implementation.

3.5 Applicability

This methodology is applicable to Agricultural Land Management (ALM) ACR project activities that involve a change in fertilizer management. This may include changes in fertilizer application rate, type (synthetic or organic fertilizers), placement, timing, use of timed-release fertilizers, use of nitrification inhibitors, and other technologies and/or practices.

The conditions under which the methodology is applicable are:

- Management in both baseline and project cases involves use of fertilizer for enhancing crop growth and survival on agricultural lands;
- Farms must have records of yields and fertilizer application amounts from at least 5 previous years;
- Projects must not lead to a significant (>5%) decrease in yields as a result of project implementation. If yield in the project scenario decreases by >5%, relative to the baseline scenario, leakage shall be calculated and deducted per section 4;
- Project must incorporate a minimum of 5 individual fields[2];
- Fertilizer use must not be increased on all crops on owned or managed lands that are not part of the Project;
- On organic soils[3] Project Activities may not lead to an increase in tillage relative to baseline practices.
- Project Activities may not involve the drainage or flooding of wetlands.
- This methodology is only applicable to those crops, management systems and Land Resources regions where the DNDC model has been sufficiently independently validated to statistically quantify model structural uncertainty (see Section 8.3).

Emission reductions from changes in fertilizer management are permanent and cannot be reversed. This methodology therefore requires no buffer or other risk mitigation mechanism.

[2] Fields may be adjacent but must be justifiable as individual fields at the time of verification.

[3] Soils are organic if they satisfy the requirements 1 and 2, or 1 and 3 below:

1. Thickness of 10 cm or more. A horizon less than 20 cm thick must have 12 percent or more organic carbon when mixed to a depth of 20 cm;

2. If the soil is never saturated with water for more than a few days, and contains more than 20 percent (by weight) organic carbon (about 35 percent organic matter);

3. If the soil is subject to water saturation episodes and has either:

(i) At least 12 percent (by weight) organic carbon (about 20 percent organic matter) if it has no clay; or

(ii) At least 18 percent (by weight) organic carbon (about 30 percent organic matter) if it has 60 percent or more clay; or

(iii) An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

4 BASELINE METHODOLOGY PROCEDURE

4.1 Project Boundary and Eligibility of Land

ACR defines the GHG offset project boundary to include a Project's geographical implementation area, the GHG sources and sinks considered, and project duration.

4.1.1 Physical boundary

The physical boundary geographically delineates the ALM Project Activity under the control of the Project Participants. The ALM ACR Project Activity may contain more than one discrete area of land. At the time the GHG Project Plan is submitted, the following shall be defined:

- Each discrete area of land shall have a unique geographic identification;
- Aggregation of agricultural properties with multiple landowners is permitted under the methodology, with aggregated areas treated as a single Project;
- The Project Proponent shall describe legal title to the land, rights of access to the avoided GHG emissions, current land tenure, and fertilizer management for each discrete area of land;
- The Project Participants shall justify that, during the project lifetime, each discrete area of land is expected to be subject to a change in fertilizer management through activities under the control of the Project Participants.

4.1.2 GHG assessment boundary

Carbon pools are not monitored as part of this methodology, as changes in stocks as a result of fertilizer management under this methodology are considered to be positive (and therefore conservative to omit) or *de minimis*.

The emission sources included in or excluded from the project boundary area shown in Table 1.

Table 1: Emissions sources included in the project boundary

Sources	Gas	Included / Excluded	Justification / Explanation of choice
Direct and Indirect Nitrous Oxide Emissions Resulting from Fertilizer Application	CO_2	Excluded	Not applicable
	CH_4	Excluded	Not applicable
	N_2O	Included	GHG emitted from fertilizer application
Emissions resulting from Fossil	CO_2	Included	GHG emitted from fossil fuel combustion

Fuel Combustion	CH_4	Included	GHG emitted from fossil fuel combustion
	N_2O	Included	GHG emitted from fossil fuel combustion

4.1.3 Project duration

Project Activities may be implemented for one year or longer. Crediting Period is as specified in the *ACR Standard* or relevant ACR sector standard. Project Proponents shall apply this methodology to model the baseline and project scenarios for each reporting year since the previous verification, using the DNDC-required inputs for that reporting year. Per the *ACR Standard*, the frequency of verification depends on desired frequency of ERT issuance; all emission reductions attributable to the Project Activity must be verified prior to issuance.

4.2 Identification of the Baseline Scenario and Additionality

4.2.1 STEP 0. Preliminary screening based on the Start Date of the ALM project activity

As indicated in the *ACR Standard*, agriculture, forestry and other land use (AFOLU) projects with a Start Date of 1 November 1997 or later are eligible for registration.

If the Project Proponent claims the Start Date of the ALM ACR project activity is more than one year before the date of submission of a GHG Project Plan, then the Proponent shall:

- Provide evidence that the Start Date of the ALM ACR Project Activity was after 1 November 1997, and
- In the case of projects using Baseline Approach 3, provide evidence that the incentive from the planned sale of ERTs was considered in the decision to proceed with the Project Activity. This evidence shall be based on (preferably official, legal and/or other corporate) documentation that was available to third parties at, or prior to, the Start Date of the Project Activity.

4.2.2 STEP 1. Determination of Baseline Scenario

Projects that fall under Baseline Approach 2 as described in section 1.3 must use a Common Practice Baseline and are deemed additional and may, therefore, skip steps 1 and 2. Projects that fall under Baseline Approaches 1 and 3 must follow steps 1 and 2.

The Project Proponent shall identify realistic and credible scenarios that would have occurred on the land within the proposed Project boundary in the absence of the ALM ACR Project Activity. All scenarios shall

be feasible for the project participants, taking into account relevant national and/or sectoral policies[4] and circumstances, such as historical practices and economic trends. The identified management scenario shall be limited to agricultural land uses. This process should clearly identify barriers and benefits of all potential scenarios.

If the current adoption rate of the proposed Project Activity is greater than 5%, the possible land-use scenarios to be evaluated shall include:

- Continuation of the pre-Project fertilizer management (historical baseline);
- Fertilizer management as modeled under the Project but in the absence of registration as an ALM ACR Project Activity;
- Adoption of precision agriculture;
- Change in crop to crops with lower fertilizer use.

For identifying realistic and credible management scenarios, field surveys, data and feedback from stakeholders, and information from other appropriate sources including Participatory Rural Appraisal (PRA)[5] may be used as appropriate. PRA techniques are not mandatory, provided the Project Proponent identifies realistic and credible management scenarios. All current fertilizer management within the boundary of the proposed ALM ACR Project Activity may be deemed realistic and credible.

Each of the identified land use scenarios shall be evaluated relative to the following tests:

- Investment analysis to determine that the proposed Project Activity is either: 1) not the most economically or financially attractive, or 2) not economically or financially feasible;
- Barriers analysis; and
- Common practice analysis.

Each of the land use scenarios that do not meet at least one of the a) common practice analysis, b) the barriers analysis and c) the investment analysis shall be excluded.

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[4] The Annex 3 to the report of the CDM Executive Board at its twenty-second meeting and the Annex 19 to the report of the EB at its twenty-third meeting clarify how the relevant national and/or sectoral policies shall be taken into account during identification of a baseline scenario. See: http://cdm.unfccc.int/Reference/Guidclarif.

[5] Participatory rural appraisal (PRA) is an approach to the analysis of local problems and the formulation of tentative solutions with local stakeholders. It makes use of a wide range of visualisation methods for group-based analysis to deal with spatial and temporal aspects of social and environmental problems. This methodology is, for example, described in Chambers R (1992): *Rural Appraisal: Rapid, Relaxed, and Participatory*. Discussion Paper 311, Institute of Development Studies, Sussex; and Theis J, Grady H (1991): *Participatory rapid appraisal for community development*. Save the Children Fund, London.

If fertilizer management as modeled under the Project but in the absence of registration as an ALM ACR Project Activity is not excluded, then the project is not additional.

Outcome of Step 1: List of plausible alternative fertilizer management scenarios to the ALM ACR Project Activity.

If the current adoption rate of the proposed Project Activity is less than or equal to 5%, the common practice of fertilizer management shall be used as the baseline scenario. The common practice of fertilizer management shall be described in terms of (1) source, (2) rate, (3) timing, and (4) placement and shall be based on actual management from at least 5 fields on which the common practice management is done. In addition, the management data shall be reviewed by at least 3 independent peer reviewers such as farm advisors, extension agents or academic scientists.

4.2.3 STEP 2. Additionality Test

If the Project uses Baseline Approach 1 or 3, the Project Proponent shall test the additionality of the Project Activity using the three-pronged ACR additionality test.[6] The Project Activity as described *ex ante* using this methodology and monitored using this methodology shall be evaluated alongside the baseline scenarios identified in Step 1. If a financial analysis or a demonstration of barriers does not lead to the preclusion of the Project Activity then the Project shall be considered non-additional. The application of an additionality tool is recommended.[7]

Outcome of Step 2: A project scenario with proven additionality or identification of a non-additional project.

If the current adoption rate of the proposed Project Activity is less than or equal to 5%, the proposed Project Activity is deemed additional. This is justified since, if the current adoption rate is less than 5% and hence a Common Practice Baseline is used, it is evident that there is no significant net advantage of implementing the Project Activity in the absence of an incentive from the planned sale of ERTs, and that barriers of a financial, technological, and/or institutional nature are present. Therefore no barrier analysis is required.

[6] As described in the *ACR Standard*.

[7] Such as the CDM Tool for the Demonstration and Assessment of Additionality at: http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-01-v5.2.pdf.

4.3 Stratification

If the Project area is not homogeneous, stratification must be carried out to improve the Accuracy and Precision of GHG emission estimates. Different stratifications may be required for the baseline and project scenarios in order to achieve optimal Accuracy and Precision of the estimates of net GHG emissions reductions.

For estimation of baseline emissions, strata must be defined on the basis of parameters that are key variables in any method used to estimate changes in agricultural emissions, for example:

- Management regime
- Soil type
- Planting history
- Drainage

The Project area must be stratified *ex ante*. Further stratification beyond the parameters given above is not usually warranted.

Note: In the equations used in this methodology, the letter *i* is used to represent a stratum and the letter *M* for the total number of strata.

4.4 Modeling Approach to Direct and Indirect Emissions from Fertilizer Management

4.4.1 Modeling of emissions from fertilizer application

The model used for calculation of emissions resulting from fertilization must be the DeNitrification-DeComposition (DNDC) model developed by the University of New Hampshire. DNDC is a computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems. The model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including nitrous oxide (N_2O), nitric oxide (NO), dinitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2).

DNDC is available at http://www.dndc.sr.unh.edu/.[8] Project Proponents shall download the latest version from that website, and must calibrate and validate the model per the guidance in this methodology. From time to time ACR may post versions of DNDC, already calibrated and validated for particular crops and

[8] Downloadable from http://www.dndc.sr.unh.edu/Models.html. Project Proponents shall use the latest version available.

regions, on the dedicated webpage for this methodology; Project Proponents should thus check the methodology webpage to see if the model has already been calibrated and validated for the crop and region of their Project, and if so may use the version of the model posted.

The model must be Parameterized for the specific conditions of the Project, and may not be used where cultivation is occurring on histosols (organic soils).

The output of the model must be the direct N_2O emissions ($NL_{DIRECT,j,i,t}$) in kg N_2O-N, the nitrate leaching loss ($NL_{LEACH,j,i,t}$) in kg NO_3^--N and the nitric oxide emissions and ammonia volatilization ($NL_{VOLAT,j,i,t}$) in kg NH_3-N, by strata, in both the baseline and project scenarios through the duration of the Project.

4.4.2 Input data to DNDC

DNDC model simulations require inputs on the location of crop fields, crops grown, local climate, soils and agricultural management practices. These input data are required for each baseline and project stratum.

The full list of inputs, units and data source is given in Table 2. More detail is found in the parameter tables.

Table 2. List of DNDC inputs with units and data source. Where two data sources are indicated, the choice rests with the Project Proponent.

Input Category	Code	Input	Units	Mandatory / Optional	Data Source			
					Project records	Measured	Look-up	Default
Location	L1	GPS location of stratum	decimal ^{o}	M		X		
Climate	CI	Atmospheric background NH_3 concentration	µg N/m^3	M				X
	C2	Atmospheric background CO_2 concentration	ppm	M				X
	C3	N concentration in rainfall	mg N/l or ppm	M			X	
	C4	Daily meteorology	multiple	M		X	X	
Soils**	S1	Land-use type	type	M	X			
	S2	Clay content	0-1	M		X	X	
	S3	Bulk density	g/cm^3	M		X	X	
	S4	Soil pH	value	M		X	X	
	S5	SOC at surface soil	kg C/kg	M		X	X	
	S6	Soil texture	type	M		X	X	
	S7	Slope	%	M		X		
	S8	Depth of water retention layer	cm	M		X	X	
	S9	High groundwater table	cm	M		X	X	
	S10	Field capacity	0-1	M		X		X
	S11	Wilting point	0-1	M		X		X
Cropping system	CR1	Crop type	type	M	X			
	CR2	Planting date	date	M	X			
	CR3	Harvest date	date	M	X			
	CR4	C/N ratio of the grain	ratio	M		X	X	
	CR5	C/N ratio of the leaf + stem tissue	ratio	M		X	X	
	CR6	C/N ratio of the root tissue	ratio	M		X	X	
	CR7	Fraction of leaves and stem left in field after harvest	0-1	M		X		
	CR8	Maximum yield	kg dry matter.ha^{-1}	M	X			

Tillage system	T1	Number of tillage events	number	M	X	
	T2	Date of tillage events	date	M	X	
	T3	Depth of tillage events	6 depths†	M	X	
N Fertilizer	F1	Number of fertilizer applications	number	M	X	
	F2	Date of each fertilizer application	date	M	X	
	F3	Application method	surface / injection	M	X	
	F4	Type of fertilizer	type*	M	X	
	F5	Fertilizer application rate	kg $N.ha^{-1}$	M	X	
	F6	Time-release fertilizer	# days for full release	M	X	
	F7	Nitrification inhibitors		M	X	
Organic Fertilizer	O1	Number of organic applications per year	number	M	X	
	O2	Date of application	date	M	X	
	O3	Type of organic amendment	type	M	X	
	O4	Application rate	kg $C.ha^{-1}$	M	X	
	O5	Amendment C/N ratio	ratio	M		X
Irrigation System	I1	Number of irrigation events	number	M	X	
	I2	Date of irrigation	date	M	X	
	I3	Irrigation type	3 types‡	M	X	
	I4	Irrigation application rate	mm	M	X	

†0, 5, 10, 20, 30, 50 cm

*DNDC accepts seven types of fertilizers: Urea, Anhydrous Ammonia, Ammonium Nitrate, Nitrate, Ammonium Bicarbonate, Ammonium Sulfate and Ammonium Phosphate.

