American Carbon Registry®
Trusted solutions for the carbon market

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

Version 1.0
June 2010

A nonprofit enterprise of
Winrock International

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
NCV	Net Calorific Value
NH_3	Ammonia
NO	Nitric oxide
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

ACKNOWLEDGEMENTS

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ACR extends its appreciation in particular to Timothy Pearson and Sandra Brown of Winrock International, William Salas of Applied Geosolutions Inc., and Walt Reid and Laura Sullivan of the Packard Foundation.

We thank the stakeholders who provided feedback on the public comment draft, as well as the standard's anonymous scientific peer reviewers.

INTRODUCTION

The American Carbon Registry® (ACR) is a voluntary, online greenhouse gas registration and emissions tracking system used by members to transparently register verified, project-based emissions reductions and removals as serialized offsets; record the purchase, sale, banking and retirement of tradable offsets, branded as Emission Reduction Tons ("ERTs"); and optionally report, in a separate account, verified greenhouse gas (GHG) inventories.

ACR was founded in 1997 as the GHG Registry by the Environmental Defense Fund and Environmental Resources Trust, and joined Winrock International in 2007. As the first private voluntary GHG registry in the United States, ACR has set the bar for transparency and integrity that is the market standard today.

Winrock International, a non-profit public benefit corporation founded in 1984, works with people in the U.S. and around the world to empower the disadvantaged, increase economic opportunity, and sustain natural resources. Central to Winrock's mission since its founding has been agricultural and livestock improvement, linking farmers to new markets, and enhancing food security – complemented in recent years by an objective to address potential impacts of climate change on agriculture and reduce the GHG intensity of agricultural production. Since the 1990s, Winrock has been a leader in developing science-based GHG measurement and monitoring protocols.

Background

This methodology results from efforts, carried out with support of the David and Lucile Packard Foundation, to improve understanding of N_2O emissions from the U.S. agricultural sector; strengthen accounting methodologies for activities to reduce N_2O emissions from fertilizer use; and link farmers who conduct such activities to carbon market opportunities.

Nitrogen fertilizers represent the dominant cause of GHG emissions from agricultural production; N_2O from agricultural soil management was responsible for 3.4% of net US emissions in 2007. Thus changing fertilizer management practices is a potentially attractive way to reduce emissions of a GHG with approximately 300 times the global warming potential of CO_2.

This methodology builds on two intermediate efforts. First, Winrock developed a simplified methodology, based on the work of Bouwman et al (2002), to estimate average annual N_2O emissions from three major U.S. crops (corn, cotton, and wheat) across 129 million acres in 31 U.S. states. This analysis estimated total annual N_2O emissions of 61 million metric tons carbon dioxide-equivalent, of which 70% were from corn, 25% from wheat and 5% from cotton. Per-acre N_2O emissions ranged between 0.12 and 1.45 t CO_2-e annually and varied by state, crop and fertilizer type (Pearson, Grimland and Brown 2010a).

Second, Winrock applied this “modified Bouwman methodology” to estimate GHG emission reductions from changes in fertilizer management (Pearson, Grimland and Brown 2010b). The objective was to improve on the Intergovernmental Panel on Climate Change (IPCC) Tier 1 approach, which predicts N_2O emissions from fertilizer quantity using simple defaults. The modified Bouwman methodology required site-specific information on type of fertilizer, soil carbon concentration, drainage, pH, soil texture and crop type. Test sites were chosen in Arkansas (cotton), Iowa (corn) and California (lettuce) for the 2009 growing season. The Denitrification-Decomposition (DNDC) model was also applied and results compared to the modified Bouwman methodology. While the methodology was effective for large-scale analysis, and for project-level calculations produced more rigorous estimates than the IPCC Tier 1 approach, Winrock concluded it did not provide sufficient rigor for carbon markets.

As a result, the present methodology uses DNDC – a peer-reviewed, tested and highly parameterized model – to estimate, for baseline and project scenarios, direct N_2O emissions as well as indirect emissions from leaching and ammonia volatilization, in an approach that is applicable not only to changes in fertilizer quantity (rate), but also fertilizer type, placement, timing, use of timed-release fertilizers, use of nitrification inhibitors and other factors. The approach is designed to produce rigorous results cost-effectively at the scale of aggregated fertilizer management projects.

