SCIENCE DISCUSSION DOCUMENT
FOR
NITROUS OXIDE EMISSION REDUCTION PROTOCOL

TO:

CLIMATE CHANGE CENTRAL

&

CANADIAN FERTILIZER INSTITUTE

24 SEPTEMBER 2008

REPORT NO. FINAL

Contents

1 Summary

The eligibility requirements of the Nitrous Oxide Emissions Reduction Protocol (NERP) are designed according to the criteria of the Alberta Offsets System **and** Canada's Offset System.

The scope of the NERP is limited to (1) on-farm reductions of (2) emissions associated with quantification categories fertilizer, manure, residues, and irrigation.

The options for baseline scenario and baseline period are presented.

The justification for the additionality or Incrementality of the comprehensive 4R N management plan is described.

The projects in the NERP are: (1) compared to the baseline scenario based on emissions per unit mass of each crop; (2) based on evidence of the implementation of a 4R NITROGEN stewardship plan; (3) quantified according to the level of complexity of the BMPs; and (4) include reductions achieved by growing pulses.

The key to the implementation of verifiable reduction projects under the NERP is the design of a demonstrable accurate 4R N stewardship plan, as assured by (1) general guidance in the NERP confirmed by third party verification, (2) detailed design instructions in the NERP, (3) conformity with a recommended predictive model, or (4) retaining services of an approved consulting professional.

The Focus Sessions of the Consultation Workshop will finalize and approve the NERP elements recommended in the Science Discussion Document, or adapt alternative

2 Introduction

Climate Change Central[1], in collaboration with the Canadian Fertilizer Institute[2], have engaged ClimateCHECK to provide a Science Discussion Document to compile and coordinate scientific information concerning the GHG emission reductions associated with best management practices (BMPs) to decrease emission of nitrous oxide (N_2O) from management of N (Nitrogen) in the Canadian Prairies. This Science Discussion Document is a continuation of past work to assess the potential of N use efficiency protocol.

In Phase 1, a framework for a proposed nitrogen use protocol was developed in a Technical Background Document. The Technical Background Document proposed a protocol framework based on a comprehensive N management plan, simple and advanced performance levels according to BMPs to support the performance areas described in the 4R stewardship model of the Canadian Fertilizer Institute — "Right Product @ Right Rate, Right Time, Right Place™". The Technical Background

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[1] Climate Change Central is a unique public-private partnership that promotes the development of innovative responses to global climate change and its impacts. Climate Change Central builds links and relationships between businesses, governments and other stakeholders in Alberta interested in pursuing greenhouse gas reduction initiatives.

[2] The Canadian Fertilizer Institute (CFI) is an industry association representing manufacturers, wholesale and retail distributors of N, phosphate and potash fertilizers. Learn more about the CFI vision & mission, CFI staff, and CFI members at the website, www.cfi.ca.

Document, and the proposed protocol framework, was accepted for further development by a steering committee comprised of public- and private-sector experts in N management.

This Science Discussion Document represents Phase 2 of the development of the protocol and focuses on supporting consensus among scientific researchers and technical practitioners concerning quantifiable and verifiable BMPs and GHG quantification methodologies to meet the 'real' emission reductions criteria of ISO 14064-based North American GHG programs. The protocol is designated as the Nitrous Oxide Reduction Protocol (NERP). The researchers and practitioners will gather at a Consultation Workshop, where consensus will be sought based on questions posed in the Science Discussion Document. The consensus of the researchers and practitioners will be incorporated to develop a final version of the Science Discussion Document after the Consultation Workshop. This final Science Discussion Document will then become the Technical Seed Document from which the NERP will be adapted for the Alberta Offset System.

The development of the Science Discussion Document is guided and reviewed by a Contract Steering Committee, comprised of the following individuals:

- Doug Beever — Agrium;
- Ray Dowbenko — Agrium;
- Clyde Graham — Canadian Fertilizer Institute;
- Karen Haugen-Kozyra — Climate Change Central;
- Tom Jensen — International Plant Nutrition Institute; and
- Len Kryzanowski — Alberta Agriculture and Rural Development.

3 Science Discussion Paper — Format, Content and Purpose

The format and content of the Science Discussion Document is determined according to the country-specific quantification approach developed for Canada's National Inventory Report, the generic guidelines of Intergovernmental Panel on Climate Change (IPCC) (where country-specific guidance is lacking), and the requirements of ISO 14064-2:2006.

The ISO 14064-2 standard (2006, Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements) is the framework for protocols in the Alberta Offsets System and in the proposed Canada's Offset System, as well as in a number of US programs (Voluntary Carbon Standard, GE-AES GGS, California Climate Action Registry, Regional Greenhouse Gas Initiative, etc.). The International Standards Organization (ISO) standard is closely related to the GHG Protocol from World Resource Institute (WRI)/World Business Council for Sustainable Development (WBCSD), and applies the following principles:

- *Completeness* -- Include all relevant GHG emissions and removals. Include all relevant information to support criteria and procedures;
- *Consistency* -- Enable meaningful comparisons in GHG-related information;
- *Accuracy* -- Reduce bias and uncertainties as far as is practical;
- *Transparency* -- Disclose sufficient and appropriate GHG-related information to allow intended users to make decisions with reasonable confidence;
- *Relevance* -- Select the GHG sources, GHG sinks, GHG reservoirs, data and methodologies appropriate to the needs of the intended user; and

- *Conservativeness* -- Use conservative assumptions, values and procedures to ensure that GHG emission reductions or removal enhancements are not over-estimated.

The objective of this Science Discussion Document, therefore, is to compile the relevant scientific information, in the context of Intergovernmental Panel on Climate Change and ISO 14064-2, to quantify GHG emissions reductions associated with BMPs to increase efficiency of N fertilizer use in the Canadian prairies. This information will then be reviewed at the Consultation Workshop to achieve consensus for the continuing design of the NERP.

PRINCIPLE: It is important to note the proposed N_20 Reduction Protocol (NERP) is designed to achieve 'accuracy in aggregate'. That is, the quantification of GHG emissions using the NERP is not intended to achieve the site-specific predictive capability of a process model. Rather, using Canada-specific quantification methods and Intergovernmental Panel on Climate Change guidance within the discipline of the ISO standard ensures the uncertainties of quantification are minimized as the NERP is applied over a large number of participating farms (uncertainties 'average out').