‡Flood, sprinkler or surface drip tape

**Soil parameters for DNDC are for the properties of the top layer of the soil profile.

4.4.3 Running the DNDC model

The DNDC model is written in Visual C++ 6.0 and must be run on a Microsoft Windows operating system[9].

STEP 1: Calibrating DNDC crop model

Proper Parameterization of soil physical conditions (which drive soil moisture dynamics) and crop simulation plays a crucial role in modeling 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 N_2O emissions.

The Project Proponent shall calibrate the DNDC crop model for cropping systems to be included in the Project. Figure 1 outlines the steps for crop Calibration. In DNDC, crops are defined by the following parameters:

- ***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 $C.ha^{-1}$ (1 kg dry matter contains 0.4 kg C). If local data are not available, then literature values can be used. Maximum yield values will be used for step 2 in figure 1 below.
- ***Biomass fraction***: The grain, leaves+stem, and root fractions of total biomass at maturity.
- ***Biomass C/N ratio***: Ratio of C/N for grain, leaves+stems, and roots at maturity.
- ***Total N demand (kg N per ha)***: Amount of the total N demanded by the crop to reach the maximum production.
- ***Thermal degree days (°C)***: Cumulative air temperature from seeding till maturity of the crop.
- ***Water demand (g water/g dry matter***): Amount of water needed for the crop to produce a unit of dry matter of biomass.
- ***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).

Default values for these parameters are provided with DNDC and can be found in the C:\DNDC\Library\Lib_crop directory. There is a Crop_parameters.txt file that provides the look-up table

[9] Download an installation package from the following site: http://www.dndc.sr.unh.edu. After uncompressing the installation file package, double click "Install" in the package folder, and all of the directories and files of DNDC will be automatically created in a folder named DNDC in the C drive of your computer. The folder DNDC on your C drive contains the latest version of DNDC (e.g., DNDC9.5) and supporting data sets. Go to C:\DNDC, and click DNDC95.exe to start the model.

for crop numbers for each crop. All crops to be included in the ACR ALM Project Activity shall be calibrated in DNDC using at least 5 years of observed yields.

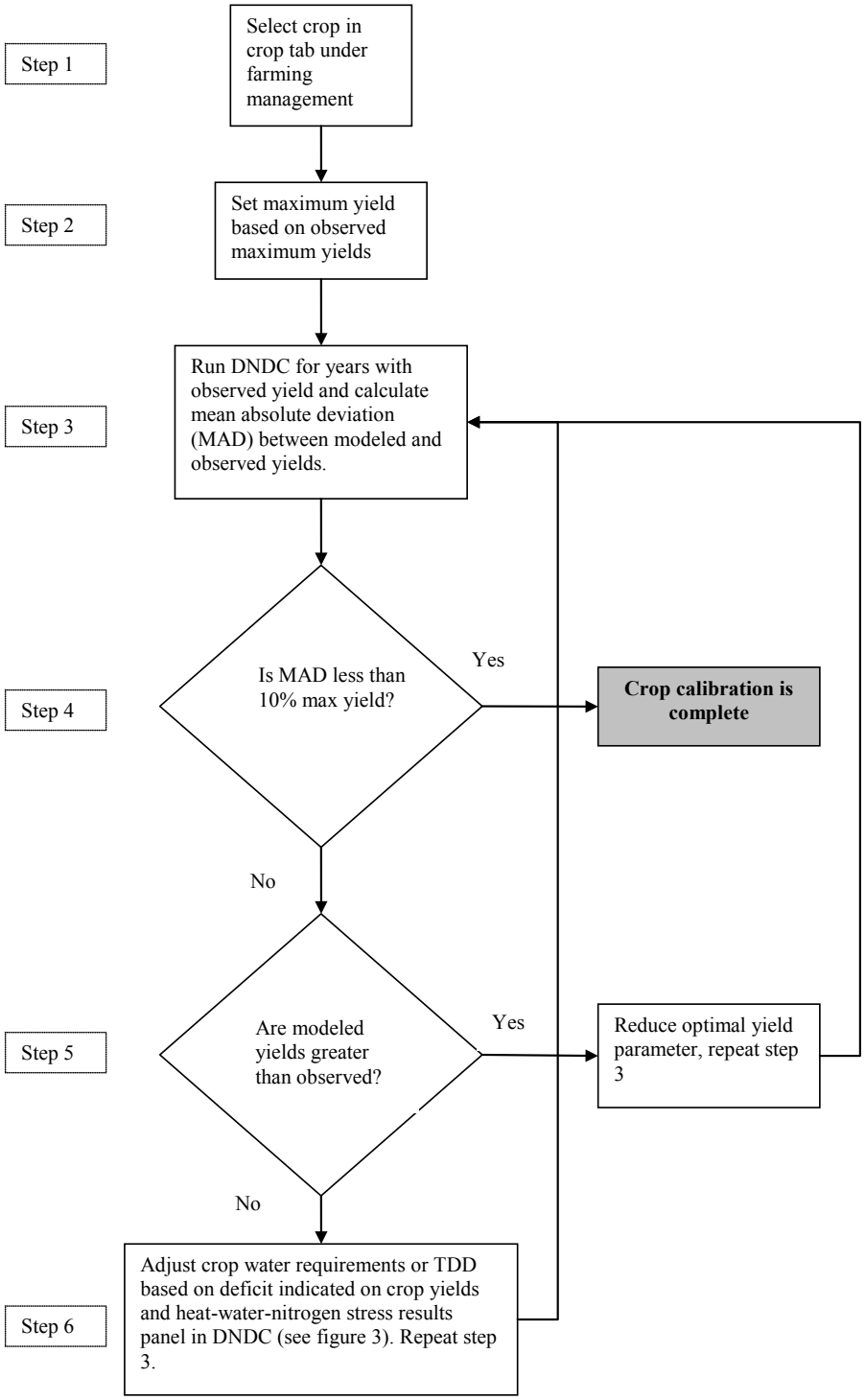


Figure 1: Crop calibration procedures. Where local data are not available literature may be used.

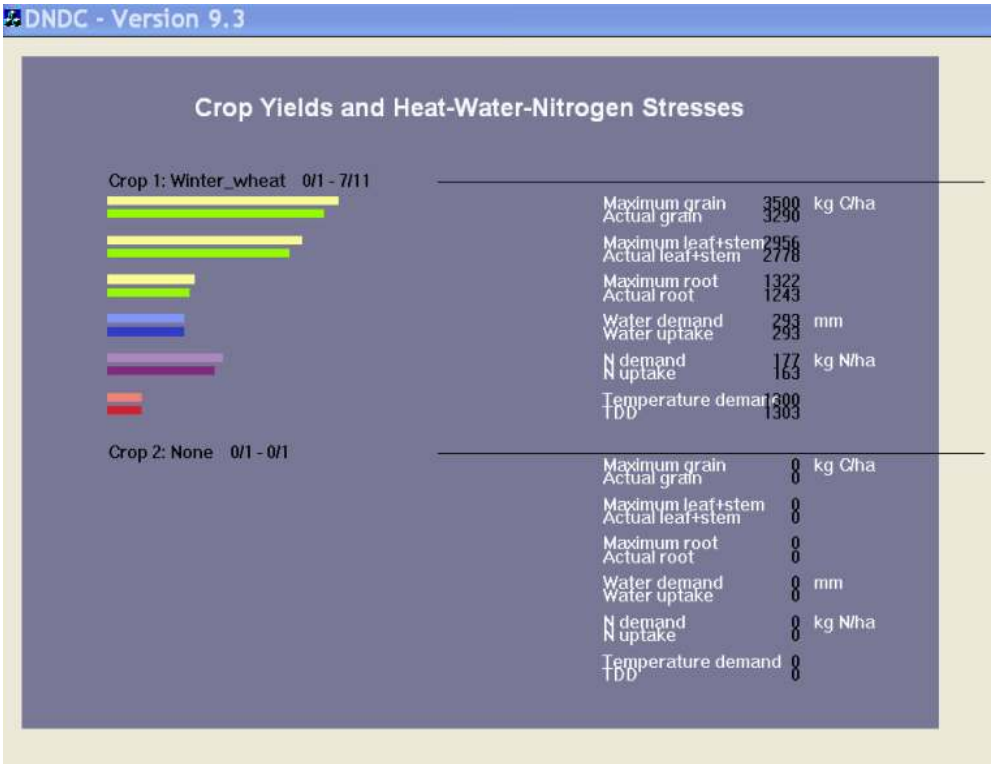


Figure 2: Example DNDC Crop Yield and Heat-Water-Nitrogen Stress panel.

Note: If maximal relative RMSE of 10% does not decrease below 10% (Step 4 in Figure 1) as crop parameters (optimal yield, TDD and crop water requirements) are refined, then choose the parameters set that provides the minimum relative RMSE and record the value of the minimum absolute deviation. Parameters shall be chosen using the literature and expert knowledge.

STEP 2: Define uncertainty ranges for input parameters

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 soil surveys. If field measurements are used, then the target precision level for each soil parameter shall be ±10% of the mean at a 90% confidence level. The distribution of the field values shall be assumed to be normally distributed.

If NRCS SSURGO soil survey data[10] are used for setting soil parameters, then default uncertainty estimates shall be set based on uncertainty estimates and probability distribution functions (PDF) listed in Table 3. For each stratum, the mean value shall be calculated as the area-weighted sum of the representative values for all compartments with the SSURGO MUKEY[11].

Table 3. Source selected from http://www.abdn.ac.uk/modelling/cost627/Questionnaire.htm

Parameter	PDF	Uncertainty
Bulk density	Log-normal	0.1 $g.cm^{-3}$
Clay content	Log-normal	+/- 10%
SOC	Log-normal	+/- 20%
pH	Normal	+/- 1 pH unit

STEP 3: Run DNDC in Monte Carlo mode for Baseline and Project N_2O Emissions

The baseline ($GHG_{BSL\_N2O,E,i,j}$) and project ($GHG_{P\_N2O,E,i,j}$) GHG emissions in stratum *i* for each Monte Carlo run *j* will be determined as the sum of direct and indirect emissions of N_2O resulting from application of fertilizers. Based on the uncertainty of input soil parameters quantified in STEP 2, DNDC will be run in Monte Carlo mode. The duration of the Monte Carlo runs should be the same as the duration of the Project (e.g. two-year Projects should perform a two-year Monte Carlo run). Previous cropping history has an impact on N_2O emissions. Thus, N_2O emissions for a given baseline year will be modeled by running DNDC for two years to include the year preceding the baseline year.

The Monte Carlo analysis is performed by modeling GHG emissions for both the baseline and project scenarios to calculate an input uncertainty deduction for each field in order to adjust for model uncertainty due to soil input parameter uncertainties. A multivariate lognormal distribution must be used to sample parameters for the Monte Carlo analysis[12]. At least 1,000 (n) different draws out of this multivariate lognormal distribution for both the Baseline Scenario and the Project Scenario and subsequent model simulations must be executed.

The DNDC model requires input parameters for soil organic carbon, clay fraction, pH and bulk density. It is well known that these soil parameters can be highly correlated. The Project Proponent may account

[10] See http://soils.usda.gov/survey/geography/ssurgo/.

[11] Polygon GIS layers are linked to attribute tables via an attribute called MUKEY.

[12] For example, using the rlnorm function of the R package (http://rss.acs.unt.edu/Rdoc/library/compositions/html/rlnorm.html).

for correlation among soils in Project areas to reduce the input uncertainty and deductions in project net emissions reductions. To do this, the Project Proponent may use soil attribute data from NRCS SSURGO soil survey in the Project area to calculate the correlation coefficient between the soil parameters by following the following 3 steps:

Step 1:Calculate Pearson correlation coefficients for each set of soil parameter pairs to create a correlation matrix.

Step 2: Apply a Cholesky decomposition of the correlation matrix to transform a set of standard-normal random numbers in the logarithm space.

Step 3: Once one soil parameter is pulled for each simulation in the Monte Carlo simulations, then the value for each of the other three soil properties is selected using the correlation based log-normal distribution.