The approach recognizes, besides the need for rigor and cost-effectiveness, two additional trends in agricultural carbon markets. First, to avoid leakage, maintain food supplies, and promote broad adoption by farmers, fertilizer management activities must be designed to minimize the risk of decreasing yields. There is some resistance in the agricultural community to methodologies that allow only reductions in fertilizer rate, because of perceptions that this will decrease yields. A methodology that allows willing farmers to reduce fertilizer rate, but allows for other practice changes as well, stands better chances of broad adoption. Second, there is an increasing trend toward aggregation in carbon markets, particularly in agriculture, with the likelihood that farmers will interface with carbon markets not as individuals but through aggregators grouping 10s or even 100s of farms together. Aggregation may be important not only for transaction cost efficiencies but also for improving modeling results and diversifying risk. Recognizing these trends, this methodology uses a model-based approach that allows for multiple practice changes and while data-intensive, is expected to produce rigorous results cost-effectively at aggregated scale.

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 rate (quantity), fertilizer type, placement, timing, use of timed-release fertilizers, use of nitrification inhibitors and other factors. Activities must meet all applicability conditions in Section I to apply this methodology.

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 verification by an ACR-approved third-party verifier of the GHG Project Plan and GHG assertions.

All ACR methodologies, whether proposed by a Proponent or developed by Winrock International, are approved following a rigorous public consultation and scientific peer review process.

Project Proponents and other interested parties should refer to www.americancarbonregistry.org for the latest version of this methodology, the *ACR Standard,* ACR sector standards, and other relevant methodologies, tools, and templates.

The appropriate citation for this document is American Carbon Registry (2010), *American Carbon Registry Methodology for Emission Reductions through Changes in Fertilizer Management, version 1.0.* Winrock International, Little Rock, Arkansas.

I. SOURCES, DEFINITIONS AND APPLICABILITY

1. Sources

This methodology is based on elements from the following methodologies:

- AR-ACM0001 “Afforestation and reforestation of degraded land”
- The “Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities”

2. Selected Baseline Approach

“Existing or historical emissions, as applicable”

3. Definitions

Definitions in the latest version of the *ACR Standard* apply.

4. 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 rate (quantity), fertilizer type, placement, timing, use of timed-release fertilizers, use of nitrification inhibitors and other factors.

The conditions under which the methodology is applicable are:

- Management in both baseline and project cases involves use of fertilizer for enhancing the growth and survival of 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 decrease in yields as a result of project implementation;
- Project must incorporate a minimum of 10 separate fields;
- Fertilizer use must not be increased in owned or managed lands that are not part of the project;
- The project does not involve the drainage or flooding of wetlands.

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

II. BASELINE METHODOLOGY PROCEDURE

1. Project Boundary and Eligibility of Land

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

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 area;
- The project participants shall describe legal title to the land, rights of access to the avoided carbon 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.

1.2 GHG assessment boundary

Carbon pools are not monitored as part of the methodology, as changes in stocks as a result of fertilizer management are considered to be *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	Non-CO_2 gas emitted from fertilizer application

Emissions resulting from Fossil Fuel Combustion	CO_2	Included	Gas emitted from fossil fuel combustion
	CH_4	Included	Gas emitted from fossil fuel combustion
	N_2O	Included	Gas emitted from fossil fuel combustion

2. *Identification of the Baseline Scenario and Additionality*

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 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
- Provide evidence that the incentive from the planned sale of ERTs was seriously 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.

ACR may accept AFOLU projects with a Start Date earlier than 1 November 1997 on a case-by-case basis, provided the Project Proponent can verifiably demonstrate that GHG mitigation was an objective from project inception.

STEP 1. Determination of Baseline Scenario

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. The scenario should be feasible for the project participants or project developers, taking into account relevant national and/or sectoral policies[1] 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.

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[1] The Annex 3 to the report of the EB 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.

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)[2] 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.

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.

STEP 2. Additionality Test

The Project Proponent shall test the additionality of the project using the three-pronged ACR additionality test.[3] The project scenario as described *ex ante* using this methodology and monitored using this

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[2] 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.

[3] As described in the *ACR Standard v2.0*.

methodology shall be evaluated alongside the baseline scenarios identified in Step 1. If a financial analysis or a demonstration of barriers does not lead the preclusion of the project scenario then the project shall be considered non-additional. The application of an additionality tool is recommended.[4]

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

3. *Stratification*

If the project activity 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. *Modeling Approach to Direct and Indirect Emissions from Fertilizer Management*

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),

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[4] 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.

ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2). DNDC is available at http://www.dndc.sr.unh.edu/. DNDC Version 9.4 or later shall be used.

The model must be:

- Used only in scenarios relevant to the scope for which the model was developed and evaluated;
- Parameterized for the specific conditions of the project.

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^- and the ammonia volatilization ($NL_{LEACH,j,i,t}$) in kg NH_3, by strata, in both the baseline and project scenarios through the duration of the project.

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 °	M		X		
Climate	*CI*	Atmospheric background NH_3 concentration	µg N/m³	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/cm³	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		
	S11	Wilting point	0-1	M		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		
	CR5	C/N ratio of the leaf + stem tissue	ratio	M		X		
	CR6	C/N ratio of the root tissue	ratio	M		X		
	CR7	Fraction of leaves and stem left in field after harvest	0-1	M		X		
	CR8	Maximum yield	kg dry matter/ha	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	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	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

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[5].

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. Users 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/ha)***: The maximum biomass productions for grain, leaves+stems (non-harvest above ground biomass), and roots under optimum growing conditions. The unit is kg C/ha (1 kg dry matter contains 0.4 kg C).
- ***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.
- ***Total N demand (kg N/ha)***: Amount of the total N demanded by the crop to reach the maximum production.
- ***Thermal degree days (°C)***: Accumulative 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.lst file that provides the look up table for crop numbers for each crop. All crops to be included in the ALM project shall be calibrated in DNDC using at least 5 years of observed yields.

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[5] 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., DNDC9.4) and supporting data sets. Go to C:\DNDC, and click DNDC94.exe to start the model.