PRINCIPLE: At the Consultation Workshop, consensus will be sought for each Decision Point, along with an opinion concerning the degree of uncertainty associated with the information to upon which the decision is based. Decision Points receiving a consensus opinion, defined as 80% agreement among designated scientific participants, will be the foundation for further NERP development. Thus, the Workshop is designed to serve as 'in-person peer review', where the collective experience and expertise of the designated scientific participants is the authority for decisions. Usually, this will mean the scientific participants will be asked to interpret and apply evidence presented in the peer-reviewed literature. But, in some instances the designated scientific participants will be asked to use their judgement to fill gaps in the published scientific literature.

4 Protocol Framework

The Science Discussion Document is organized to reflect the framework of the NERP from Phase 1 of the protocol development process. This framework will be discussed, revised, and finalized at the Consultation Workshop through the Decision Points of the Science Discussion Document.

4.1 Eligibility Criteria

The primary objective of the Science Discussion Document is to support the development of the NERP for submission to the Alberta Offset System. However, as the rules and procedures emerge for Canada's Offset System, it may be prudent to develop the NERP to comply with these criteria.

4.1.1 Alberta Offset System

Excerpt from Carbon Offset Solutions (www.carbonoffsetsolutions.ca).

> These offsets must be Alberta based and meet a number of criteria in order to be used to reach compliance. An offset must originate from a voluntary action in a non-regulated sector or operation. Additional criteria include:

a) Result from actions taken on or after January 1, 2002;
b) Occur on or after January 1, 2002;
c) Be real, demonstrable, quantifiable;
d) Not be required by law;
e) Have clearly established ownership;
f) Be counted once for compliance purposes.
g) Be verified by a qualified third party; and,
h) Have occurred in Alberta.

4.1.2 Canada's Offset System

Excerpt from DRAFT Guide for Protocol Developers (the final Guide is promised for November 2008).

a) Scope: The project must take place in Canada; the activity must achieve reductions in one or more of the following GHGs: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride; and the activity must be included in Canada's inventory of GHGs.
b) Real: A project must be a specific and identifiable action that results in a net reduction of GHGs after accounting for all relevant GHG sources, sinks and reservoirs. Projects may also be required to identify and address increases in emissions of air pollutants that will be regulated.
c) Incremental: There are five components of the incremental criterion:
    - Projects must have started on or after January 1, 2000.
    - Credits may be issued for reductions achieved after January 1, 2008.
    - Reductions achieved must go beyond the baseline defined for the project type.
    - Reductions are surplus to all legal requirements (federal, provincial/territorial and regional).
    - Reductions are beyond what is expected from receipt of other climate change incentives (federal, provincial/territorial).
d) Quantifiable: GHG reductions must be quantified as specified in an Offset System Quantification Protocol for the project type.
e) Verifiable: A recognized verifier must be able to provide a reasonable level of assurance that the reductions claimed from the project have been monitored/estimated, quantified and reported as set out in the Registered Project Document.
f) Unique: A GHG reduction can be used only once to create an offset credit.

Decision point 4.1: The NERP should be designed to comply with the criteria of the Alberta Offset System and Canada's Offset System (If ***disagree***, this means ***agree*** with developing only for the Alberta Offset System).

Agree _____ Disagree _____

4.2 Scope

4.2.1 Protocol Fundamentals

These protocol fundamentals are proposed following completion of the Phase 1 of the NERP development. The Phase 1 effort comprised a Technical Background Document prepared for a committee of public- and private-sector experts in N management. The Technical Background Document described the range of possibilities, with associated rationale, for an approach to a protocol to reduce emissions of N_2O from agricultural soils. The committee reviewed and revised the Technical Background Document to develop the following fundamentals proposed for the NERP.

The proposed NERP uses farm-specific criteria for eligibility. That is, the baseline GHG emissions will be calculated for each participating farm, and evidence of innovation will be the basis of eligibility to participate in the NERP for each farm. This Science Discussion Document provides the basis for the quantification method to be used, sets out the basis for determining which BMPs are expected to reduce GHG emissions from the baseline scenario, and states the eligibility requirements to participate in the NERP. But, each farm will need to calculate emission estimates for the baseline period and will need to provide evidence that the innovative BMPs were adopted after the baseline period. The fundamental innovative practice to initiate the NERP is implementation of a comprehensive N stewardship plan. This farm-specific approach is proposed to avoid the discounted reduction factors and questionable additionality associated with default approaches used in other agricultural protocols.

Finally, this Science Discussion Document describes a graded approach for the proposed NERP, with increasingly comprehensive requirements and corresponding increasingly large reductions. All levels will use the same criteria for participation; namely, implementation of a 4R N stewardship plan (described below). But, the more advanced levels will result in greater emissions reduction credits by requiring more comprehensive data for N recommendations, more extensive monitoring procedures in the 4R N stewardship plan, and more sophisticated BMPs. Thus, the decision for which level a project participant will use will be determined according to the cost of the intensive implementation and monitoring needed versus the value of the additional credits earned. Also, it is expected as research advances and more BMPs are developed these will be added to the NERP to achieve greater N_2O emission reductions.

4.2.2 Eligible Activities

The Canadian Fertilizer Institute promotes a nutrient stewardship system that promotes BMPs for use of fertilizer N to increase the efficacy of N use (see Canadian Fertilizer Institute website, http://www.cfi.ca). The system focuses on four interconnected performance areas — Right Product, Right Rate, Right Time, Right Place (4R). By emphasizing the individual BMPs need to address all four areas to enhance N use sustainability, this 4R system promotes an integrated approach to N_2O emission reductions. That is, a BMP that focuses on applying the right rate of N fertilizer may not enhance efficacy and efficiency of fertilizer use, nor achieve reductions of GHGs, if the N fertilizer is applied in incorrect time or place or form. Thus, a protocol linked to the Canadian Fertilizer Institute stewardship system needs to require BMPs to specify sufficient ancillary requirements to ensure that errors in other aspects of N fertilizer management do not undermine reductions achieved using the eligible individual BMPs. By implementing the 4R N stewardship plan, the participating farm ensures that all BMPs will contribute to reduction of N_2O emissions.