Once the Monte Carlo run is complete, extract the direct N_2O emissions, nitrate leaching, NH_3 and NO emissions from the DNDC outputs for Monte Carlo run *j* in each stratum *i* as follows:

$NL_{DIRECT,j,i}$ Direct annual N_2O emissions in stratum *i* from Monte Carlo run *j*; kg N_2O-N.ha^{-1}

$NL_{LEACH,j,i}$ Annual nitrate leaching loss in stratum *i* from Monte Carlo run *j*; kg NO_3^--N.ha^{-1}

$NL_{VOLAT,j,i}$ Annual ammonia volatilization and nitric oxide emissions in stratum *i* from Monte Carlo run *j*; kg NH_3-N.ha^{-1} + NO_X-N.ha^{-1} volatilized

Calculate total average N_2O emissions in metric tons (t) CO_2-e.ha^{-1} in stratum *i* for all Monte Carlo runs as follows:

$$GHG_{BSL\_N_2O,E,j,i} = \left(NL_{DIRECT,j,i} + \left(NL_{VOLAT,j,i} * EF_4\right) + \left(NL_{LEACH,j,i} * EF_5\right)\right) * \frac{44}{28} * GWP_{N_2O} \quad \textbf{(1)}$$

$$GHG_{P\_N_2O,E,j,i} = \left(NL_{DIRECT,j,i} + \left(NL_{VOLAT,j,i} * EF_4\right) + \left(NL_{LEACH,j,i} * EF_5\right)\right) * \frac{44}{28} * GWP_{N_2O} \quad \textbf{(2)}$$

$$GHG_{BSL\_N_2O,E,i} = \frac{\sum_{j=1}^{N}\left(GHG_{BSL,N_2O,E,j,i}\right)}{n} \quad \textbf{(3)}$$

$$GHG_{P\_N_2O,E,i} = \frac{\sum_{j=1}^{N}\left(GHG_{P,N_2O,E,j,i}\right)}{n} \quad \textbf{(4)}$$

Where

$GHG_{BSL\_N2O,E,j,i}$	N_2O emissions as a result of fertilizer management Project Activities for Monte Carlo run *j* in stratum *i* within the project boundary in the baseline; t CO_2-e.ha^{-1}
$GHG_{P\_N2O,E,j,i}$	N_2O emissions as a result of fertilizer management Project Activities for Monte Carlo run *j* in stratum *i* within the project boundary for the project scenario; t CO_2-e.ha^{-1}
$GHG_{BSL\_N2O,E,j,i}$	N_2O emissions as a result of fertilizer application within the Project boundary in the baseline scenario for Monte Carlo run *j* in stratum *i*; t CO_2-e.ha^{-1}
$GHG_{P\_N2O,E,j,i}$	N_2O emissions as a result of fertilizer application within the Project boundary in the project scenario for Monte Carlo run *j* in stratum *i*; t CO_2-e.ha^{-1}
$NL_{DIRECT,j,i}$	Direct annual N_2O emissions in stratum *i* from Monte Carlo run *j*; kg N_2O-N.ha^{-1}
$NL_{LEACH,j,i}$	Annual nitrate leaching loss in stratum *i* from Monte Carlo run *j*; kg NO_3-N.ha^{-1}
$NL_{VOLAT,j,i}$	Annual ammonia volatilization and nitric oxide emissions in stratum *i* from Monte Carlo run *j*; kg NH_3-N.ha^{-1} + NO_X-N.ha^{-1} volatilized
EF_4	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 Vol.4 Ch.11 Table 11.3); kg N_2O-N (kg NH_3-N + NO_X-N volatilized)$^{-1}$
EF_5	Emission factor for N_2O emission from N leaching and runoff (default = 0.0075; IPCC AFOLU Guidelines 2006 Vol.4 Ch.11 Table 11.3); kg N_2O-N (kg N leaching/runoff)$^{-1}$
44/28	Ratio of molecular weights of N_2O and N; mol mol^{-1}
GWP_{N2O}	Global warming potential for N_2O (default = 310 for SAR-100 value in IPCC Fourth Assessment Report); t CO_2-e (t N_2O)$^{-1}$
j	*1, 2, 3 … N* Monte Carlo runs

i 1, 2, 3 …*M* strata

4.5 Baseline Net GHG Emissions

The baseline GHG emissions will be determined as the emissions of N_2O resulting from application of fertilizers. Changes in carbon stocks will not be significant and are not tracked.

$$BE = GHG_{BSL\_N_2O,E} + GHG_{BSL\_FF,E} + GHG_{BSL,F,E} \quad \textbf{(5)}$$

Where

BE Baseline greenhouse gas emissions; t CO_2-e

$GHG_{BSL\_N2O,E}$ N_2O emissions as a result of fertilizer management Project Activities within the Project boundary in the baseline; t CO_2-e

$GHG_{BSL\_FF,E}$ GHG emissions as a result of fossil fuel combustion within the project boundary in the baseline; t CO_2-e

$GHG_{BSL\_F,E}$ GHG emissions as a result of production of fertilizer used in the baseline; t CO_2-e

4.5.1 Accounting baseline emissions from fertilizer application

The GHG emissions in the baseline within the project boundary can be estimated as the sum of GHG emissions for all strata as follows:

$$GHG_{BSL\_N_2O,E} = \sum_{t=1}^{t^*}\left(\sum_{i=1}^{M}\left(GHG_{BSL,N_2O,E,i} * A_i\right)\right) \quad \textbf{(6)}$$

Where

$GHG_{BSL\_N2O,E}$ N_2O emissions as a result of fertilizer management Project Activities within the Project boundary in the baseline; t CO_2-e

$GHG_{BSL\_N2O,E,i}$ N_2O emissions from stratum *i* as a result of fertilizer application within the Project boundary in the baseline; t CO_2-e.ha^{-1}

A_i Area of stratum *i*

i	1, 2, 3 …*M* strata
t	*1, 2, 3 …t** years elapsed since the start of the ALM ACR project activity

4.5.2 Accounting baseline emissions from fossil fuel combustion

Emissions resulting from fossil fuel combustion during agricultural land management shall be calculated as follows:

$$GHG_{BSL\_FF,E} = \sum_{a} (Fuel_{a,t} \times EF_a) \quad \textbf{(7)}$$

Where

$GHG_{BSL\_FF,E}$	Net CO_2-e emissions from fossil fuel consumption in the baseline scenario; tCO_2-e
$Fuel_{a,t}$	Amount of fuel of type *a* consumed in year *t*; terrajoule (TJ)
EF_a	Emission Factor of Fuel type *a*; tCO_2-e.TJ^{-1}
a	Fuel type *a* (e.g. diesel, gasoline, etc.)

Where fuel data are collected in liters, the amount of fuel of a particular kind combusted in year *t* ($Fuel_{a,t}$) can be estimated as:

$$Fuel_{a,t} = \frac{\left(Liters_{Fuel_{a,t}} \times Density_{Fuel_a} \times NCV_{Fuel}\right)}{10^6} \quad \textbf{(8)}$$

Where

$Fuel_{a,t}$	Amount of fuel type *a* consumed in year *t*; TJ
$Liters_{Fuel\ a,t}$	Quantity of fuel of type *a* consumed in year *t*; ltr
$Density_{Fuel\ a}$	Density of fuel type *a*; $kg.ltr^{-1}$
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; $TJ.Gg^{-1}$
a	Fuel type *a* (e.g. diesel, gasoline, etc.)

In the parameter tables default values are provided for all parameters not monitored.

Where fuel data are collected in US gallons, the amount of fuel of a particular kind combusted in year *t* ($Fuel_{a,t}$) can be estimated as:

$$Fuel_{a,t} = \frac{\left(Gallons_{Fuel_{a,t}} \times Density_{Fuel_a} \times NCV_{Fuel}\right)}{10^6} \quad \textbf{(9)}$$

Where

$Fuel_{a,t}$	Amount of fuel type *a* consumed in year *t*; TJ
$Gallons_{Fuel\ a,t}$	Quantity of fuel of type *a* consumed in year *t*; gal
$Density_{Fuel\ a}$	Density of fuel type *a*; kg.gal^{-1}
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; TJ.Gg^{-1}
a	Fuel type *a* (e.g. diesel, gasoline, etc.)

In the parameter tables default values are provided for all parameters not monitored.

4.5.3 Accounting baseline emissions from fertilizer production

The CO_2 baseline emissions from the production of fertilizer applied on per cropland land area j are calculated as follows[13]:

$$GHG_{BSL,F,E} = \sum_{t=1}^{t}\left(\sum_{i=1}^{M}(A_i * AR_{i,f}\ ,*EF_{CO_2 f})\right) \quad \textbf{(10)}$$

Where

$GHG_{BSL\_F,E}$	Baseline GHG emissions as a result of production of fertilizer used; t CO_2-e
EF_{CO2f}	Emission factor for the production of synthetic nitrogen fertilizer; t CO_2 per ton synthetic nitrogen fertilizer
A_i	Area of land where fertilizer is applied for stratum *i*
$AR_{i,f}$	Average application rate of fertilizer *f* for stratum *i; t.ha^{-1}*

[13] Methods derived from CDM methodology "Offsetting of synthetic nitrogen fertilizers by inoculants application in legumes-grass rotations on acidic soils on existing cropland". Available at: http://cdm.unfccc.int/UserManagement/FileStorage/BZG8LM2WO95IDQJCF634VUYTPNEKRX

$EF_{CO2,f}$ is calculated following IPCC and CDM guidelines as follows:

If the fertilizer used is urea, the $EF_{CO2,f}$ = 1.54 t CO_2e per ton urea based on IPCC default values shall be used, which takes into account the fact that the total GHG emissions from urea would be GHG emissions during ammonia production – intermediate CO_2 storage in urea + CO_2 release due to urea application (see 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3: Industrial Processes and Product Use; Chapter 3.2 Ammonia Production).

In case of other synthetic nitrogen fertilizers in the absence of reliable project specific data, conservative values may be calculated (as long as the mass ratio of N in the fertilizer is known) using the following formula:

$$EF_{CO_2,f} = Ncont_f * 0.82 * 2.014 \quad \textbf{(11)}$$

Where

$EF_{CO2,f}$	The emission factor for the production of fertilizer *f*; t CO_2 per ton fertilizer *f*
$Ncont_f$	The N content of fertilizer *f* on a mass ratio basis (see parameter table for examples for common synthetic N fertilizer types); %
0.82	The mass ratio between N and NH_3
2.014	A conservative emission factor for ammonia production; t CO_2 per ton NH_3

4.6 Actual Net GHG Project Emissions

The actual net GHG project emissions shall be estimated using the equations in this section. When applying these equations for the *ex ante* calculation of net GHG project emissions, Project Proponents shall provide estimates of the values of those parameters that are not available before the start of monitoring activities. Project Proponents must retain a conservative approach in making these estimates.

$$PE = GHG_{P\_N_2O,E} + GHG_{P\_FF,E} + GHG_{P,F,E} \quad \textbf{(12)}$$

Where

PE	Actual net project emissions; t CO_2-e

$GHG_{P\_N2O,E}$ N_2O emissions as a result of fertilization within the Project boundaries in the project scenario; t CO_2-e

$GHG_{P\_FF,E}$ GHG emissions as a result of fossil fuel combustion within the Project boundaries in the project scenario; t CO_2-e

$GHG_{P\_F,E}$ Project GHG emissions as a result of production of fertilizer used; t CO_2-e

4.6.1 Estimation of GHG emissions within the Project boundary from fertilizer application

The GHG emissions from fertilization within the Project boundary can be estimated as the sum of GHG emissions from all strata as follows:

$$GHG_{P\_N_2O,E} = \sum_{t=1}^{t^*}\left(\sum_{i=1}^{M}\left(GHG_{P,N_2O,E,i} * A_i\right)\right) \quad \textbf{(13)}$$

Where

$GHG_{P\_N2O,E}$ N_2O emissions as a result of fertilization within the Project boundaries in the project scenario; t CO_2-e

$GHG_{P\_N2O,E,i}$ N_2O emissions from stratum *i* as a result of fertilizer application within the Project boundary in the project scenario; t CO_2-e.ha^{-1}

A_i Area of stratum *i*

i 1, 2, 3 …*M* strata

t *1, 2, 3 …t** years elapsed since the start of the ALM ACR Project Activity

4.6.2 Estimation of GHG emissions within the project boundary from fossil fuel combustion

Emissions resulting from fossil fuel combustion during agricultural land management shall be calculated as follows:

$$GHG_{P\_FF,E} = \sum_{a}(Fuel_{a,t} \times EF_a) \quad \textbf{(14)}$$

Where

$GHG_{P\_FF,E}$	Net CO_2-e emissions of fossil fuel consumption in the project scenario; tCO_2-e
$Fuel_{a,t}$	Amount of fuel of type *a* consumed in year *t*; terrajoule (TJ)
EF_a	Emission Factor of fuel type *a*; tCO2-e.TJ^{-1}
a	Fuel type *a* (e.g. diesel, gasoline, etc.)

Where fuel data are collected in liters, the amount of fuel of a particular kind combusted in year *t* ($Fuel_{a,t}$) can be estimated as:

$$Fuel_{a,t} = \frac{\left(Liters_{Fuel_{a,t}} \times Density_{Fuel_a} \times NCV_{Fuel}\right)}{10^6} \quad \textbf{(15)}$$

Where

$Fuel_{a,t}$	Amount of fuel type *a* consumed in year *t*; TJ
$Liters_{Fuel\ a,t}$	Quantity of fuel of type *a* consumed in year *t*; ltr
$Density_{Fuel\ a}$	Density of fuel type *a*; kg.ltr^{-1}
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; TJ.Gg^{-1}
a	Fuel type *a* (e.g. diesel, gasoline, etc.)

In the parameter tables default values are provided for all parameters not monitored.

Where fuel data are collected in US gallons, the amount of fuel of a particular kind combusted in year *t* ($Fuel_{a,t}$) can be estimated as:

$$Fuel_{a,t} = \frac{\left(Gallons_{Fuel_{a,t}} \times Density_{Fuel_a} \times NCV_{Fuel}\right)}{10^6} \quad \textbf{(16)}$$

Where

$Fuel_{a,t}$	Amount of fuel type *a* consumed in year *t*; TJ
$Gallons_{Fuel\ a,t}$	Quantity of fuel of type *a* consumed in year *t*; gal
$Density_{Fuel\ a}$	Density of fuel type *a*; kg.gal^{-1}
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; TJ.Gg^{-1}

a Fuel type *a* (e.g. diesel, gasoline, etc.)