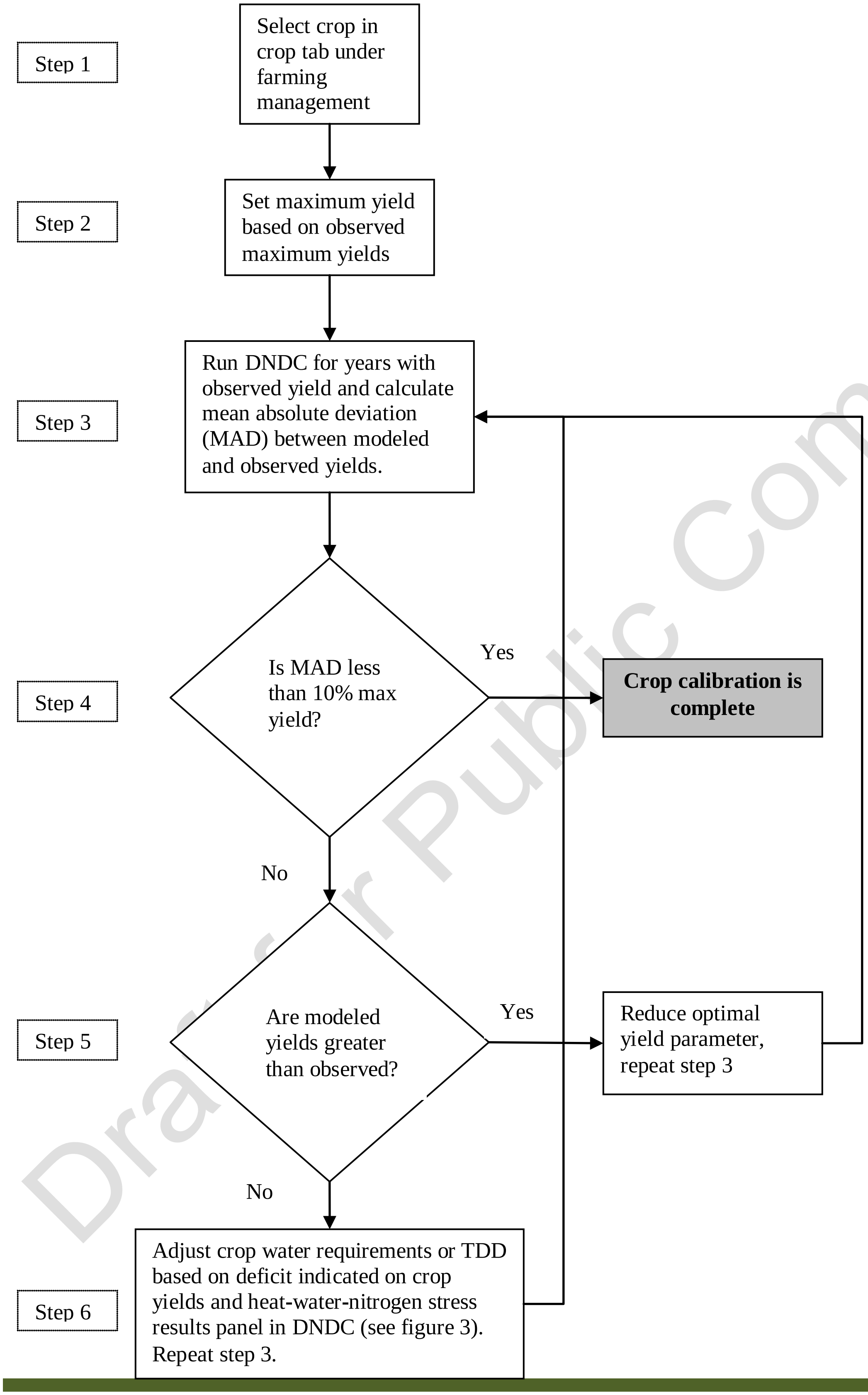
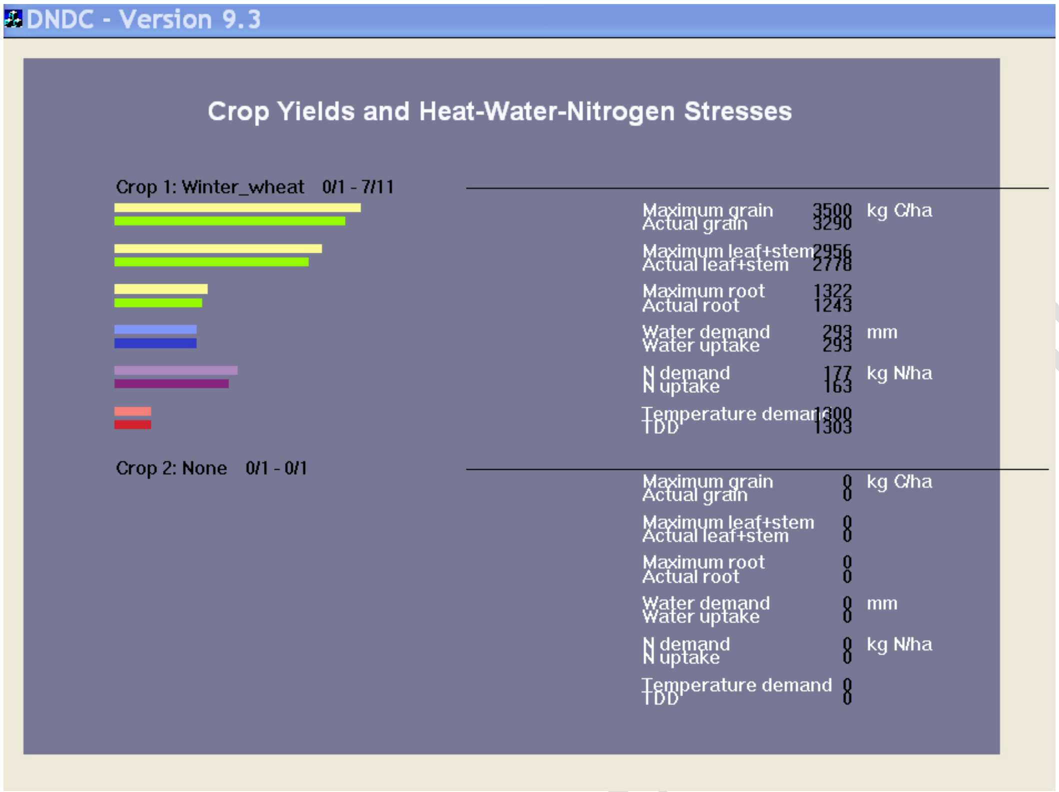

Step 1
Select crop in crop tab under farming management
Step 2
Set maximum yield based on observed maximum yields
Step 3
Run DNDC for years with observed yield and calculate mean absolute deviation (MAD) between modeled and observed yields.
Step 4
Is MAD less than 10% max yield?
Yes
Crop calibration is complete
No
Step 5
Are modeled yields greater than observed?
Yes
Reduce optimal yield parameter, repeat step 3
No
Step 6
Adjust crop water requirements or TDD based on deficit indicated on crop yields and heat-water-nitrogen stress results panel in DNDC (see figure 3). Repeat step 3.