The scientific data to support a protocol specifying BMPs for management of N to achieve reduction of GHGs based on the 4R system. An important compilation of this evidence, published by the International Plant Nutrition Institute, is *Greenhouse Gas Emissions from Cropping Systems and the Influence of Fertilizer Management* (Snyder *et al.* 2007). Based on scientific evidence, the BMPs proposed for the NERP achieve GHG reductions by two possible processes. First, these BMPs decrease GHG emissions by optimizing the addition of C to soil as crop residue per unit of added N. When N fertilizer is applied as required for crop growth, soil C content is generally increased (Paustian *et al.* 1992). Second, and most important, these BMPs minimize the opportunity for nitrate N to accumulate or persist in the soil during the anaerobic conditions conducive to N_2O emissions (Dobermann 2007, Snyder and Bruulsema 2007, Dobermann and Cassman 2004, Mosier *et al.* 2004, Cassman *et al.* 2002).

This Science Discussion Document also is based on evidence that data collected in the monitoring of the protocol projects, and integrated in the 4N stewardship plan, will serve as an internal check on the efficacy of the prescribed BMPs. That is, the BMPs are considered in the context of the Right Product-Right Rate-Right Place-Right Time (4R) stewardship system to optimize crop response to added N and to minimize accumulation of nitrate N in soil. So, the Science Discussion Document proposes scientific evidence supports the rationale that an N balance, based on collected data of fertilizer application and total crop nutrient content, is an important component of a 4R N stewardship plan.

This Science Discussion Document proposes the BMPs, particularly the comprehensive 4R N stewardship plan, will differ in spatial resolution and technological sophistication going from the simpler to the more advanced levels of the proposed NERP. For example, the on-farm corroboration will be based on field-scale yield data in the Simple level, while in the Advanced level the assessment will address finer resolution (slope and aspect according to GPS positioning) and the corroboration will be monitored according to yield from GPS-driven yield instrumentation. And, the landscape-directed management, involving assessment of concave and convex field areas according to farmer judgement, will be introduced in the Intermediate level, with management by geomatically-determined sectors added in the Advanced level.

4.2.3 Boundaries

As proposed in Phase 1, the NERP addresses only the GHG emissions and reductions occurring on the farm. This means that if NERP participants use less fertilizer, no GHG reduction credits will be generated as a result of decreased requirement to manufacture and distribute N fertilizers. First, GHG emissions from the manufacture and distribution of N fertilizers are excluded from quantification as a conservative measure. The BMPs (which are integrated in a comprehensive N stewardship plan) of the NERP are expected to decrease the amount of N fertilizer needed per unit of crop production, thereby decreasing the emissions per unit of production from the off-farm sources. Lemke *et al.* (2007) support this conservative assumption, reporting that substituting biologically-fixed N for fertilizer N, by including pulses in rotations, increases the energy efficiency of the cropping system. Second, limiting the scope of the NERP to on-farm emissions facilitates the calculation of reductions from on-farm data collected in the monitoring plan. The importance of using data from parameters controlled by the project proponent to generate GHG reductions is emphasized in GHG offset guidance. For example, consider the white paper published by the Offset Quality Initiative (available at http://www.offsetquality initiative.org/documents/WhitePaper.pdf).

Decision point 4.2.3.a: The NERP should be designed to address only on-farm GHG reductions associated with innovative management of N.

Agree _____ Disagree _____

Furthermore, the NERP addresses only the GHG emissions and reductions associated with N_2O emissions from soil. Thus, emissions from sources such as fuel use are predicted to be similar in the baseline scenario and project conditions. This decision is considered conservative, since an expected benefit of the BMPs implemented in the NERP is increased crop productivity per unit of N input (see discussion of Functional Equivalence in Section 4.4.1).

Decision point 4.2.3.b: The NERP should be designed to address only emissions of N_2O associated with innovative management of Nitrogen.

Agree _____ Disagree _____

4.2.4 Quantification of Emissions

The GHG emissions quantified by the NERP in the baseline scenario and project condition are calculated according to the methodology use in Canada's National Inventory Report (See Annex 1). In this methodology, the direct and indirect emissions of N_2O from soil are calculated according to the categories of synthetic fertilizer, livestock manure added as fertilizer, crop residue decomposition, and irrigation. These categories thus are not to be confused with BMPs, but rather represent the framework within which the influences of the NERP BMPs are estimated. The NERP does not address the categories of modification of tillage practices and summerfallow, because these categories are addressed in other quantification protocols.

Decision point 4.2.4. Categories of emissions within the scope of the NERP:

	Certainty		
Include fertilizer, manure, residues, and irrigation	L	M	H
Exclude tillage modifications and summerfallow	L	M	H

The method for quantifying N_2O emissions from agricultural soils in Canada is described in Section A.3.4.5 of Canada's National Inventory Report (2007). The National Inventory Report method for quantifying N_2O emissions is specific to the ecodistrict where the farm is located. This means that the calculated N_2O emissions are corrected for the predominant soil type, the representative topography, and the climate for the farm. Application of the National Inventory Report factors and formulae to the geographical location and management practices of the project farm at the baseline year determines the baseline N_2O emissions. Therefore, the proposed NERP can be used in all parts of Canada, without additional consideration for the location of participating farms. The detailed description of the National Inventory Report method for quantifying N_2O emissions from agricultural soil is attached as Annex 1.

4.3 Baseline

In Phase 1, the baseline scenario was determined as the set of practices in place on the specific farm before implementation of the comprehensive N stewardship plan required for participation in the NERP. And, the baseline level of N_2O emissions is determined according to the methodology used for Canada's National Inventory Report, involving country-specific factors to estimate direct emissions (Rochette *et* *al.* In Press) and Intergovernmental Panel on Climate Change default methodology to estimate indirect sources (2006).

4.3.1 Baseline Scenario Selection

This Science Discussion Document presents the evidence used to determine the baseline proposed in Phase 1 represents a justifiable reference for quantification of GHG reductions. The participants in the Consultation Workshop need to endorse the baseline scenario proposed in Phase 1, or endorse an alternative scenario.

The proposed premise for the NERP is that the baseline, the 'business-as-usual' practice, is characterized by the absence of intentional management to prevent N_2O emission from soil. In this Science Discussion Document, then, the baseline is defined as N management practices before implementation of the 4R N stewardship plan. The task for participants in the Consultation Workshop is to come to consensus concerning the best approach to determine what practices would have been used on farms in the absence of the NERP. Several approaches could be used to determine the 'pre-NERP' scenario (Table 1).