In the parameter tables default values are provided for all parameters not monitored.

4.6.3 Accounting project emissions from fertilizer production

The CO_2 project emissions from the production of fertilizer applied on per cropland land area j are calculated as follows[14]:

$$GHG_{P,F,E} = \sum_{t=1}^{t} \left(\sum_{i=1}^{M} (A_i * AR_{i,f} \ ,* EF_{CO_2 f}) \right) \quad \textbf{(17)}$$

Where

$GHG_{P\_F,E}$ Project GHG emissions as a result of production of fertilizer used; t CO_2-e

$EF_{CO2,f}$ Emission factor for the production of synthetic nitrogen fertilizer; t CO_2 per ton synthetic nitrogen fertilizer

A_i Area of land where fertilizer is applied for stratum *i*

$AR_{i,f}$ Average application rate of fertilizer *f* for stratum *i*; $t.ha^{-1}$

$EF_{CO2,f}$ is calculated following IPCC and CDM guidelines as follows:

If the fertilizer used is urea, the $EF_{CO2,f}$ = 1.54 tCO_2e per ton urea based on IPCC may be used which takes into account the fact that the total GHG emissions from urea would be GHG emissions during ammonia production – intermediate CO_2 storage in urea + CO_2 release due to urea application (see 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3: Industrial Processes and Product Use; Chapter 3.2 Ammonia Production).

In case of other synthetic nitrogen fertilizers in the absence of reliable project specific data, conservative values may be calculated as long as the mass ratio of N in the fertilizer is known using the following formula:

[14] Methods derived from CDM methodology "Offsetting of synthetic nitrogen fertilizers by inoculants application in legumes-grass rotations on acidic soils on existing cropland". Available at: http://cdm.unfccc.int/UserManagement/FileStorage/BZG8LM2WO95IDQJCF634VUYTPNEKRX

$$EF_{CO_2,f} = Ncont_f * 0.82 * 2.014 \quad \textbf{(18)}$$

Where

$EF_{CO2,f}$	The emission factor for the production of fertilizer *f*; t CO_2 per ton fertilizer *f*)
$Ncont_f$	The N content of fertilizer *f* on a mass ratio basis (see parameter table for examples for common synthetic N fertilizer types); %
0.82	The mass ratio between N and NH_3
2.014	Conservative emission factor for ammonia production; t CO_2 per ton NH_3

4.7 Leakage

Under the applicability conditions of this methodology, Projects must not lead to a significant decrease in yields. There can be no shifting of activities nor any significant market impacts of the project. Specifically, fertilizer use may not be decreased in one location and increased in another location outside the Project boundary. There shall be no limitation on the management of fields outside the Project boundaries, but Project Proponents shall demonstrate that fertilizer use has not been shifted.

The ex-ante estimate for leakage under this methodology is therefore equal to zero. However, it is possible that the Project Activities have an unforeseen impact on crop yield. If the latter is the case, the Project is not automatically ineligible. Rather, the impact of the leakage shall be calculated and deducted from credits. The test to verify that cropping yields have not decreased due to the Project Activity shall take into account seasonal fluctuations in yield that are not attributable to the Project Activity, through a comparison with average yields within the county of the Project following the procedures below.

It is possible that yields will increase in the project scenario relative to the baseline, potentially leading to *positive leakage* (a reduction in emissions outside the Project boundary due to market effects of increased yield in the project scenario). This increases the benefit of the project and the conservativeness of estimates, but the GHG benefits of positive leakage are not quantified or credited.

4.7.1 Procedure to Calculate Leakage due to Project Activities

If the Project Activities lead to a statistically significant decrease in the yield totaled over all participating Rice Fields, compared to the available yields of at least three of the five years before the Project Start

Date, credits must be discounted according to the procedures this section. This deduction is necessary to account for potential market leakage effects.

Agricultural yields fluctuate annually depending on climate and other factors. Therefore, yields must be (1) compared to the natural variation in available yields during the five years before the Start Date and (2) normalized to average annual county yields from USDA - National Agricultural Statistics Service (NASS) statistics..

Use the following procedure to conduct this test and calculate any potential leakage:.

(1) Divide the historical yields averaged over the fields participating in the Project by the county mean for three years before Start Date. The county mean yields for a specific year, crop, and county shall be obtained from the USDA NASS (http://quickstats.nass.usda.gov). These ratios are referred to as normalized yields (y_norm).

(2) Calculate the mean and standard deviation of this ratio as $\overline{y\_norm}$ and $s(y\_norm)$.

(3) Calculate the “minimum yield threshold" below which normalized yields are significantly smaller than the county mean:

$$y\_min = \overline{y\_norm_{t,i}} - t(0.10, n-1) \cdot s_i \quad \textbf{(19)}$$

Where:

y_min_i	Minimum yield threshold for individual field i
$\overline{y\_norm_{t,i}}$	Average of the historical normalized yields for individual field i [Mg ha^{-1}]
$t(0.10, n-1)$	t-distribution value with 90% confidence (for a one-tailed test) and $n-1$ degrees of freedom [-]
s_i	Standard deviation of the historical normalized yields for individual field i [Mg ha^{-1}]

where n is 3, and $t(0.10, n-1)$ the t-distribution value with 90% confidence (for a one-tailed test) and $n-1$ degrees of freedom.

(4) For every year of the Crediting Period, calculate the actual y_norm, the ratio of the average cropping yields to the county average yield and compare this value to y_min, which is based on historical data. If the actual y_norm is smaller than y_min, yields have significantly decreased compared to historical data, even normalized for inter-annual differences. In this case, the emissions from leakage shall be calculated as[15]:

$$E_{leakage,t} = \varepsilon_{crop,crop} \cdot \left(y_{baseline_{t,i}} - y_{t,i}\right) \cdot \frac{BE_{t,i}}{y_{baseline_{t,i}}} . A \quad \textbf{(20)}$$

Where:

$E_{leakage,t,i}$	Emissions from leakage in year t for individual field i [tCO_2-eq yr^{-1}]
$\varepsilon_{crop,crop}$	Own-price elasticity for the crop considered. [-]
$y\_baseline_{t,i}$	Baseline yield at time t for individual field i, the (theoretical) yield that could have been attained without Project Activities, calculated as the product of $\overline{y\_norm}$ and y_county_t.
$\overline{y\_norm_{t,i}}$	Average of the historical normalized yields for individual field i [Mg ha^{-1}]
y_county_t	Average yield of the county at time t [Mg ha^{-1}]
$y_{t,i}$	Actual yield at time t for individual field i [Mg ha^{-1}]
$BE_{t,i}$	Baseline emissions in year y for individual field i [tCO_2-eq yr^{-1}]
A	Total Project size [ha]

[15] In this calculation, it is assumed that the GHG intensity of crop production where the leakage occurs is similar to the baseline GHG intensity, and that the cross-price crop acreage elasticity can be conservatively omitted.

Box 1: Example of Normalized Yield Calculation

A project includes three corn fields in Pottawattamie County in Iowa. The project starts in 2012 and the historical yield information for the three fields, as well as the county average are shown below.

	Yields for Corn in Bu/Acre				
	Field 1	Field 2	Field 3	Project average	County average
2011	183.9	218.9	234.9	212.6	170.9
2010	173.8	206.8	230.8	203.8	164.8
2009	230.0	236.0	258.0	241.3	194.0
Average	195.9	220.6	241.2	219.2	176.6

Step 1. Calculate Ratios. The ratio of the Project average and the County average is shown below

	Project average	County average	Y_norm
2011	164.9	170.9	0.96
2010	177.5	164.8	1.08
2009	195.0	194.0	1.01

Step 2. The mean and standard deviation of the values in the previous table are 1.016 and 0.057, respectively.

Step 3. The minimal yield threshold calculated using the equation above is: $y_{min} = 1.016 - t(0.10,2) \cdot 0.057 = 0.85$

Step 4. The project is now one year into the project period (2012). Assume that the yields for the three fields were 154, 105, and 176 bushels per acre. Assume the average county yield in Pottawattamie was 127. Therefore,

$$y_{norm} = \frac{(154 + 105 + 176)}{3} \cdot \frac{1}{127} = 1.14$$

Since 1.14 is greater than y_{min}, 0.85, there is no significant decrease in yields, $E_{leakage,2012}$ is 0, and Step 5 can be skipped.

Assume, however, the yields were 128, 61, and 130 bushels per acre. Further assume the same average county yield, y_{norm} is now 0.83. Under this scenario the average y_{norm} for 2012 is smaller than the y_{min} cutoff, and leakage must be calculated following Step 5.

Step 5. The theoretical yield that could have been attained is the product of $\overline{y\_norm}$ and y_county_t, or 1.016 x 127 = 129 bu/acre. The actual average yield is 106.3 bu/acre. The own-price elasticity for corn is 0.5 according to Huang and Khanna (2010)[16]. Assuming that the baseline emissions were 1.4 t CO2-eq/acre/year and the total project size is 500 acres:

$E_{leakage,t} = 0.5 \cdot (129 - 106) \cdot \frac{1.4}{129} \cdot 500 = 62$ t CO2-eq/ year

4.8 Net GHG Emissions

The net GHG emission reduction is the actual net project GHG emissions minus the baseline GHG emissions, minus leakage. The following general formula can be used to calculate the net GHG removals by emission reductions of an ALM ACR project activity ($C_{ALM-ACR}$) in t CO_2-e.

$$ER_{ALM-ACR} = PE - BE - E_{leakage,t,i} \quad \textbf{(21)}$$

Where

$ER_{ALM-ACR}$	Net greenhouse gas emission reduction; t CO_2-e
PE	Actual net project emissions; t CO_2-e
BE	Baseline emissions; t CO_2-e
$E_{leakage,t,i}$	Emissions from leakage in year t for individual field i [tCO_2-eq yr^{-1}]

Estimated GHG emissions from ACR ALM Project Activities have uncertainties associated with the measures/estimates of area or other activity data, DNDC inputs and coefficients. It is assumed that the uncertainties associated with the estimates of the various input data are available (see section 2.4.3, Step 2), either as default values or estimates based on sound statistical sampling. Uncertainties arising from the measurement and monitoring shall always be quantified.

Uncertainty at all times is defined as the 90% confidence interval as a percentage of the mean.

[16] Huang H and Khanna M (2010). An Econometric Analysis of U.S. Crop Yield and Cropland Acreage: Implications for the Impact of Climate Change. Agricultural & Applied Economics Association 2010 AAEA, CAES, & WAEA Joint Annual Meeting, Denver, Colorado, July 25-27, 2010

4.8.1 The use of planning to diminish uncertainty

Under the DNDC modeling 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 deductions in credited ERTs.

When Project-specific measurements are included, a measurement plan should be constructed that minimizes uncertainty. By developing a measurement plan that includes proper stratification and sufficient measurement plots, the Proponent can minimize uncertainty and maximize the potential for full crediting.

It is good practice to consider uncertainty at an early stage to identify the data sources with the highest uncertainty. The timely consideration of uncertainty provides the opportunity to conduct further work to diminish uncertainty.

4.8.2 Estimation of input uncertainty for modeled emissions

Accounting for uncertainty due to input data accuracy shall be quantified by Monte Carlo analysis. Step 3 on page 25 describes how to perform the Monte Carlo analysis. The results from those run shall be used for quantifying the input uncertainty on modeled emissions. The input uncertainty ($\mu_{inputs,i}$) for GHG emissions due to uncertainty in input parameters for field *i* shall be calculated as the half-width of the 90% confidence interval of the modeled reductions, where the modeled reductions for each Monte Carlo run j are calculated as: ($\mu_{inputs,i}$) = half-width of 90% confidence interval of distribution of modeled baseline versus project emissions expressed as a percent of the mean GHG emission reduction ($\overline{GHG}_{reduction,i}$) of field *i* where

$$\mu_{inputs,i} = 1 - \frac{GHG_{reduction\_10\%,i}}{\overline{GHG}_{reduction,i}} \quad \text{(expressed as a percentage)} \qquad \textbf{(22)}$$

$$\overline{GHG}_{reduction,i} = \frac{\sum_{j=1}^{n}(GHG_{BSL\_N_2O,j,i} - GHG_{P\_N_2O,j,i})}{n} \qquad \textbf{(23)}$$

Where

$GHG_{reduction\_10\%,i}$	Value of the 10th quantile of the n Monte Carlo modeled emission reductions for strata *i*.

$GHG_{BSL\_N2O,j,i}$	N_2O emissions as a result of fertilizer application within the Project boundary in the baseline scenario for Monte Carlo run j in stratum i; t CO_2-e.ha^{-1}
$GHG_{P\_N2O,j,i}$	N_2O emissions as a result of fertilizer application within the Project boundary in the project scenario for Monte Carlo run j in stratum i; t CO_2-e.ha^{-1}
j	1, 2, 3 … N Monte Carlo runs
i	1, 2, 3 …M strata

4.8.3 Estimation of structural uncertainty for modeled emissions

The geographic applicability area of a model has to be justified by considering whether variations in climate, soil types, and management present within the area are handled well by the model. While in theory, process based models can be used to simulate emissions in a wide range of circumstances, the model's performance will only be reliable under the conditions for which it was calibrated and independently validated. Most process based model calibration and validation efforts were done in an ad hoc fashion and with a goal of validating the model performance for a single site. Each of these efforts has employed a unique approach to parameterization and calibration that is challenging to apply beyond the conditions and circumstances of the field the model was validated for.