Figure 1: Crop calibration procedures (preceding page)



Crop Yields and Heat-Water-Nitrogen Stresses

Crop 1: Winter_wheat 0/1 - 7/11

Maximum grain	3500	kg C/ha
Actual grain	3290	
Maximum leaf+stem	2956	
Actual leaf+stem	2778	
Maximum root	1322	
Actual root	1243	
Water demand	293	mm
Water uptake	293	
N demand	177	kg N/ha
N uptake	163	
Temperature demand	1300	
TDD	1303	

Crop 2: None 0/1 - 0/1

Maximum grain	0	kg C/ha
Actual grain	0	
Maximum leaf+stem	0	
Actual leaf+stem	0	
Maximum root	0	
Actual root	0	
Water demand	0	mm
Water uptake	0	
N demand	0	kg N/ha
N uptake	0	
Temperature demand	0	
TDD	0	

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

Note: If the mean absolute deviation 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 mean absolute deviation and record the value of the minimum absolute deviation.

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[6] 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[7].

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

Parameter	PDF	Uncertainty
Bulk density	Log-normal	0.1 kg/m^3
Clay content	Log-normal	+/- 10%
SOC	Log-normal	+/- 20%
pH	Normal	+/- 1 pH unit

A selection of 4,096 soil parameter (SOC, pH, clay fraction and bulk density) combinations shall be compiled for the Monte Carlo DNDC model runs (STEPS 3 and 4). The selection soil parameter combination will be random selection for each parameter based on the PDF and uncertainty estimates (derived from field measurements).

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. 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.

Once the Monte Carlo run is complete, results are recorded in a CSV file in the C:\DNDC\Result\Record\MonteCarlo folder. The name of the file is the site name as entered into DNDC. From the CSV file extract the direct N_2O emissions, nitrate leaching, NH_3 and NO emissions for Monte Carlo run *j* 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}

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

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

$NL_{VOLAT,j,i}$	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 t CO_2-e/ha in stratum *i* for all Monte Carlo runs as follows:

$$GHG_{BSL,N2O,E,j,i} = \left(NL_{DIRECT,j,i} + \left(NL_{VOLAT,j,i} * EF_4\right) + \left(NL_{LEACH,j,i} * EF_5\right)\right) * \frac{44}{28} * GWP_{N2O} \quad \textbf{(1)}$$

$$GHG_{P,N2O,E,j,i} = \left(NL_{DIRECT,j,i} + \left(NL_{VOLAT,j,i} * EF_4\right) + \left(NL_{LEACH,j,i} * EF_5\right)\right) * \frac{44}{28} * GWP_{N2O} \quad \textbf{(2)}$$

$$GHG_{BSL,N2O,E,i} = \frac{\sum_{j=1}^{N}\left(GHG_{BSL,N2O,E,j,i}\right)}{n} \quad \textbf{(3)}$$

$$GHG_{BSL,N2O,E,i} = \frac{\sum_{j=1}^{N}\left(GHG_{BSL,N2O,E,j,i}\right)}{n} \quad \textbf{(4)}$$

Where

$GHG_{BSL\_N2O,E,i}$	N_2O emissions as a result of fertilizer management activities in stratum *i* within the project boundary in the baseline; t CO_2-e.ha^{-1}
$GHG_{P\_N2O,E,i}$	N_2O emissions as a result of fertilizer management activities 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}
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	$1, 2, 3 \ldots N$ Monte Carlo runs
i	1, 2, 3 …M strata

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.

$$BE = GHG_{BSL\_N2O,E} + GHG_{BSL\_FF,E} \tag{5}$$

Where

BE	Baseline greenhouse gas emissions; t CO_2-e
$GHG_{BSL\_N2O,E}$	N_2O emissions as a result of fertilizer management 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

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:

$$GHG_{BSL\_N20,E} = \sum_{t=1}^{t^*}\left(\sum_{i=1}^{M}\left(GHG_{BSL,N2O,E,i} * A_i\right)\right) \tag{6}$$

Where

$GHG_{BSL\_N2O,E}$	N_2O emissions as a result of fertilizer management 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

5.2 Accounting baseline emissions from fossil fuel combustion

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

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

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*; tCO2-e/TJ
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:

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

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
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; TJ/Gg
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:

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

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
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; TJ/Gg
a	Fuel type *a* (e.g. diesel, gasoline, etc.)