Table 1: Assessment of Potential Baseline Scenario Approaches

Possible Baseline	Rationale For	Rationale Against
Historic Benchmark (this represents the farm-specific scenario proposed in Phase 1).	Accurate, historical data of crop management and N use is available for most farms for an appropriate operating period. Historical data best represents the conditions that would have taken place on a specific farm in the absence of the NERP project.	Since agriculture is an unregulated sector, farm-specific historical data is voluntary and may not have been recorded accurately. A historic benchmark assumes that past predominant N use patterns will continue into the future.
Performance Standard	Historical data of crop management and N use for the farm may not be available. Canadian Fertilizer Institute has an historical database of purchased fertilizer N, which could be used to calculate a standard N balance, and associated N_2O emission dynamics, for farms in eco-geographical regions.	Does not necessarily represent the N use and N_2O dynamics of a specific farm. It is likely the farmers interested in NERP projects have 'better-than-average' N management — if reductions are determined against a performance standard, reductions are likely to be over-estimated.
Projection-Based	Predictive simulation models are increasingly used to inform regional and national accounting of GHG emissions from soils.	Although a number of pertinent simulation models are available, obtaining the data required to initialize and to drive these models remains a challenging deficiency.

Decision point 4.3.1. Baseline scenarios.

	Certainty		
Historic Benchmark (farm-specific)	L	M	H
Performance Standard (regional)	L	M	H
Projection-based (simulation model)	L	M	H
Other — ___________	L	M	H

4.3.2 Baseline Year Determination

Regardless of the baseline scenario selected, it remains to determine the timing and length of the baseline period. A number of options exist:

1. Standardized baseline year: This option is used in existing protocols, such as the Quantification Protocol for Tillage System Management. In this option, researchers and technical experts could select a year which best represented typical or standard N management practices (i.e. a year with standard crop prices and weather patterns, etc.).
2. Year preceding project: This would likely be the most straight-forward option. But, the possibility exists that the year before the project may have been an unusual one for the participating farm.
3. Three-year average — immediately preceding project: This option would serve to ameliorate the risk of unusual activities immediately before the start of project participation. The longer the baseline period, however, the greater the risk of deficiencies in data to generate the baseline.
4. Three-year average — representative years: In this option, the researchers and technical experts would have the greatest opportunity to ensure appropriate baseline N dynamics for the baseline calculation. However, the risk of farmers having gaps in their farm data, or the effort needed to develop a performance standard, is increased.

Decision point 4.3.2: Baseline years.

	Certainty		
Standardized baseline year	L	M	H
Year preceding project	L	M	H
Three-year average — immediately preceding project	L	M	H
Three-year average — representative years	L	M	H
Other — ___________	L	M	H

4.3.3 Additionality or Incrementality Justification

The development effort to date provides evidence the GHG reductions generated by the practices of the NERP go beyond business-as-usual. However, the Technical Background Document and this Science Discussion Document do not assert the GHG reductions from the NERP would not be captured without the financial benefit from the participation in offset markets this instrument facilitates. Indeed, in a report submitted by the George Morris Centre to the Crop Nutrients Council, evidence is presented that the few farmers in Canada who do use nutrient management plans believe this tool provides a net economic benefit (Brethour *et al.* 2007). Rather, this development documentation is intended to demonstrate the barriers to implementation of comprehensive N management planning, and to assert the NERP will accelerate adoption of management practices for economic and environmental benefit.

The innovative character of the BMPs of the NERP, in particular the comprehensive nutrient management plan, and the need for the incentive provided by GHG reduction offsets, can be justified according to several tests:

1. Surplus to regulation: Agriculture remains for the most part an unregulated sector in Canada. Some jurisdictions require farmers to submit nutrient management plans (e.g. Quebec), but these plans are intended primarily to prevent pollution of surface and groundwater by livestock manure, and often do not address nutrients from other sources.
2. Investment Barriers: Significant financial obstacles exist for the BMPs of the NERP. The cost of developing and implementing comprehensive nutrient management plans is a barrier to farmer participation in the NERP. Additional testing (of soil and crop) and record keeping will be required. Some farmers will need to retain services of a qualified professional. If practices involving innovative fertilizer products are implemented, these products are more expensive than conventional products. Also, the cost of innovative equipment to achieve variable rate application of fertilizer, or to capture yield data by landscape position, is a barrier to farmer participation in the more complex versions of the NERP.
3. Technological barriers: The technology required to implement the NERP has both information and equipment components, both of which are in development, and which therefore represent a barrier to implementation of the NERP. Information regarding the recommendation for variable rate fertilizer application, for example, requires refinement. Also, research continues to refine technologies such as yield monitors, controlled release N fertilizer products, and so on.

   The fundamental technological barrier, however, is the lack of studies to provide data from the integrated application of the 4R system across the range of soils and climates of Canada.
4. Institutional barriers: For the most part, farmers are not accustomed to detailed data monitoring and management. Thus, the information requirements of the NERP represent a cultural shift and may be barrier to participation for farmers.
5. Not common practice: The Farm Environmental Management Survey in 2001 (FEMS2001) states only 19.5% of farms in Canada reported annual testing of soil nutrients (Table 2). And, only 14.8% of farms reported use of a nutrient management plan, although the percentage in Quebec (47.0%) substantially exceeded the national average (Table 3). But, the nutrient plans in Quebec are focused on manure, and do not address use of fertilizer. It is important to note, however, typical N management plans are as sophisticated as the 4R stewardship plan described for the proposed NERP. For example, no data is available to date pertaining to adoption levels of landscape-directed testing and on-farm N balance estimation.

Table 2. Frequency of soil nutrient testing, by percentage of farms, Canada and provinces, 2001

	Every year	Every 2 - 3 years	Every 4 - 5 years	Every 5 years or more	Not tested
Newfoundland & Labrador	22.9	27.1	14.6	X	X

Prince Edward Island	29.0	29.8	14.9	X	X
Nova Scotia	10.5	22.9	17.0	20.6	29.6
New Brunswick	22.7	22.1	16.4	20.8	18.6
Quebec	20.1	39.2	23.3	9.1	8.3
Ontario	13.5	38.3	15.4	12.6	20.1
Manitoba	25.7	26.6	9.1	13.4	25.1
Saskatchewan	17.4	24.2	10.2	13.4	34.7
Alberta	26.4	22.5	9.3	12.0	29.8
British Columbia	15.9	22.8	10.2	18.6	32.6
Canada	19.5	29.5	13.1	12.7	25.3
Table source: Statistics Canada, 2004, Farm Environmental Management in Canada, "Fertilizer and Pesticide Management in Canada," Catalogue number 21-021-MWE.					