Therefore, for this methodology, a comprehensive and systematic validation of the DNDC model using independent field measurements is required by crop, management system and NRCS Land Resource Region to statistically quantify uncertainties in model-based estimates of GHG emission reductions that are obtained by a standardized approach to parameterization and calibration that can be applied across a whole region. Section 5.3.2 presents the procedures for using independent validation of the model to calculate model uncertainty. Appendix A describes general criteria for measurement protocols to be used to collect new field data or to evaluate suitability of existing field data for model validation. Appendix B presents an example illustrating how model structural uncertainty is calculated and approaches for compensating for uncertainties through a deduction process.

4.8.4 Verification of the lack of bias

The derivation of the structural uncertainty term assumes that no bias exists between measured and modeled results, or that $E(Y_{meas}) = E(Y_{model})$. The DNDC model has been shown to predict greenhouse fluxes without bias, when correctly calibrated. This methodology specifies how model inputs can be set

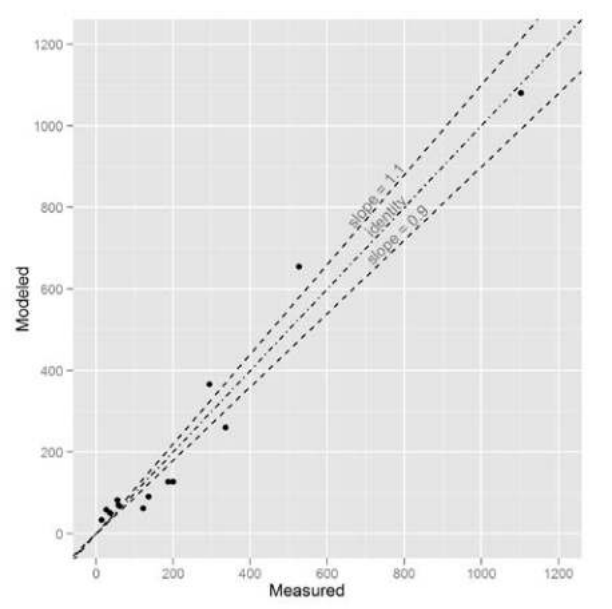
so that the model is calibrated correctly. It must still be explicitly tested that the model calibration strategy does not lead to bias by comparing modeled and measured emissions. A classical paired t-test is suboptimal since the goal is not to demonstrate a significant difference between modeled and measured values using a set confidence, but rather the lack of a difference. In such a case, Two One-Sided Tests (TOST) equivalence testing is superior. For equivalence tests, a tolerable deviation between measured and modeled results must be defined. We set this tolerable deviation to the statistical convention of 10%. In practice, a regression must be executed between measured and modeled values, and it must be ensured that the slope is not smaller than 0.90 with 90% confidence, as well as not greater than 1.1 with 90% confidence.

Box 2: Example of Verification of the Lack of Bias

A dataset of 13 Modeled and Measured values is available and read into a dataframe of the free R open-source statistics package. A graph of the Modeled vs. Measured values is shown below. The following R code was run to conduct a TOST equivalence test:

```
model <- lm(Modeled ~ Measured + 0, data = d)
slopeEst <- summary(model)$coefficients[1]
stdErr <- summary(model)$coefficients[2]
df <- summary(model)$df[2]
# probability that slope is greater than 1.1
pt((slopeEst-1.1)/stdErr, df, lower.tail = FALSE)
# probability that slope is smaller than 0.9
pt((slopeEst-0.9)/stdErr, df, lower.tail = TRUE)
```

The slope of the original relation was 1.000405. The probability that the slope is greater than 1.1 is 0.9757179 and smaller than 0.9 is 0.9764839. As a consequence, no bias exists.



If the slope of the regression is smaller than 0.90 with 90% confidence, or greater than 1.1 with 90% confidence, this indicates bias in the model. If this is the case, the Project will not be eligible until ACR has approved a bias correction method, indicating how to quantify bias and account for it in the

quantification of structural uncertainty, and posted this on the dedicated webpage for this methodology.[17] In the interim, in the case the slope of the regression indicates bias, Project Proponents may propose a bias correction method. All approved methods will be made available on the methodology webpage.

4.8.5 Structural Uncertainty Quantification

The calculation of u_{struct} is critically dependent on the standard deviation of the residuals s and the correlation between the residuals of the project emissions and the residuals of the baseline emissions ρ.

Assume k pairs of $\left(Y_{meas}(i), Y_{model}(i)\right)$, the quantity s can be calculated as the standard deviation of the difference between $Y_{meas}(i)$ and $Y_{meas}(i)$. The quantity ρ can be estimated by dividing the measurements in "baseline" cases, $BE_{meas}(i)$ and "project cases", $PE_{meas}(i)$. Using conventional terminology, the baseline would be the control or conventional treatment. Subsequently, pairs of measured and simulated emission reductions $DER_{meas}(i)$ and $DER_{model}(i)$ can be calculated as the difference between $PE_{meas}(i)$ and $BE_{meas}(i)$, and $PE_{model}(i)$ and $BE_{model}(i)$, respectively. Calculate ρ as the correlation coefficient between $DER_{meas}(i)$ and $DER_{model}(i)$. Smaller correlation coefficients will result in greater uncertainty deductions. Therefore, it is good practice to calculate a set of correlation coefficients through leave-one-out jackknifing and set the correlation coefficient to the low range of this set of values.

The quantities s and ρ can be calculated with more accuracy based on daily values of these quantities as:

$$s_{annual} = 365 \cdot s_{daily}$$
$$\rho_{annual} = \rho_{daily}$$

Note that measurements aggregated over any other time period than daily can be used to estimate ρ. This methodology requires the Project Proponent to use at least 50 measurements to calculate ρ.

$$UNC\_STRUCT = \frac{s\sqrt{2(1-\rho)}}{\sqrt{n}} \cdot t_{inv}(0.90, k) \quad \textbf{(24)}$$

Where:

u_{struct} = Structural uncertainty factor

s = Standard deviation

ρ = Correlation between project residuals and baseline residuals

[17] As of the release of this methodology version, work on this bias correction method is underway and will be published shortly.

t_{inv} = Inverse of the cumulative t-distribution with a specific confidence and degrees of freedom

k = Number of pairs of modeled and measured values used for model verification.

n = Number of fields in the Project

4.8.6 Total uncertainty of ACR-ALM project

The total project uncertainty ($ER_{ALM\text{-}ACR\_ERROR}$) is calculated at the time of reporting through propagating the uncertainty due to inputs across strata and total model structural uncertainty in the project:

$$ER_{ALM-ACR\_ERROR} = INPUT_{Uncertainty} + STRUCT_{Uncertainty} \quad \textbf{(25)}$$

$$INPUT_{Uncertainty} = \sqrt{\sum_{i=1}^{m} (\mu_{inputs,i})^2} \quad \textbf{(26)}$$

$$STRUCT_{Uncertainty} = \frac{\mu_{struct} * A}{ER_{ALM-ACR}} \quad \textbf{(27)}$$

Where

$ER_{ALM\text{-}ACR\_ERROR}$	Total uncertainty for ALM-ACR Project; %
$ER_{ALM\text{-}ACR}$	Net GHG reductions Project; t $CO_{2\text{-}e}$
$INPUT_{Uncertainty}$	Total uncertainty due to input uncertainty for the project; %
$STRUCT_{Uncertainty}$	Total uncertainty due to model structural uncertainty; %
A	Total project area; hectares
i	1, 2, 3 …M strata

4.8.7 Uncertainty Deduction

If $ER_{ALM\text{-}ACR\_ERROR} \leq 10\%$ of $ER_{ALM\text{-}ACR}$ then no deduction for uncertainty is required.

If $ER_{ALM\text{-}ACR\_ERROR} > 10\%$ of $ER_{ALM\text{-}ACR}$ then the modified value for $C_{ALM\text{-}ACR}$ to account for uncertainty shall be:

$$= ER_{ALM-ACR} - \left(ER_{ALM-ACR} * \left(ER_{ALM-ACR\_ERROR} - 10\%\right)\right) \quad \textbf{(28)}$$

Where

$ER_{ALM-ACR}$ Net GHG emission reduction; t CO_2-e

$ER_{ALM-ACR\_ERROR}$ Total uncertainty for ALM-ACR Project; %

4.8.8 Calculation of ERTs

To estimate the amount of ERTs that can be issued at time $t=t_2$ (the date of verification) for monitoring period $T=t_2-t_1$, this methodology uses the following equation:

$$ERTs = ER_{ALM-ACR,t2} - ER_{ALM-ACR,t1} \quad \textbf{(29)}$$

Where

ERTs Emission Reduction Tons

$ER_{ALM-ACR,t2}$ Net GHG emission reduction, as estimated for $t^*=t_2$; t CO_2-e

$ER_{ALM-ACR,t1}$ Net GHG emission reduction, as estimated for $t^*=t_1$; t CO_2-e

Emission reductions from changes in fertilizer management are permanent and cannot be reversed. The calculation of ERTs therefore requires no buffer deduction or other risk mitigation mechanism.

4.9 Data and parameters not Monitored (Default or Possibly Measured One Time)

In addition to the parameters listed in the tables below, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

In choosing key parameters or making important assumptions based on information that is not specific to the project circumstances, such as in use of existing published data, Project Proponents must retain a conservative approach: that is, if different values for a parameter are equally plausible, a value that does not lead to under-estimation of net GHG emissions must be selected.

4.9.1 DNDC Inputs

Soil Input Parameters:

Data / parameter:	**S1**: Land use
Data unit:	N/A
Used in equations:	Used by DNDC
Description:	Description of land use
Source of data:	Users shall select one of the four options in DNDC: upland crop field, rice paddy field, moist grassland/pasture or dry grassland/pasture.
Measurement procedures (if any):	N/A
Any comment:	

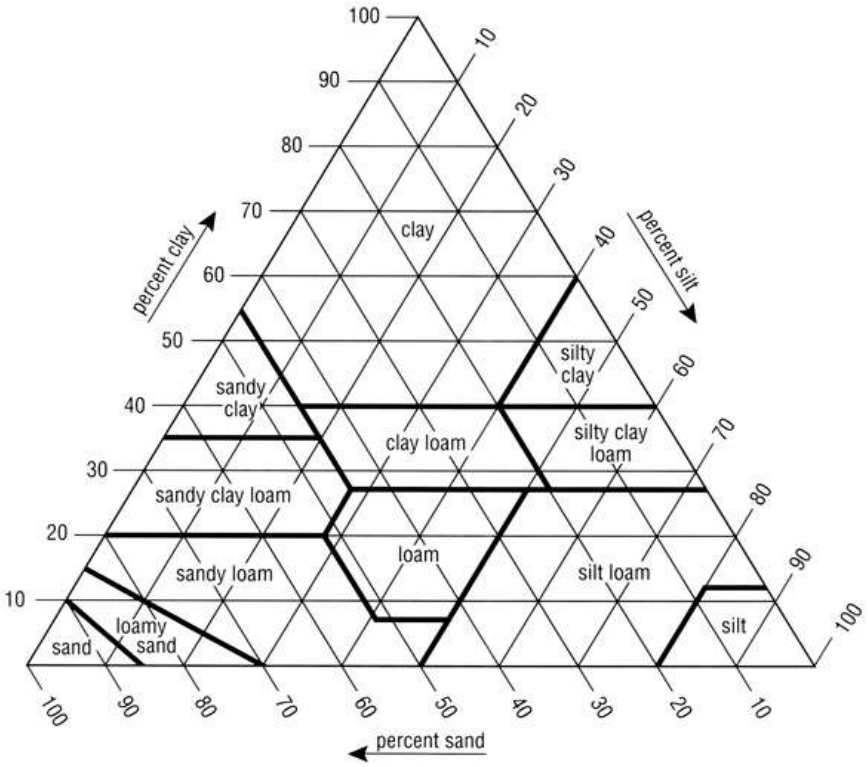
Data / parameter:	**S2**: Soil Clay Content
Data unit:	% clay
Used in equations:	Used by DNDC
Description:	% clay particles of the top 10cm of soil.
Source of data:	Field measurement or use of NRCS Soil Survey Geographic (SSURGO) Database defaults
Measurement procedures (if any):	If field measurements are used, then the soil suspension by hydrometer method shall be used to quantify % clay. Discussion of this method can be found in Sheldrick and Wang (1993).
Any comment:	Sheldrick, B. H. and Wang, C. 1993. Particle-size Distribution. pp. 499-511. In: Carter, M. R. (ed), Soil Sampling and Methods of Analysis, Canadian Society of Soil Science, Lewis Publishers, Ann Arbor, MI.

Data / parameter:	**S3**: Soil Bulk Density
Data unit:	g/cm^3
Used in equations:	Used by DNDC
Description:	Soil bulk density of the top 10cm of soil. Bulk density is the ratio of the mass of dry solids to the bulk volume of the soil
Source of data:	Field measurement or use of NRCS Soil Survey Geographic (SSURGO) Database defaults.
Measurement procedures (if any):	If field measurements are used, then quantify soil bulk density by direct by measurement of soil volume (core measurement) and mass (drying and weighing soil sample).
Any comment:	See Blake, G. R. and Hartge, K. H. 1986. Bulk density. p. 363-375. ***In:*** A. Klute et al. (ed.) Methods of soil analysis: Part 1: Physical and Mineralogical Methods. Monograph Number 9 (Second Edition). ASA, Madison, WI.