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

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.

$$PE = GHG_{P\_N2O,E} + GHG_{P\_FF,E} \tag{10}$$

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 with-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 with-project scenario; t CO_2-e

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:

$$GHG_{P\_N20,E} = \sum_{t=1}^{t^*}\left(\sum_{i=1}^{M}\left(GHG_{P,N2O,E,i} * A_i\right)\right) \qquad \textbf{(11)}$$

Where

$GHG_{P\_N2O,E}$	N_2O emissions as a result of fertilization within the project boundaries in the with-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 with-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

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:

$$GHG_{P\_FF,E} = \sum_{a}(Fuel_{a,t} \times EF_a) \qquad \textbf{(12)}$$

Where

$GHG_{P\_FF,E}$	Net CO_2-e emissions of fossil fuel consumption in the with-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
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:

$$Fuel_{a,t} = \frac{\left(Liters_{Fuel_{a,t}} \times Density_{Fuel_a} \times NCV_{Fuel}\right)}{10^6} \tag{13}$$

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
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; TJ/Gg
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:

$$Fuel_{a,t} = \frac{\left(Gallons_{Fuel_{a,t}} \times Density_{Fuel_a} \times NCV_{Fuel}\right)}{10^6} \tag{14}$$

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
$NCV_{Fuel\ a}$	Net Calorific Value of Fuel type *a*; TJ/Gg

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

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

7. Leakage

Under the applicability conditions of this methodology yields may not be decreased as a result of project implementation. As a result there can be no shifting of activities nor any market impacts of the project.

Leakage under this methodology is therefore equal to zero. This shall be demonstrated through a comparison of the yield estimations by DNDC across the project for the baseline case against the with-project case. Total yield shall not differ between the baseline and with-project scenarios by more than 5% in any given year.

8. Net GHG Emissions

The net GHG emission reduction is the actual net project GHG emissions minus the baseline GHG emissions. 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.

$$ER_{ALM-ACR} = PE - BE \qquad \textbf{(15)}$$

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

Estimated GHG emissions from ALM 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 4, Step 2), either as default values or estimates based of 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.

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.

8.2 Estimation of uncertainty for modeled emissions

Model uncertainty shall be derived from the set of 4,096 Monte Carlo runs for both the baseline and project simulations separately. Model uncertainty at 90% confidence level shall be calculated on a per stratum basis as follows:

$$UNCERTAINTY_{BSL,i} = \frac{\left(\frac{s_{BSL,i}}{\sqrt{4096}}\right) * 1.645}{GHG_{BSL\_N2O,E,i}} \tag{16}$$

$$UNCERTAINTY_{P,i} = \frac{\left(\frac{s_{P,i}}{\sqrt{4096}}\right) * 1.645}{GHG_{P\_N2O,E,i}} \tag{17}$$

$$S_{BSL,i} = \sqrt{\frac{\sum_{j=1}^{n}\left(GHG_{BSL\_N2O,E,j,i} - GHG_{BSL\_N2O,E,i}\right)}{(4096-1)}} \tag{18}$$

$$S_{P,i} = \sqrt{\frac{\sum_{j=1}^{n}\left(GHG_{P\_N2O,e,j,i} - GHG_{P\_N2O,E,i}\right)}{(4096-1)}} \tag{19}$$

Where

$UNCERTAINTY_{BSL,i}$	Total uncertainty in stratum i in baseline scenario; %
$UNCERTAINTY_{P,i}$	Total uncertainty in stratum i in the with-project scenario; %
$S_{BSL,i}$	Standard deviation of the modeled baseline GHG emissions in stratum i derived from the Monte Carlo runs.
$S_{P,i}$	Standard deviation of project GHG emissions in stratum i derived from the Monte Carlo runs.
$GHG_{BSL\_N2O,E,i}$	N_2O emissions as a result of fertilizer application within the project boundary in the baseline scenario for stratum i; t CO_2-e.ha^{-1}
$GHG_{P\_N2O,E,i}$	N_2O emissions as a result of fertilizer application within the project boundary in the project scenario for stratum i; 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}
j	1, 2, 3 … N Monte Carlo runs
i	1, 2, 3 …M strata