Table 3. Nutrient management plans, Canada and provinces, 2001

	Yes		No	
	Number of farms	**Share of farms (percentage)**	**Number of farms**	**Share of farms (percentage)**
Newfoundland & Labrador	25	9.5	215	90.5
Prince Edward Island	110	8.9	1,130	91.1
Nova Scotia	100	5.2	1,845	94.8
New Brunswick	225	14.3	1,355	85.7
Quebec	10,925	47.0	12,340	53.0
Ontario	4,795	11.6	36,600	88.4
Manitoba	1,815	13.1	12,040	86.9
Saskatchewan	2,630	6.2	39,825	93.8
Alberta	3,865	10.5	33,085	89.5
British Columbia	820	10.8	6,780	89.2
Canada	25,310	14.8	145,215	85.2
Table source: Statistics Canada, 2004, Farm Environmental Management in Canada, "Fertilizer and Pesticide Management in Canada," Catalogue number 21-021-MWE.				

Decision point 4.3.3: To demonstrate the NERP practices are not 'business-as-usual', the NERP fulfills the following tests:

	Certainty		
Surplus to regulation	L	M	H
Investment barriers	L	M	H
Technological barriers	L	M	H
Institutional barriers	L	M	H
Not common practice	L	M	H

4.4 Project

In the NERP, the project is proposed as the set of approved BMPs implemented on the specific farm as guided within the comprehensive 4R N stewardship plan.

4.4.1 Operational Unit of NERP (Functional Equivalence)

To quantify the GHG reductions associated with the BMPs eligible in the NERP, it is necessary to establish an operational unit which has functional equivalence with the baseline scenario. This is made complex, because N requirements are different between crops, and the crop mix may vary according to global market conditions for crop prices or input costs. And, since one purpose of the 4R N stewardship plan is to ensure the optimum amount of fertilizer is used, it would be beneficial for the NERP to capture N_2O reductions associated with more effective use of N fertilizer. If emissions in the baseline and the project are quantified per unit mass of crop produced per unit area in a field, reductions can be quantified on an equivalent basis. This means the baseline emission per unit area must be estimated for each crop to be included in the project. Thus, emissions in the baseline and project will be quantified for each participating farm as kg of carbon dioxide equivalents (CO_2e) per kg crop per hectare.

Decision point 4.4.1: To ensure functional equivalence, emissions per hectare under the conditions of the NERP must be compared for each crop to the emissions per hectare for the same crop estimated during the baseline period.

Agree _____ Disagree _____

4.4.2 Based on evidence of practice change

A key decision in Phase 1 introduced the requirement of 'evidence of practice change' for participation in the NERP. This requires NERP participants to prove implementation of the sophisticated 4R N stewardship plan, and eliminates the possibility of a 'default' or 'discount' approach.

The proposed premise for the NERP is that the baseline, the 'business-as-usual' practice, is characterized by the absence of intentional management to prevent N_2O emission from soil. And, the project condition of intentional management to prevent N_2O emission from soil is defined as:

- Implementation of a 4R N stewardship plan.
  - Includes all nutrient sources and the BMPs within the performance areas of Right Product, Right Rate, Right Time, Right Place;
  - Based on landscape-directed annual assessment of N availability (e.g. soil testing or nutrient balance); and
  - Corroborated by N balance, as measured using on-farm N input data and crop yield and protein analyses.
  - Several levels of complexity of the NERP can be implemented, corresponding to different levels of generated GHG reduction offsets.

- Implementation of additional BMPs in the context of the 4R N stewardship plan[3].
- GHG reductions calculated using level-specific factor to modify project N_2O emissions estimated according to the National Inventory Report quantification method.

Decision point 4.4.2: The implementation of the 4R N stewardship plan of the NERP, in several levels of complexity, constitutes a practice change to generate real, additional/incremental, demonstrable, quantifiable, verifiable, and unique GHG reductions. Agree ___________ Disagree ___________

Principle: The on-farm efforts to monitor N balance do not constitute the basis for emission reductions. That is, the NERP does not quantify emission reductions according to the degree of N uptake achieved. Rather, the monitoring of N balance is used as an internal corroboration of optimized yields and minimized losses by N_2O emissions. And, in addition, the yield/protein assessment may replace soil testing to predict N availability in some circumstances.

4.4.3 Proposed BMPs

The proposed BMPs are relevant to the climate and soils of Canada. In most regions of Canada, for example, soils are thawing and wet in spring, increasing the likelihood of conditions conducive to denitrification of accumulated nitrate. Such conditions may not arise in other parts of the world, and therefore in those regions BMPs to avoid accumulation of nitrate may not be as effective in decreasing N_2O emissions.

4.4.3.1 Fertilizer Formulation (Right Form)

Based on expert opinion represented on the Steering Committee, the NERP proposes ammonium-based fertilizers, when applied at a rate/time/place to prevent accumulation of nitrate in soil during water-logged conditions, tend to minimize N_2O emissions. This recommendation is specific to the cold-winter conditions prevalent in most regions of Canada.

4.4.3.2 Season of Application (Right Time)

The following excerpt (See Eq in Annex 1) describes the Environment Canada approach to quantifying N_2O emissions during the spring thaw in eastern Canada and the Prairies.

> Average annual snowfall in eastern Canada varies between 1 and 4.5 m (Environment Canada, 2002). Snowmelt water in the spring creates wet soil conditions that favour N_2O

[3] An example of examination of BMPs in relation to the 4R performance framework is developed by Snyder (2008). Snyder's discussion and guidelines are oriented toward the central U.S. Corn Belt, but are relevant to other cropping systems with similar crop geographies.

production. Accordingly, results from micrometeorological studies show that significant N_2O emissions can occur during spring thaw in Ontario (Wagner-Riddle *et al*., 1997; Wagner-Riddle and Thurtell, 1998; Grant and Pattey, 2003) and that estimating emissions only in the snow-free period underestimates total annual emissions of N_2O. For reasons including lower annual snowfall, spring thaw emissions are usually smaller in the Prairies than in eastern Canada (Lemke *et al*., 1999).