Data / parameter:	**S4**: Soil pH
Data unit:	pH units
Used in equations:	Used by DNDC
Description:	Soil pH of the top 10cm of soil is the negative logarithm of the hydrogen ion concentration of soils.
Source of data:	Field measurement or use of NRCS Soil Survey Geographic (SSURGO) Database defaults.
Measurement procedures (if any):	If field measurements are used, then quantify soil pH using the saturated paste and pH meter.
Any comment:	See U.S. Salinity Laboratory Staff. 1954. pH reading of saturated soil paste. p. 102. ***In:*** L. A. Richards (ed.) Diagnosis and improvement of saline and alkali soils. USDA Agricultural Handbook 60. U.S. Government Printing Office, Washington, D.C. for a description of the saturated paste and pH meter approach.

Data / parameter:	**S5**: Soil carbon concentration
Data unit:	%
Used in equations:	Used by DNDC
Description:	Concentration of soil carbon in the top 5cm of soil in each stratum
Source of data:	Field measurement or use of NRCS Soil Survey Geographic (SSURGO) Database defaults
Measurement procedures (if any):	If field measurements are used, then the following measurement procedures shall be followed: Step 1. Collect soil samples of the top 0-5cm of soils. See guidance in Pearson et al. 2005 and 2007 Step 2. Measure % soil organic matter. Measurement methods are: (1) loss-on-ignition, (2) hydrogen peroxide digestion or (3) Walkley-Black Method. Step 3: Convert % soil organic matter to % soil organic carbon. A conversion factor of 1.724 has been used to convert organic matter to organic carbon based on the assumption that organic matter contains 58% organic C (i.e., g organic matter/l .724 = g organic C) (Nelson and Sommers, 1996).
Any comment:	Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis, Part 2, 2nd ed., A.L. Page et al., Ed. Agronomy. 9:961-1010. Am. Soc. of Agron., Inc. Madison, WI. Pearson, T., S. Walker and S. Brown (2005) Sourcebook for BioCarbon Fund Projects. Prepared for BioCarbon Fund of World Bank. Pearson, TRH, S.L. Brown and R.A. Birdsey. 2007. Measurement guidelines for the sequestration of forest carbon. Gen. Tech. Rep. NRS-18.Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 42 p.

Data / parameter:	**S6**: Soil Texture Class
Data unit:	N/A
Used in equations:	Used by DNDC

Description:	NRCS Soil Texture class
Source of data:	Field measurement or use of NRCS Soil Survey Geographic (SSURGO) Database defaults.
Measurement procedures (if any):	Use NRCS Soil texture lookup table. Users shall select the soil texture class based on their soil's clay, silt and sand content following the NRCS soil texture class definition: 
Any comment:	

Data / parameter:	**S7**: Field Slope
Data unit:	% slope
Used in equations:	Used by DNDC
Description:	Slope of the field

Source of data:	Field measurement.
Measurement procedures (if any):	
Any comment:	The slope for level soil is 0

Data / parameter:	**S8**: Depth of water-retention layer
Data unit:	cm
Used in equations:	Used by DNDC
Description:	Water retention layer is layer in the soil that restricts water movement down through the soil. Depth to the water retention layer is distance from the soil surface down to the retention layer.
Source of data:	Measurement.
Measurement procedures (if any):	Users shall measure the depth to the plow pan.
Any comment:	This field is required only for sites with periodic ponding or the soil drainage class is defined as somewhat poorly drained, poorly drained or very poorly drained in the NRCS SSURGO database. Applicable water-retention layers exist only within the top 100cm of the soil profile. Water retention layers can be formed by soil compaction (common for intensively grazed pasture or a plow pan).

Data / parameter:	**S9**: Ground water table
Data unit:	cm
Used in equations:	Used by DNDC
Description:	Daily estimate of depth to water table.
Source of data:	Measurement.

Measurement procedures (if any):	If fields are tile drained, then one can assume that the water table is at the depth of the tile drains. Local well measurements can be used to estimate daily water table depth.
Any comment:	These data are required only if the water table is either seasonally above 50cm or the soil drainage class is defined as somewhat poorly drained, poorly drained or very poorly drained in the NRCS SSURGO database.

Data / parameter:	**S10**: Field Capacity
Data unit:	0 - 1
Used in equations:	Used by DNDC
Description:	WFPS (Water Filled Pore Space) at soil field capacity. Field capacity is the point at which the excess water has drained from the soil (soil moisture at 1/10 bar tension).
Source of data:	Field measurement or use DNDC defaults, which are based on soil texture.
Measurement procedures (if any):	Field capacity WFPS is calculated as the ratio of volumetric water content (θ) and total soil porosity (P_t) at soil moisture content of 1/10 bars tension: $\%WFPS = (\theta/P_t) \cdot 100$
Any comment:	

Data / parameter:	**S11**: Wilting Point
Data unit:	0 - 1
Used in equations:	Used by DNDC
Description:	WFPS (Water Filled Pore Space) at wilting point. Wilting point is the minimal soil moisture content where crop will not wilt (soil moisture at 15 bars tension)
Source of data:	Field measurement or use DNDC defaults, which are based on soil texture.
Measurement	Wilting Point WFPS is calculated as the ratio of volumetric water content (θ) and total soil

procedures (if any):	porosity (P_t) at soil moisture content of 15 bars tension: $\%WFPS = (\theta/P_t) \cdot 100$
Any comment:	

Cropping System Input Parameters:

Data / parameter:	**CR9**: Maximum Crop Yield
Data unit:	Kg dry matter.ha^{-1}
Used in equations:	Used by DNDC
Description:	This is the maximum achievable crop yield for the region.
Source of data:	Farmer's records.
Measurement procedures (if any):	
Any comment:	This is the highest historical yield from at least the past 5 years. This will be used for crop parameterization (Step 1 in section 4.1.1.2)

4.9.2 Other inputs

Fossil Fuel Combustion:

Data / parameter:	EF_a
Data unit:	tCO_2-e.TJ^{-1}
Used in equations:	7, 14
Description:	Emission factor
Source of data:	Table 1.4 Chapter 1 Volume 2 of IPCC, 2006.
Measurement procedures (if any):	Default emission factors are presented in the table below. Table: Road transport default CO_2 emission factors.[a]

	<table><tr><th>Fuel Type</th><th>Default effective CO_2 emission factor ($tCO_2.TJ^{-1}$)</th></tr><tr><td>Motor gasoline</td><td>69.3</td></tr><tr><td>Gas/Diesel Oil</td><td>74.1</td></tr><tr><td>Liquefied Petroleum Gases</td><td>63.1</td></tr><tr><td>Kerosene</td><td>71.9</td></tr><tr><td>Lubricants</td><td>73.3</td></tr><tr><td>Compressed Natural Gas</td><td>56.1</td></tr><tr><td>Liquefied Natural Gas</td><td>56.1</td></tr></table> [a] Values represent 100% oxidation of fuel carbon content. The emission factors assume that 100% of the carbon content of the fuel is oxidized during or immediately following the combustion process (for all fuel types in all vehicles) irrespective of whether the CO_2 has been emitted as CO_2, CH_4, CO or NMVOC or as particulate matter.
Any comment:	

Data / parameter:	$Density_{Fuel\ a}$
Data unit:	kg/ltr of kg/gal (US gallons)
Used in equations:	8 / 9, 15 / 16
Description:	Density of Fuel type
Source of data:	Table A3.8 Page 181 of the Energy Statistics Manual of OECD/IEA, 2005.
Measurement procedures (if any):	Densities for relevant petroleum products as presented in table A3.8

Typical Density Values for Selected Petroleum Products

Fuel Type	Density ($kg.ltr^{-1}$)	Liters per ton	Density ($kg.gal^{-1}$)	Gallons per ton
Motor gasoline	0.7407	1350	2.800	357
Gas/Diesel Oil	0.8439	1185	3.190	313
Naphtha	0.6906	1448	2.610	383
Aviation gasoline	0.7168	1350	2.710	357
Aviation Turbine fuel	0.8026	1246	3.034	330
Other kerosene	0.8026	1246	3.034	330

Any comment:

Data / parameter:	NCV_a
Data unit:	GJ/tonne
Used in equations:	8 / 9, 15 / 16
Description:	Net Caloric Value per Fuel Type
Source of data:	Table A3.8, page 181, IEA Statistics Manual, OECD/IEA, 2005; and, Table 1.2, Chapter 1, Volume 2, IPCC 2006 Inventory Guidelines
Measurement procedures (if any):	Default NCVs are presented in tables below.

Fuel Type	Density ($kg.ltr^{-1}$)	NCV ($GJ.t^{-1}$)[a]

Motor gasoline	0.7407	44.75
Gas/Diesel Oil	0.8439	43.38
Naphtha	0.6906	45.34
Aviation gasoline	0.7168	45.03
Aviation Turbine fuel	0.8026	43.92
Other kerosene	0.8026	43.92

[a] 1000 GJ = 1 TJ

Table: Default NCVs (excerpt from table 1.2, Chapter 1, Volume 2, IPCC, 2006 Inventory Guidelines)

Fuel type (English description)	Default Net Caloric Value (NCV) (TJ.Gg^{-1})[b]
Crude Oil	42.3
Orimulsion	27.5
Natural Gas Liquids	44.2
Motor Gasoline	44.3
Aviation Gasoline	44.3
Jet Gasoline	44.3
Jet Kerosene	44.1
Other Kerosene	43.8
Gas/Diesel Oil	43.0
bio-gasoline/bio-diesel	27.0
other liquid biofuels	27.4

	[b] $TJ.Gg^{-1} = GJ.t^{-1}$
Any comment:	For more NCVs for other fuels, see the original data sources.

Fertilizer Production:

Data / parameter:	$Ncont_f$
Data unit:	N content (% of mass)
Used in equations:	11,18
Description:	The N content of fertilizer *f* on a mass ratio basis
Source of data:	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3: Industrial Processes and Product Use
Measurement procedures (if any):	

Synthetic nitrogen fertilizer types	N content (% of mass)
Single nutrient products N-fertilizer	
Anhydrous Ammonia (NH_3) "Ammonia"	82
Ammonium Sulfate [$(NH_4)2SO_4$]	21
Monoammonium Phosphate (MAP)	11
Diammonium Phosphate (DAP)	18
Ammonium Nitrate (NH_4NO_3)	33.5
Calcium Ammonium Nitrate (CAN)	26
Any other synthetic nitrogen fertilizer (e.g., multi nutrient fertilizers (N-P-K))	Project proponent to calculate

Any comment:	

5 MONITORING METHODOLOGY

All data collected as part of monitoring must be archived electronically and retained for at least two years after the end of the Project. 100% of the data must be monitored if not indicated otherwise in tables below. All measurements must be conducted according to relevant standards.

5.1 Monitoring of Project Implementation

Information shall be provided, and recorded in the GHG Project Plan, to establish that:

i. The geographic position of the Project boundary is recorded for all areas of land;
   - The geographic coordinates of the Project boundary (and any stratification inside the boundary) are established, recorded and archived. This can be achieved by field survey (e.g., using GPS), or by using georeferenced spatial data (e.g., maps, GIS datasets, orthorectified aerial photography, or georeferenced remote sensing images).

ii. Commonly accepted principles of agricultural land management are implemented;
   - Standard operating procedures (SOPs) and quality control / quality assurance (QA/QC) procedures for field data collection and data management shall be applied. Use or adaptation of SOPs already applied in national monitoring, or available from published handbooks, or from the *IPCC AFOLU Guidelines 2006*, is recommended;
   - The fertilizer management plan, together with a record of the plan as actually implemented during the Project shall be available for verification, as appropriate.

5.2 Data and Parameters Monitored

The following parameters must be monitored during the Project Activity. When applying all relevant equations provided in this methodology for the *ex ante* calculation of net GHG emissions, Project Proponents shall provide transparent estimations for the parameters that are monitored during the Crediting Period. These estimates shall be based on measured or existing published data where possible. Project Proponents must retain a conservative approach: that is, if different values for a parameter are equally plausible, a value that does not lead to over-estimation of net GHG emissions must be selected.

Location Input Parameter:

Data / parameter:	A_i
Data unit:	ha
Used in equations:	6, 10, 13, 17 and implicitly used in Section 4 (*Location Parameter L1*)
Description:	Area of stratum *i*
Source of data:	GPS coordinates and / or legal parcel records and farm records
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	
Any comment:	It shall be assumed ex-ante that field boundaries and strata areas shall not change through time

Climate Input Parameters:

Data / parameter:	**C1**: Background NH_3 Concentration
Data unit:	$\mu g\ N.m^{-3}$
Used in equations:	Used by DNDC
Description:	Average background concentration of atmospheric NH_3.
Source of data:	Default value is 0.06 $\mu g\ N.m^{-3}$
Measurement procedures (if any):	N/A
Any comment:	If the users decide to modify the default values, then rationale for the changes must be recorded

Data / parameter:	**C2**: Background CO_2 Concentration
Data unit:	ppm
Used in equations:	Used by DNDC
Description:	Average background concentration of atmospheric CO_2.
Source of data:	Default value is 350 ppm
Measurement procedures (if any):	N/A
Any comment:	If the users decide to modify the default values, then rationale for the changes must be recorded.