8.3 Total uncertainty of ACR-ALM project

The total project uncertainty is calculated at the time of reporting through propagating the errors across strata and then between the error in baseline emissions and the error in the project emissions:

$$UNCERTAINTY_{BSL} = \sqrt{UNCERTAINTY_{BSL,i1}{}^2 + UNCERTAINTY_{BSL,i1}{}^2 + \ldots + UNCERTAINTY_{BSL,iM}{}^2} \tag{20}$$

$$UNCERTAINTY_{P} = \sqrt{UNCERTAINTY_{P,i1}{}^2 + UNCERTAINTY_{P,i1}{}^2 + \ldots + UNCERTAINTY_{P,iM}{}^2} \tag{21}$$

$$ER_{ALM-ACR\_ERROR} = \sqrt{\mathrm{UNCERTAINTY}_{\mathrm{BSL}}{}^2 + \mathrm{UNCERTAINTY}_{\mathrm{P}}{}^2} \tag{22}$$

Where

$ER_{ALM-ACR\_ERROR}$	Total uncertainty for ALM-ACR Project; %
$Uncertainty_{BSL}$	Total uncertainty in baseline scenario; %
$Uncertainty_{P}$	Total uncertainty in the with-project scenario; %
$Uncertainty_{BSL,i}$	Total uncertainty in stratum i in baseline scenario; %
$Uncertainty_{P,i}$	Total uncertainty in stratum i in the with-project scenario; %
i	1, 2, 3 …M strata

8.4 Uncertainty Deduction

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

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

$$= ER_{ALM-ACR} - \left(ER_{ALM-ACR} * \left(ER_{ALM-ACR\_ERROR} - 10\%\right)\right) \qquad (23)$$

Where

$ER_{ALM-ACR}$	Net GHG emission reduction; t CO_2-e
$ER_{ALM-ACR\_ERROR}$	Total uncertainty for ALM-ACR Project; %

8.5 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:

$$ERTs = ER_{ALM-ACR,t2} - ER_{ALM-ACR,t1} \qquad (24)$$

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

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.

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.

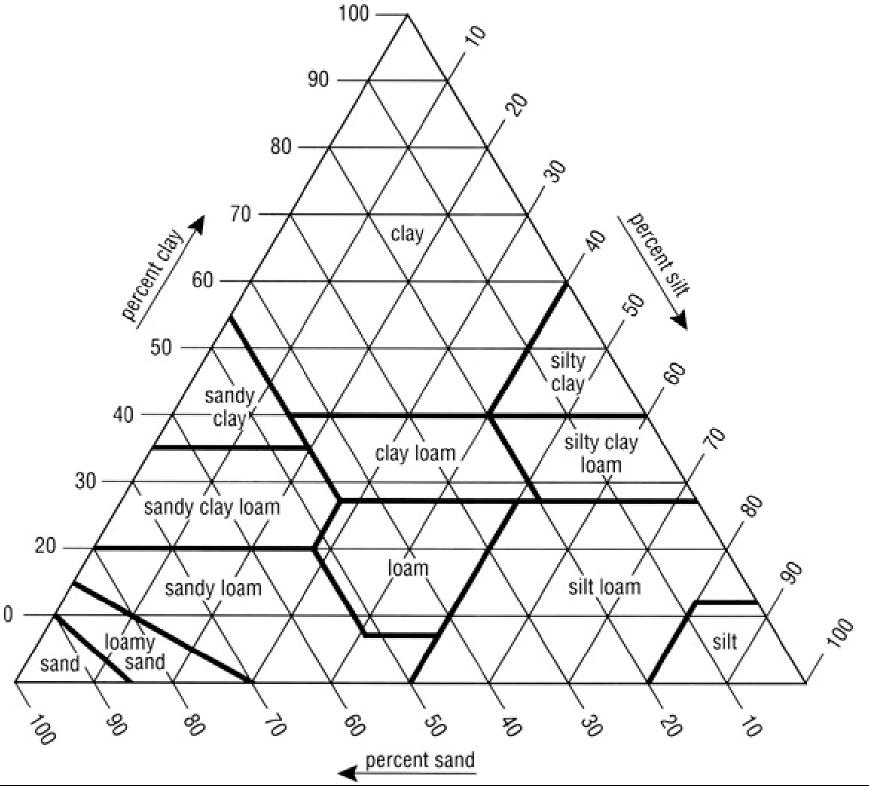
Data / parameter:	***S3**: Soil Bulk Density*
Data unit:	g/cm^3
Used in equations:	Used by DNDC
Description:	Soil bulk density of the top 10cm of soil. Bulk density is the ratio of the mass of dry solids to the bulk volume of the soil
Source of data:	Field measurement or use of NRCS Soil Survey Geographic (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 procedures (if any):	Wilting Point WFPS is calculated as the ratio of volumetric water content (θ) and total soil porosity (P_t) at soil moisture content of 15 bars tension: %WFPS = (θ/P_t) • 100
Any comment:	