Gregorich *et al*. (2005) summarized field measurements of N_2O emissions from agricultural soils under various conditions in Quebec and Ontario. Based on these data reported on annual crops, the ratio factor for spring thaw (RF_{THAW}) was defined as the ratio of the mean N_2O emissions during spring thaw (1.19 kg N_2O-N/ha; n = 10 site-years) to emissions during the snow-free season (2.82 kg N_2O-N/ha; n = 58 site-years) (Gregorich *et al*., 2005). Thus, RF_{THAW} was estimated as "1.4 = 1 + 1.2/2.8" for the Quebec–Ontario region and the Atlantic provinces. Chamber flux measurements used to estimate EF_{CT} in the Prairies include spring thaw emissions, because low snow accumulation in that region allows chamber deployments during that period. Cumulative snow-free-season N_2O emissions include spring thaw emissions (R. Lemke, personal communication). Therefore, no adjustment to the EF_{CT} for the spring thaw emissions is required in the Prairies (RF_{THAW} = 1).

Thus, the National Inventory Report quantification approach includes a ration factor to account for N_2O emission from fertilizer during the spring thaw. But, the quantification approach does not address the season when the fertilizer is spread. Thus, an opinion is required from the authors of the National Inventory Report to determine if it is correct to interpret that fertilizer spread in spring in eastern Canada will result in decreased N_2O emissions as compared to fertilizer applied in fall. It is important to note, however, that the Alberta Quantification Protocol for Innovative Feeding of Swine and Storing and Spreading of Swine Manure (Pork Protocol) uses a ratio factor, RF_{SEASON}, to attribute in all areas of Canada 20% more N_2O emissions from N in manure spread after August than from manure N spread before August.

4.4.3.3 Landscape-Directed Fertilizer Recommendation (Right Rate, Right Place)

Data exists to support the conclusion that N_2O emissions are affected both by the amount of N fertilizer applied relative to crop needs, and the location in the landscape of the N fertilizer application.

The literature review of the International Plant Nutrition Institute (Snyder *et al.* 2007) provides evidence that N_2O emissions (kg N_2O–N ha^{-1}) increase as N fertilizer application rates exceed the uptake capacity of the agro-ecosystem. These data are derived both from emissions measured in the field (Bouwman *et al.* 2002, Kachanoski *et al.* 2003, Malhi *et al.* 2006, McSwiney and Robertson 2005) and from emissions predicted by a number of models (Del Grosso *et al.* 2006, Grant *et al.* 2006).

Based on this evidence, a strategy emerges to provide sufficient N fertilizer to meet the uptake capacity of the agro-ecosystem, and thereby to achieve economic yields and to prevent depletion of long-term soil productivity (Jaynes and Karlen 2005), but to avoid the over-application of N fertilizer that exacerbates N_2O emissions. In terms of the proposed NERP, the comprehensive 4R stewardship plan (with testing and corroboration) represents a means to derive the N uptake capacity of the agro-ecosystem and to manage application of N fertilizer accordingly.

The following excerpt (p. 346-347, National Inventory Report, references not included in this report) describes the decision made for the national inventory concerning the relationship of N_2O emission intensity to landscape position in the Prairies.

> Landscape segmentation data were incorporated into the calculation of the national N_2O emission estimates, based upon the observations that N_2O emissions are greater in lower sections of the Prairie landscape where intermittently saturated soil conditions that are favourable to denitrification occur (Corre *et al*., 1996, 1999; Pennock and Corre, 2001; Izaurralde *et al*., 2004). The fraction of the landscape occupied by such lower sections, or F_{TOPO}, was applied to concave portions of the landscape (i.e. lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and soils are imperfectly and poorly drained with mottles within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower, and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine proportions of landforms in the Soil Landscapes of Canada (SLC), which was the basis for determining the proportion of the landscape to apply F_{TOPO} for deriving N_2O emission estimates (Rochette *et al*. 2007).

Based on the strategy already implemented at the level of the national GHG inventory, it is reasonable to assert that decreasing the N fertilizer applied to the concave sections of the farm landscape will decrease N_2O emissions for the farm. The landscape-directed soil testing will determine the existing N status on these concave sections to drive recommendations for N fertilizer application, and the comprehensive N stewardship plan will determine the N use efficacy on these sections. This is the approach followed in the simple level of the proposed NERP. The advanced approaches will begin from the premise outlined in the National Inventory Report , but will refine N recommendations for the various landscape sectors to increase N use efficacy (and thereby to decrease the potential for N_2O emissions) based on the monitoring and corroboration process involved in the NERP 4R stewardship plan.

4.4.3.4 Fertilizer Application (Right Place, Right Time)

The 'fertilizer placement' BMP encompasses both distribution of fertilizer in the landscape and the depth/geometry of fertilizer incorporation into the soil. As such, this BMP requires both information to guide the distribution and incorporation, as well as the equipment or technology to accomplish it.

The relationship between the geometry of the fertilizer band with resulting N_2O emissions is specific to the climate and soils of Canada. Thus, the role of this BMP in the NERP depends on the expert judgment of scientific participants.

Tiessen *et al.* (2008) examined N use by spring wheat receiving fall-banded urea in the eastern Prairie region of Canada. These researchers conclude "In the low landscape positions, grain yield, total crop N uptake, grain yield increases, and crop N use efficiency for fall-banded urea (all relative to spring-banded urea) increased linearly with delayed application dates and declining soil temperatures on date of application", and "In the high landscape positions, the performance of fall-banded urea was not related to any measures of time and/or soil temperature". Without addressing N_2O emissions directly, this evidence supports the relevance of landscape position and soil temperature for N management.

The International Plant Nutrition Institute review also identifies proper calibration of application equipment as an issue of importance for reduction of N_2O emissions from fertilizer. This issue arises from the decreased long-term productivity related to under-application of N, and from the exacerbated N_2O emissions associated with N fertilizer application in excess of agro-ecosystem uptake capacity.

Participation in the 'fertilizer placement' BMP thus requires the knowledge and equipment to deliver the exact rate to the specified location at the required depth in the soil according to the temperature- and landscape-directed recommendations derived in the comprehensive 4R stewardship plan.

4.4.3.5 Fertilizer Nitrogen Availability Synchronized with Crop Uptake (Right Time)

Synchronization of N availability and crop uptake requirements can be achieved by applying the fertilizer as recommended in the N stewardship plan in spring or in fall, depending on the fertilizer formulation.