Data / parameter:	**C3**: Atmospheric N Deposition
Data unit:	mg $N.l^{-1}$ or ppm
Used in equations:	Used by DNDC
Description:	Average annual N (dissolved nitrate and ammonium) concentration in rainfall
Source of data:	These data are available from National Atmospheric Deposition Program National Trends Network (http://nadp.sws.uiuc.edu/Default.aspx).
Measurement procedures (if any):	N/A
Any comment:	

Data / parameter:	**C4**: Daily Meteorology
Data unit:	Temperature in degrees Celsius, Precipitation in cm, wind speed in m/sec, solar radiation in MJ/m2/day
Used in equations:	Used by DNDC

Description:	Daily weather data from local weather station
Source of data:	These data shall either be collected from the nearest weather station.
Measurement procedures (if any):	N/A
Any comment:	Meteorology Format 1: The first line is a file name. The first column contains dates in Julian day, the second column maximum daily air temperatures in ºC, the third column minimum daily air temperatures in ºC, and the forth column daily precipitation in cm. The following is an example of Format 1: Example1 1 -0.5 -4.5 0.0 2 0.0 -1.2 1.2 3 3.5 0.8 0.5 4 5.7 2.0 0.0 . . 365 5.6 -0.2 0.0 Meteorology Format 2: The first line is a file name, which must be a string. The first column contains dates in Julian day, the second column maximum daily air temperatures in ºC, the third column minimum daily air temperatures in ºC, the fourth column daily precipitation in cm, and the fifth column solar radiation in million J/m^2/day. The following is an example of Format 2: Example2 1 -0.5 -4.5 0.0 1.23

	2	0.0	-1.2	1.2	1.59
	3	3.5	0.8	0.5	3.20
	4	5.7	2.0	0.0	2.25
	.				
	.				
	365	5.6	-0.2	0.0	1.11

Meteorology Format 3:

The first line is a file name, which must be a string. The first column contains dates in Julian day, the second column maximum daily air temperatures in ºC, the third column minimum daily air temperatures in ºC, the forth column daily precipitation in cm, and the fifth column daily average wind speed in m/second. The following is an example of Format 3:

Example3				
1	-0.5	-4.5	0.0	0.25
2	0.0	-1.2	1.2	1.10
3	3.5	0.8	0.5	0.80
4	5.7	2.0	0.0	0.02
.				
.				
365	5.6	-0.2	0.0	0.00

Meteorology Format 4:

The first line is a file name, which must be a string. The first column contains dates in Julian day, the second column maximum daily air temperatures in ºC, the third column minimum daily air temperatures in ºC, the forth column daily precipitation in cm, the fifth column daily average wind speed in m/second, and the sixth column

	solar radiation in MJ/m^2/day. The following is an example of Format 4: Example4 1 -0.5 -4.5 0.0 0.25 19.169 2 0.0 -1.2 1.2 1.10 16.321 3 3.5 0.8 0.5 0.80 17.418 4 5.7 2.0 0.0 0.02 21.009 . . 365 5.6 -0.2 0.0 0.00 17.239

Cropping System Input Parameters:

Data / parameter:	**CR1**: Crop Type
Data unit:	N/A
Used in equations:	Used by DNDC
Description:	This is the crop or crops that were grown on the site.
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	Use of cover crops in the rotation shall be identified as such

Data / parameter:	**CR2**: Planting Date
Data unit:	Month, day and year.
Used in equations:	Used by DNDC

Description:	Date of planting.
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**CR3**: Harvest Date
Data unit:	Month, day and year.
Used in equations:	Used by DNDC
Description:	This is the date of the crop harvest.
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**CR4**: C/N ratio of the grain
Data unit:	(unitless)
Used in equations:	Used by DNDC
Description:	This is the ratio of the carbon and nitrogen content of the harvest portion of the crop.
Source of data:	Tissue sampling measurement
Measurement procedures (if any):	Standard lab techniques.
Any comment:	

Data / parameter:	**CR5**: C/N ratio of leaf+stem tissue
Data unit:	(unitless)
Used in equations:	Used by DNDC
Description:	This is the ratio of carbon and nitrogen content of the leaf and stem tissues combined.
Source of data:	Tissue sampling measurement.
Measurement procedures (if any):	Standard lab techniques.
Any comment:	

Data / parameter:	**CR6**: C/N ratio of root tissue
Data unit:	(unitless)
Used in equations:	Used by DNDC
Description:	This is the ratio of carbon and nitrogen content of the root tissues.
Source of data:	Tissue sampling measurements.
Measurement procedures (if any):	Standard lab techniques.
Any comment:	

Data / parameter:	**CR7**: Fraction of leaves and stems left in field after harvest
Data unit:	%
Used in equations:	Used by DNDC
Description:	This is the fraction of leaves and stems left in the field after harvest.

Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Tillage System Input Parameters:

Data / parameter:	**T1**: Number of tillage events
Data unit:	N/A
Used in equations:	Used by DNDC
Description:	This is the number of days when the field is tilled.
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	A tillage event is defined as day in which the fields are tilled. Multiple pass on the same day are considered a single event.

Data / parameter:	**T2**: Date of each tillage event
Data unit:	Month, day and year.
Used in equations:	Used by DNDC
Description:	Date of each tillage event.
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**T3**: Depth of each tillage event
Data unit:	Cm
Used in equations:	Used by DNDC
Description:	This is the depth of the tillage for each event.
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	DNDC allows for 6 depths: 0cm (mulch crop residue), 5cm, 10cm, 20cm, 30cm and 50cm.

Nitrogen Fertilizer Input Parameters:

Data / parameter:	**F1**: Number of fertilizer applications
Data unit:	N/A
Used in equations:	Used by DNDC
Description:	This is the number of days with nitrogen fertilizer application in a given year
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**F2**: Date of each fertilizer event
Data unit:	Month, day and year.
Used in equations:	Used by DNDC
Description:	Date of each nitrogen fertilizer application event.

Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**F3**: Fertilizer application method
Data unit:	N/A
Used in equations:	Used by DNDC
Description:	This is a description of how the nitrogen fertilizer was applied for each event. There are two options: surface or injection. If injection was used, then user's must specify the depth in cm.
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**F4**: Fertilizer Type
Data unit:	N/A
Used in equations:	Used by DNDC
Description:	Type of fertilizer used for each fertilizer event. DNDC accepts seven types of fertilizers: Urea, Anhydrous Ammonia, Ammonium Nitrate, Nitrate, Ammonium Bicarbonate, Ammonium Sulfate and Ammonium Phosphate
Source of data:	Farmer records.
Measurement procedures (if any):	

Any comment:	If the fertilizer used is a combination of types (e.g. UAN which is a combination of urea and ammonium nitrate), then separate the application into several fertilizer types based on the combination ratios

Data / parameter:	**F5**: Fertilizer application rate
Data unit:	kg $N.ha^{-1}$
Used in equations:	Used by DNDC
Description:	Application rate of nitrogen fertilizer in kg $N.ha^{-1}$ for each fertilizer type
Source of data:	Farmer records.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**F6**: Use of time release fertilizer
Data unit:	Days
Used in equations:	Used by DNDC
Description:	If farmer's used time release fertilizer, then they must specify the release rate in days.
Source of data:	Farmer records and published release rates from fertilizer manufacturer.
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**F7**: Use of Nitrification Inhibitors
Data unit:	Effectiveness (% reduction in nitrification) and duration of the nitrification inhibitor

	(days)
Used in equations:	Used by DNDC
Description:	If farmer uses a nitrification inhibitor, then this parameter describes its effectives in terms of % reduction in nitrification rates and the duration in days the inhibitor works.
Source of data:	Fertilizer manufacturer records.
Measurement procedures (if any):	
Any comment:	Efficiency is defined as the percent reduction in rates of nitrification. Values of 0.5 and 1 indicate a 50% and 100% reduction of nitrification for the effective duration are needed.

Organic Amendment Input Parameters:

Data / parameter:	**O1**: Number of Organic Amendment Applications Per Year
Data unit:	dimensionless
Used in equations:	Used by DNDC
Description:	Number of applications in the year
Source of data:	Farmer records
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**O2**: Date of Application
Data unit:	dimensionless

Used in equations:	Used by DNDC
Description:	The date of each application of organic amendments listed in input O1
Source of data:	Farmer records
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**O3**: Type of Organic Amendment
Data unit:	dimensionless
Used in equations:	Used by DNDC
Description:	Type of manure. Five types of manure (e.g., farmyard manure, green manure, straw, liquid animal waste, and compost) are parameterized in DNDC.
Source of data:	Farmer records
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**O4**: Application Rate
Data unit:	kg $C.ha^{-1}$
Used in equations:	Used by DNDC
Description:	The application rate of the organic amendments in kg C per ha per application
Source of data:	Farmer records
Measurement procedures (if any):	

Any comment:	

Data / parameter:	**O5**: Amendment C/N Ratio
Data unit:	dimensionless
Used in equations:	Used by DNDC
Description:	The ratio of C/N in the organic amendment.
Source of data:	The default value is provided by DNDC but should be modified if data are available
Measurement procedures (if any):	
Any comment:	

Irrigation System Input Parameters:

Data / parameter:	**I1**: Number of Irrigation Events
Data unit:	dimensionless
Used in equations:	Used by DNDC
Description:	Number of irrigation events each year
Source of data:	Farmer records
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**I2**:Date of Irrigation Events
Data unit:	dimensionless

Used in equations:	Used by DNDC
Description:	The date of each irrigation event specified input I1
Source of data:	Farmer records
Measurement procedures (if any):	
Any comment:	

Data / parameter:	**I3**:Irrigation Type
Data unit:	dimensionless
Used in equations:	Used by DNDC
Description:	The type of irrigation system used
Source of data:	Farmer records
Measurement procedures (if any):	
Any comment:	DNDC has three irrigation type settings: flood, sprinkler or surface drip tape.

Data / parameter:	**I4**:Irrigation Application Rate
Data unit:	mm
Used in equations:	Used by DNDC
Description:	Amount of water applied during each irrigation event listed in input I1
Source of data:	Farmer records
Measurement procedures (if any):	

Any comment:	

Fossil Fuel Combustion:

Data / parameter:	$Liters_{Fuel,a,t}$ or $Gallons_{Fuel,a,t}$
Data unit:	liters or US gallons
Used in equations:	8 / 9, 15 / 16
Description:	Fuel consumed
Source of data:	Records of fuel consumed or distance travelled by vehicles (farmer records).
Measurement procedures (if any):	In the absence of direct fuel consumption data, each major fuel type used by each road vehicle type can be estimated from data of vehicle kilometers travelled (which requires a km registration system) or from the expenditure on fuel (on the basis of receipts/fuel acquired). Records / monitoring shall be continuous and consumption/mileage shall be divided by equipment type / road vehicle type. Where estimation of fossil fuel combustion is elected as an emission source, fossil fuel use by the project both inside and outside the project boundary shall be recorded and considered as project emissions.
Any comment:	For the baseline case, fossil fuel use shall be derived from farm records collected over at least the previous two years.

Fertilizer Production:

Data / parameter:	$AR_{i,f}$
Data unit:	(metric) $t.ha^{-1}$
Used in equations:	10,17
Description:	Average application rate of fertilizer *f* for stratum *i*

Source of data:	Farmer records
Measurement procedures (if any):	
Any comment:	

5.3 Conservative Approach and Uncertainties

To help reduce uncertainties in accounting of emissions and removals, this methodology uses, whenever possible, the proven methods from the GPG-LULUCF, GPG-2000, the IPCC's Revised 2006 Guidelines and the tools and methodologies of the CDM Executive Board. Tools and guidance from the CDM Executive Board on conservative estimation of emissions and removals are also used. Despite this, potential uncertainties still arise from the choice of parameters to be used. Uncertainties may result in uncertainties in the estimation of both baseline net GHG emissions and the actual net GHG emissions, especially when global default values are used.

It is recommended that Project Proponents identify key parameters that would significantly influence the accuracy of estimates. Local values that are specific to the project circumstances must then be obtained for these key parameters, whenever possible. These values must be based on:

- Data from well-referenced peer-reviewed literature or other well-established published sources[18];
- National inventory data or default data from IPCC literature that has, whenever possible and necessary, been checked for consistency against available local data specific to the project circumstances; or
- In the absence of the above sources of information, expert opinion may be used to assist with data selection. Experts will often provide a range of data, as well as a most probable value for the data. The rationale for selecting a particular data value must be briefly noted in the GHG Project Plan. For any data provided by experts, the GHG Project Plan shall also record the expert's name, affiliation, and principal qualification as an expert (e.g., that they are a member of a country's national agricultural statistics technical advisory group), and should include in an annex a 1-page summary CV for each expert consulted.

[18] Typically, citations for sources of data used should include: the report or paper title, publisher, page numbers, publication date etc (or a detailed web address). If web-based reports are cited, hardcopies should be included as Annexes in the GHG Project Plan if there is any likelihood such reports may not be permanently available.

In choosing key parameters of making important assumptions based on information that is not specific to the Project circumstances, such as in use of default data, Project Proponents must select values that will lead to an accurate estimation of net GHG emissions, taking into account uncertainties. If uncertainty is significant, Project Proponents must choose data such that it tends to over-estimate, rather than under-estimate, net GHG emissions.

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7 APPENDIX A: REQUIRED PROTOCOLS FOR COLLECTING FIELD MEASUREMENTS OF NITROUS OXIDE EMISSIONS

Variability in field data collection and quality is a continuing challenge for independent validation of process models. Even though there are some statistical "work-arounds," comparing historical, current, and ongoing field data sets is a problem. Fortunately, procedures for collecting field data are becoming more standardized as time goes on, and models are improving as they are calibrated with a growing set of high quality field data. How the data are used is a critical component to data issues as well.

There are different approaches for measuring fluxes of nitrous oxide from agricultural soils. These methods include micrometeorological and chamber techniques. Chamber techniques can rely on either static or automated chambers. In general, chamber techniques are preferred because micrometeorological techniques require expensive equipment and measure larger and variable areas which tend to be harder to characterize for use in independent process model validation. Techniques for designing chamber measurements, sampling designs, setting of gas standards and analytical analysis and modeling of gas samples have improved significantly over the past decade. Through the USDA ARS GraceNet efforts a protocol for chamber based measurements has been developed Parkin and Venterea, 2010 (see chapter 3)[19].