Cropping System Input Parameters

Data / parameter:	***CR9**: Maximum Crop Yield*
Data unit:	Kg dry matter/ha
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)

9.2 Other inputs

Fossil Fuel Combustion

Data / parameter:	EF_a
Data unit:	tCO_2-e/TJ
Used in equations:	7, 12
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]

Fuel Type	Default effective CO_2 emission factor (tCO_2/TJ)
Motor gasoline	69.3

Gas/Diesel Oil	74.1
Liquefied Petroleum Gases	63.1
Kerosene	71.9
Lubricants	73.3
Compressed Natural Gas	56.1
Liquefied Natural Gas	56.1

[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, 13 / 14
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)	Liters per tonne	Density (kg/gal)	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, 13 / 14
Description:	Net Caloric Value per Fuel Type

<table>
<tr><td>Source of data:</td><td>Table A3.8, page 181, IEA Statistics Manual, OECD/IEA, 2005;
and,
Table 1.2, Chapter 1, Volume 2, IPCC 2006 Inventory Guidelines</td></tr>
<tr><td>Measurement procedures (if any):</td><td>Default NCVs are presented in tables below.
<table>
<tr><th>Fuel Type</th><th>Density (kg / ltr)</th><th>NCV (GJ/t)[a]</th></tr>
<tr><td>Motor gasoline</td><td>0.7407</td><td>44.75</td></tr>
<tr><td>Gas/Diesel Oil</td><td>0.8439</td><td>43.38</td></tr>
<tr><td>Naphtha</td><td>0.6906</td><td>45.34</td></tr>
<tr><td>Aviation gasoline</td><td>0.7168</td><td>45.03</td></tr>
<tr><td>Aviation Turbine fuel</td><td>0.8026</td><td>43.92</td></tr>
<tr><td>Other kerosene</td><td>0.8026</td><td>43.92</td></tr>
</table>
[a] 1000 GJ = 1 TJ
Table: Default NCVs (excerpt from table 1.2, Chapter 1, Volume 2, IPCC, 2006 Inventory Guidelines)
<table>
<tr><th>Fuel type (English description)</th><th>Default Net Caloric Value (NCV) (TJ/Gg)[b]</th></tr>
<tr><td>Crude Oil</td><td>42.3</td></tr>
<tr><td>Orimulsion</td><td>27.5</td></tr>
<tr><td>Natural Gas Liquids</td><td>44.2</td></tr>
<tr><td>Motor Gasoline</td><td>44.3</td></tr>
<tr><td>Aviation Gasoline</td><td>44.3</td></tr>
<tr><td>Jet Gasoline</td><td>44.3</td></tr>
<tr><td>Jet Kerosene</td><td>44.1</td></tr>
<tr><td>Other Kerosene</td><td>43.8</td></tr>
<tr><td>Gas/Diesel Oil</td><td>43.0</td></tr>
<tr><td>bio-gasoline/bio-diesel</td><td>27.0</td></tr>
<tr><td>other liquid biofuels</td><td>27.4</td></tr>
</table>
[b] TJ/Gg = GJ/t</td></tr>
<tr><td>Any comment:</td><td>For more NCVs for other fuels, see the original data sources.</td></tr>
</table>

III. 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.

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.

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, 11 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:	***µg 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 µg 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 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’s 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	Standard lab techniques.

procedures (if any):	
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's 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’s 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’s 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
Used in equations:	Used by DNDC
Description:	Application rate of nitrogen fertilizer in kg N/ha 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
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, 13 / 14
Description:	Fuel consumed
Source of data:	Records of fuel consumed or distance travelled by vehicles (farm 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.

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[8];
- 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.

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 participants must choose data such that it tends to over-estimate, rather than under-estimate, net GHG emissions.

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[8] 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.

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