The International Plant Nutrition Institute literature review (Snyder *et al.* 2007) concludes that synchronizing N availability with crop uptake involves (1) time of application (spring and/or split applications), and (2) balanced fertilization to ensure crop growth and N uptake is not limited by, for example, phosphorus (P) deficiency (Schlegel *et al.* 1996). In a series of experiments to test the efficacy of controlled release urea, Grant and Wu (2007) determined that N_2O emissions from control release urea were generally similar to or lower than from uncoated urea. Further, fall-applied control release urea resulted in lower soil nitrate and lower N_2O emissions than did fall-applied uncoated urea, but resulted in nitrate and N_2O levels similar to spring-applied uncoated urea. Thus, BMPs using spring applications of conventional fertilizer or using fall applications of controlled-release fertilizer can be included in the Intermediate or Advanced version of the proposed NERP.

Also, the International Plant Nutrition Institute literature review compiles data to support the use of nitrification inhibitors to decrease N_2O emissions. In the assessment of the N_2O emission reduction associated with various innovations in N fertilizer management, however, results are typically reported as "similar or less than" emission associated with business-as-usual practices — quantitative data of emission reductions is lacking.

In recent research, Halvorson *et al.* (2008) conclude polymer-coated urea "showed potential for reducing N_2O emissions from irrigated cropping systems".

4.4.3.6 Including Pulses in Rotation

A review of scientific literature supports the conclusion that N_2O emissions are lower from soil seeded to inoculated pulses (Lemke *et al.* 2007). Lemke *et al.* (2007) summarized data from growing season N_2O emissions from the following studies:

Table 4. Data from Lemke *et al.* (2007) of N_2O emissions from pulse crops compared to various crops under differing conditions.

	Conditions	Crops	Comparisons
Lemke *et al.* (2002)	Western Canada	field peas, lentils, and fertilized cereals	N_2O from inoculated crops, and similar to estimated background.
Rochette *et al.* (2004)	Eastern Canada	soybean and non-fertilized reference crops	N_2O from inoculated crops similar to non-fertilized crops.
Zhong *et al.* (2004)	Growth Room	inoculated lentils and field pea, fertilized non-inoculated lentil and	N_2O from inoculated crops lower than from fertilized crops, and

		field pea, and fertilized and non-fertilized wheat	similar to non-fertilized crops.

However, a practical difficulty arises with including pulses in rotation as a BMP from the NERP. That is, since pulses do not require addition of N, the 4R N stewardship plan for pulses in the NERP may not differ from baseline practices. And, therefore the emissions per hectare from a pulse crop may be similar under the baseline scenario and in the project condition.

Decision point 4.4.3: Based on knowledge from the scientific literature and from expert opinion, the following represent BMPs (when implemented in the context of a 4R N stewardship plan) to decrease N_2O emissions from agricultural soils:

	Certainty		
Use of ammonium-based formulations	L	M	H
Use of controlled-release formulations	L	M	H
Use of split applications	L	M	H
Application by banding	L	M	H
Application rates specific to landscape position	L	M	H
Application into cool soils in fall	L	M	H
Application in spring	L	M	H
Including pulses in rotation	L	M	H
Other — ___________________	L	M	H

4.4.4 Level of NERP Determines Degree of Reduction.

A main premise of the NERP is that the degree of integration of the 4R N stewardship plan is linked to the BMPs used, and is directly proportional to the degree of N_2O reduction achieved. For example, even if a NERP participant has the equipment capable of variable rate application of fertilizer, an advanced stewardship plan is needed to provide the application recommendations, and to evaluate the N use and yield response resulting from the application. Thus, 4R N stewardship plans of increasing integration and sophistication are required for the Simple, Intermediate, and Advanced levels of the NERP.

The options to assure the integrity and accuracy of the 4R N plan for various levels of the NERP, as well as the effectiveness of the BMPs in the plan, are described below (Section 5).

Decision point 4.4.4.a: The NERP should be designed to generate GHG reduction credits according to Simple, Intermediate, and Advanced levels.

Agree _____ Disagree _____

As proposed in this Science Discussion Document (See Table 5), the levels of the NERP are differentiated according to the degree of spatial specificity of the 4R N stewardship plan and of the fertilizer application recommendation. The eligible BMPs pertaining to the form of fertilizer product, timing of fertilizer application and/or availability, and depth and geometry of fertilizer placement are similar among the levels of NERP. Alternatively, the NERP could require proponents to implement more BMPs in the more advanced levels — this would involve 'stacking' of BMPs in the more advanced levels. Also, as the scientific understanding of N management and N_2O reduction strategy is evolving, new BMPs may arise — this provides the opportunity to add BMPs to all levels or to restrict new BMPs to only the Advanced levels.

Table 5. Differentiation of 4R N stewardship plans and BMPs for the levels of NERP.

	Right Product	Right Rate	Right Time	Right Place	Proposed Modifier
Simple	Ammonium-based formulation.	Apply N according to recommendation of 4R N stewardship plan, using annual soil testing and/or N balance to determine application rate.	Apply in spring, or split apply, or after soil cools in fall, or use controlled release fertilizer formulations.	Apply in shallow bands.	0.8
Intermediate	Ammonium-based formulation.	Apply N according to recommendation of stewardship plan for concave and convex sectors of field as estimated by farmer (fertilizer application and yield and N balance assessment for convex and concave sectors).	Apply in spring, or split apply, or after soil cools in fall, or use controlled release fertilizer formulations.	Apply in shallow bands.	0.65
Advanced	Ammonium-based formulation.	Apply N according to recommendation of stewardship plan for sectors of field as guided by digitized geomatic criteria (variable rate fertilizer application and GPS-guided yield and N balance assessment).	Apply in spring, or split apply, or after soil cools in fall, or use controlled release fertilizer formulations.	Apply in shallow bands.	0.5

Decision point 4.4.4.b: The BMPs for the levels of the NERP are allowed as follows:

	Certainty		
BMPs for Product, Time, and Place similar in all levels	L	M	H
BMPs for Product, Time, and Place 'stacked' in advanced levels	L	M	H
Newly developed BMPs eligible for all levels	L	M	H
Newly developed BMPs eligible for only advanced levels	L	M	H

The proposed modifiers are presented as place-holders for discussion purposes. Although parameters such as F_{TILL} (See Equation A3-27, Annex 1) in the National Inventory Report provide a precedent, the concept of emission modifiers to describe the integrated influence of a suite of BMPs on N_2O emissions from agricultural soils is not described definitively in the scientific literature. Thus, the scientific participants of the Consultation Workshop are encouraged to use their expert judgment to derive appropriate modifiers for the levels of the NERP.