Key considerations for the sampling and measurement process for N_2O include:

- ✓ Data collected following the GraceNet protocol or other recently (from 2010 forward?) peer-reviewed protocols are sufficient.
- ✓ Data should be peer reviewed and published if possible. If not published, Project Proponent must demonstrate that the data were collected using measurement procedures that follow guidelines set forth in GraceNet protocol where daily fluxes can be derived with some estimate of uncertainty.
- ✓ General guidelines for field measurements:
    - Replicates of field measurements.
    - Use of static or automated chambers
    - Gas samples are withdrawn from chambers at regular intervals (at least 3 times) with the closed chambers staying in place for not more than 60 minutes (longer than that will bias the measurements as the chamber will change the soil environment). However, the

[19] http://www.ars.usda.gov/research/programs/programs.htm?np_code=212&docid=21223&page=2

chamber should be in place long enough to measure a change in gas concentrations with time to estimate flux.

- ✓ General guidelines on frequency and timing of sampling measurements
  - Measurements should be made at approximately the same time of day to avoid bias due to diurnal variations in fluxes.
  - Measurements should be collected at least once every 1 to 2 weeks (more frequently is preferred) throughout the season or year.
  - Sampling frequency should include “event” based sampling to capture peaks in N_2O emissions. Following rainfall, fertilizer, organic amendments or tillage events, daily measurements should be collected daily until the peak emissions subside.

8 APPENDIX B: UNCERTAINTY DISCUSSION

Models are often divided into empirical and process-based biogeochemical models (PBMs). While empirical models fit a line or a curve through the field measurements as a basis for future predictions, process-based biogeochemical models, like DNDC, are a distinct class of models that simulate the biological, chemical and physical processes that control carbon and nitrogen cycling and production, consumption and emissions of greenhouse gases.

Sources of Uncertainty

For any model, the total uncertainty is usually divided into two main sources: (1) uncertainty due to input data accuracy and (2) structural uncertainty inherent in the model. The methods used to quantify either source of uncertainty are quite different, as are the methods to mitigate the uncertainty. The distinction between input data uncertainty and structural uncertainty is an important one since the structural uncertainty is inherent to the model and cannot be reduced unless the model itself is improved, while the uncertainty in input data can be, to some extent, controlled by users of a model, for example by expanding the number of samples on which input data is based. A sound uncertainty analysis estimates the impacts of both sources of uncertainty.

Approach for calculating input uncertainty at the field level

Accounting for uncertainty due to input data accuracy shall be quantified by Monte Carlo analysis. The Monte Carlo analysis is performed by modeling GHG emissions for both the baseline and project scenarios to calculate an input uncertainty deduction for each field in order to adjust for model uncertainty due to input parameter uncertainties. A multivariate lognormal distribution must be used to sample parameters for the Monte Carlo analysis[20]. At least 1000 (n) different draws out of this multivariate lognormal distribution for both the Baseline Scenario and the Project Scenario and subsequent model simulations must be executed. For each of the n draws of the distribution, one emission reduction is calculated by subtracting the Baseline emissions from the Project emissions. The input uncertainty ($\mu_{inputs,i}$) for greenhouse gas emissions due to uncertainty in input parameters for field *i* shall be calculated as the half-width of the 90 percent confidence interval of the modeled reductions, where the modeled reductions for each Monte Carlo run j are calculated as: ($\mu_{inputs,i}$) = half-width of 90% confidence interval of distribution of modeled baseline versus project emissions expressed as a percent of the mean GHG emission reduction ($\overline{GHG}_{reduction,i}$) of field *i* .

[20] For example, using the rlnorm function of the R package (http://rss.acs.unt.edu/Rdoc/library/compositions/html/rlnorm.html).

Approach for calculating model structural uncertainty

The calculation of u_{struct} is critically dependent on the standard deviation of the residuals s and the correlation between the residuals of the project emissions and the residuals of the baseline emissions ρ.

Assume k pairs of $\left(Y_{meas}(i), Y_{model}(i)\right)$, the quantity s can be calculated as the standard deviation of the difference between $Y_{meas}(i)$ and $Y_{meas}(i)$. The quantity ρ can be estimated by dividing the measurements in "baseline" cases, $BE_{meas}(i)$ and "project cases", $PE_{meas}(i)$. Using conventional terminology, the baseline would be the control or conventional treatment. Subsequently, pairs of measured and simulated emission reductions $DER_{meas}(i)$ and $DER_{model}(i)$ can be calculated as the difference between $PE_{meas}(i)$ and $BE_{meas}(i)$, and $PE_{model}(i)$ and $BE_{model}(i)$, respectively. Calculate ρ as the correlation coefficient between $DER_{meas}(i)$ and $DER_{model}(i)$. Smaller correlation coefficients will result in greater uncertainty deductions. Therefore, it is good practice to calculate a set of correlation coefficients through leave-one-out jackknifing and set the correlation coefficient to the low range of this set of values.

The quantities s and ρ can be calculated with more accuracy based on daily values of these quantities as:

$$s_{annual} = 365 \cdot s_{daily}$$
$$\rho_{annual} = \rho_{daily}$$

Note that measurements aggregated over any other time period than daily can be used to estimate ρ. This protocol requires to use at least 50 measurements to calculate ρ.

$$UNC\_STRUCT = \frac{s\sqrt{2(1-\rho)}}{\sqrt{n}} \cdot t_{inv}(0.90, k)$$

Where:

u_{struct}	=	Structural uncertainty factor
s	=	Standard deviation
ρ	=	Correlation between project residuals and baseline residuals
t_{inv}	=	Inverse of the cumulative t-distribution with a specific confidence and degrees of freedom
k	=	Number of pairs of modeled and measured values used for model verification.
n	=	Size of the Project Area [ha]

Example: Calculation of DNDC Structural Uncertainty for corn production systems in LRR-M.

Independent validation of DNDC. For this example, field data were collected from a paper by Hoben et al. (2011)[21]. This study measured nitrous oxide emissions from five sites in Michigan across a range of 6 different nitrogen application rates (0 to 225 kg N/ha/year of Urea) over two growing seasons (2007 and 2008). Based on the data provided in the paper, an independent validation of DNDC was conducted resulting in 48 sets of measured versus modeled pairs. The standard deviation of the residuals (measured minus modeled emissions) was 1.2. The validation results are presented in the following 5 tables by site.

Site 1: Kellogg Biological Station, Michigan

Site Name	Treatment	Observed (kg N-N2O/ha)	Modeled (kg N-N2O/ha)
KBS	Control_2007	0.34	**0.31**
	Control_2008	0.39	**0.51**
	45 kg N/ha_2007	0.44	**0.49**
	45 kg N/ha_2008	0.53	**0.86**
	90 kg N /ha_2007	0.63	**0.68**
	90 kg N /ha_2008	0.93	**1.39**
	135 kg N/ha_2007	0.82	**0.92**
	135 kg N/ha_2008	1.48	**1.84**
	180 kg N/ha_2007	1.09	**1.5**
	180 kg N/ha_2008	1.05	**2.21**
	225 Kg N/ha_2007	1.65	**2**

[21] Hoben JP, Gehl RJ, Millar N, Grace PR, Robertson GP. 2011. Nonlinear nitrous oxide (N_2O) response to nitrogen fertilizer in on-farm corn crops of the US Midwest. Global Change Biology 17: 1140-1152.

	225 Kg N/ha_2008	2.48	**2.82**

Site 2: Reese Michigan

Site Name	Treatment	Observed (kg N-N2O/ha)	Modeled (kg N-N2O/ha)
Reese	Control_2007	0.9	0.37
	Control_2008	0.57	0.6
	45 kg N/ha_2007	1.33	0.44
	45 kg N/ha_2008	0.83	0.67
	90 kg N /ha_2007	2.27	0.69
	90 kg N /ha_2008	0.85	0.78
	135 kg N/ha_2007	2.79	1.02
	135 kg N/ha_2008	0.89	1.01
	180 kg N/ha_2007	2.94	1.17
	180 kg N/ha_2008	0.92	1.66
	225 Kg N/ha_2007	3.65	1.29
	225 Kg N/ha_2008	1.11	2.56

Site 3: Fairgrove, Michigan

Site Name	Treatment	Observed (kg N-N2O/ha)	Modeled (kg N-N2O/ha)

Fairgrove	Control_2007	0.92	**0.51**
	Control_2008	0.64	**0.75**
	45 kg N/ha_2007	1.36	**0.82**
	45 kg N/ha_2008	0.75	**0.88**
	90 kg N /ha_2007	1.92	**1.15**
	90 kg N /ha_2008	1.03	**1.05**
	135 kg N/ha_2007	2.22	**1.31**
	135 kg N/ha_2008	1.07	**1.39**
	180 kg N/ha_2007	3.04	**1.43**
	180 kg N/ha_2008	1.12	**2.67**
	225 Kg N/ha_2007	5.12	**1.55**
	225 Kg N/ha_2008	1.46	**3.33**

Site 4: Mason, Michigan

Site Name	Treatment	Observed (kg N-N2O/ha)	Modeled (kg N-N2O/ha)
Mason	Control_2007	0.53	**0.49**
	45 kg N/ha_2007	0.71	**0.6**
	90 kg N /ha_2007	0.83	**0.71**
	135 kg N/ha_2007	1.09	**0.82**

	180 kg N/ha_2007	1.94	**1.05**
	225 Kg N/ha_2007	1.94	**1.18**

Site 5: Stockbridge, Michigan

Site Name	Treatment	Observed (kg N-N2O/ha)	Modeled (kg N-N2O/ha)
Stockbridge	Control_2008	0.63	**0.83**
	45 kg N/ha_2008	0.76	**2.55**
	90 kg N /ha_2008	0.81	**3.81**
	135 kg N/ha_2008	2.02	**4.94**
	180 kg N/ha_2008	4.2	**6.17**
	225 Kg N/ha_2008	6.91	**6.93**

From the data in the tables above, we can create 120 pairs of measured and modeled emission reductions. The correlation between the measured and modeled emission reductions (120 pairs of reductions) from a change in nitrogen fertilizer application rates was 0.56. Based on these results, we estimate the model structural uncertainty as follows:

$$UNC_{STRUCT} = \frac{1.2\sqrt{2(1-0.56)}}{\sqrt{n}} \cdot 1.3$$

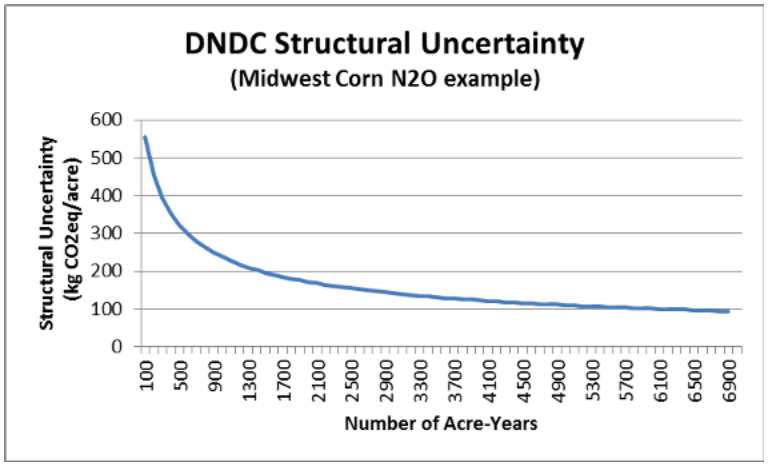
$UNC_{STRUCT} = \frac{1.46}{\sqrt{n}}$ $(units\ of\ \frac{kgN-N20}{ha})$.

Approach for deducting model structural uncertainties

Once we have calculated the model structural uncertainty (as demonstrated above), we can account for it by establishing a discount factor that ensures that the DNDC model estimates of emission reductions are conservative. It is clear from the equation above, as we add more fields to the project or program, the discount for structural uncertainty decreases.

The figure below shows the discount factors based on the example structural uncertainty for LRR-M corn above and number of fields in a project/program. From this figure it is clear that the discount factors are considerable for projects (or programs) with only a few fields (or acres). For example, a project with fewer than 20 fields would require a deduction of 0.4 tCO_2eq/ha to well over 1 tCO_2eq/ha deduction. Projects with over 50 fields would require deductions less than 0.25 tCO_2eq/ha.

The field measurements usually cover an area much smaller than an average field. Here we assume that the field measurements for collecting the independent field data, which serve as the basis of the derivation of model structural uncertainty, represent an area no larger than 20 acres. This is a very conservative estimate given the guidelines and measurement protocols used in the field studies and the use of chambers for measuring daily fluxes (See GraceNet measurement protocol). The following figure present the discount factor in units of kg CO2eq/acre based on either number of fields or total acreage. The discount curve for the total acreage calculations was derived assuming the validation sites were representative of 20 acres. In this case, projects over 1500 acres would have a deduction factor smaller than 0.2 tCO_2eq/ha.



The figure illustrates how on the structural uncertainty discounting is applied to the modeled emission reductions based on the size of the project. This approach is shown in the formula below:

$$ER_{ALM-ACR} = \sum_{i=1}^{m} \mu_{inputs\_i} * (GHG_{BSL,i} - GHG_{P,i}) - A * \mu_{struct-A}$$

Where,

$ER_{ALM-ACR}$	=	Net greenhouse gas emissions reductions over the project area
m	=	Number of individual field-years included in the project area
$\mu_{inputs,i}$	=	Accuracy deduction factor for individual field *i* due to input uncertainties (% reduction for each field)
GHG_{P_i}	=	Project emissions in for individual field *i*
GHG_{BSL_i}	=	Baseline emissions in for individual field *i*
A	=	Area of all the fields in the project for that project year
$\mu_{struct-A}$	=	Accuracy deduction from model structural uncertainty (% reduction) for *A* acre-years in the project

9 CONTACT INFORMATION

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