Decision point 4.4.4.c: To estimate reductions in N_2O emissions achieved by implementing the NERP, the project farm N_2O emissions calculated according the National Inventory Report methodology (See Annex 1) are multiplied by the following modifiers:

	Certainty		
Simple level modifier corresponds to __________	L	M	H
Intermediate level modifier corresponds to __________	L	M	H
Advanced level modifier corresponds to ___________	L	M	H

5 Design of a Verifiable 4R Nutrient Stewardship Plan

A component common to all levels of the proposed NERP is the 4R stewardship plan, and serves as the 'gate' to participation in the NERP. The comprehensive 4R N stewardship plan is the foundation for the eligible BMPs and, with increasing in sophistication, is the primary differentiation between the levels of the NERP. Thus, the completeness and accuracy of the 4R N stewardship plan will determine the integrity of the NERP with respect to the quantification of GHG reductions. This Science Discussion Document describes the components of the 4R N stewardship plan, but the Consultation Workshop participants will need to make the decisions needed to endorse the proposed design of the stewardship plan or to derive an alternative one.

This 4R N stewardship plan will involve:

- Determining mineral N status by soil test, or (if weather prevents sampling) by N balance, for the individual fields (Simple Level), for concave and convex portions of each field (Intermediate Level), or for the geomatically classified sectors of each field (Advanced Level);
- Predicting N (and P, K, S) fertilizer rate to achieve optimum yield (by spatial resolution appropriate to Simple, Intermediate, or Advanced level);
- Determining N balance by assessing crop yield and analyzing crop protein content (by spatial resolution appropriate to Simple, Intermediate, or Advanced level);
- Adjusting next year's 4R N stewardship plan using results of N balance determination (by spatial resolution appropriate to Simple, Intermediate, or Advanced level), and accounting for N from fertilizer, crop residues, and manure; and
- Ensuring sufficiency of P, K, S.

Since the comprehensive 4R N stewardship plan is essential to the implementation of the NERP, assuring the plan for each project participant is demonstrably correct is fundamental to achieving verifiable reductions. In addition, since the 4R N stewardship plan must be implemented in the BMPs, the design of the stewardship plan is not complete without selection of appropriate BMPs. A number of options could be accepted for assuring the integrity of the 4R N stewardship plan and the effectiveness of the integrated BMPs for each farm participating in the NERP.

1. General guidance: An option to maintain the accuracy and integrity of the 4R N stewardship plan is give general guidance in the protocol, and then to rely on the third party verifier to provide an independent check on the plan used by the project proponent. This is likely the simplest and most flexible approach, but it also relies on the agronomic and nutrient management expertise of the verifier. Also, to assure integrity of the offset program as a whole, further assessment will be required to determine all verifiers take a consistent approach.
2. Content prescribed: The option with the highest assurance of project and program integrity, but with the least flexibility, is to prescribe in the NERP all elements of the 4R N stewardship plan for each level. This approach requires approval at the Consultation Workshop of elements of 4R N stewardship plans for every soil type, landscape description, crop choice, BMP selection, etc.
3. Model prescribed: Predictive models are essential to deriving the factors used to quantify GHG emissions for the National Inventory of Canada. Therefore, it may be reasonable to prescribe the use of approved model(s) to develop 4R N stewardship plans for the farms participating in the NERP. Various public (e.g. AFFIRM software from Alberta Agriculture and Rural Development) and proprietary tools are available. Since a high level of agronomic and nutrient management expertise is required to use models effectively, a mechanism to check the implementation of the projects is needed if this option is chosen.
4. Advisor approved: To implement the practices of the Intermediate and Advanced levels of the NERP, most farmers will need to retain advisors with expertise in comprehensive and geomatically-based nutrient management plans. If professionals of a suitable accreditation can be designated as approved to develop 4R N stewardship plans, this option could provide the balance between accuracy and flexibility required to implement the NERP and to achieve verifiable GHG reductions. In relation to this option, the Canadian Fertilizer Institute is developing a training program to ensure practitioners possess understanding of the 4R N stewardship system.

Decision point 5: To achieve verifiable reductions, but to maintain flexibility needed to implement the NERP, and appropriate BMPs, on the diverse farms in the Prairies (in Canada, in North America), the 4R N stewardship plans for the participating farms should be developed as follows:

	Certainty		
General Guidance Provided	L	M	H
Content Prescribed	L	M	H
Model Prescribed	L	M	H
Advisor Approved	L	M	H
Other — ____________________	L	M	H

6 Consultation Workshop — Areas of Focus

This Science Discussion Document prepares participants for the decisions necessary during the four 'Focus Sessions' of the Consultation Workshop, as introduced in the Consultation Workshop Agenda for the distributed by Climate Change Central. These Areas of Focus will provide the context for specific decisions to facilitate the development of the NERP following the Consultation Workshop.

The Decision Points introduced above provide guidance for the pre- Consultation Workshop preparation of participants. That is, these Decision Points raise the issues to be resolved during the Consultation Workshop. Thus, the Decision Points will be addressed during the Focus Sessions of the Consultation Workshop.

6.1 Measurement — Emissions Factors

- The consensus in scientific literature is clear that decreased accumulation of mineral N in soil reduces the potential for N_2O emission. Consultation with researchers, however, is necessary to quantify the degree of reduction expected when N fertilizer is applied according to a N stewardship plan to achieve right product/rate/right place/right time management.
- The consensus in scientific literature is clear, and the National Inventory Report quantification approach endorses, that N_2O emission potential increases in wetter sectors of the landscape. It is equally clear, however, that the crop yield potential can also increase in these sectors. Thus, the N stewardship plan must account for this balance between avoiding N accumulation and optimizing crop production in developing the recommended rate of N application. Consultation with researchers is required to derive a relationship between sophistication of landscape classification (i.e. none vs. concave/convex vs. GIS-directed) and the degree of emission reduction expected.
- Ensure participants in Consultation Workshop understand the combination of Intergovernmental Panel on Climate Change Tier 1 factors and Canada-specific methodology used to quantify N_2O emissions for the baseline, and estimate emissions for the Project before multiplication by reduction modifiers (See Annex 1).
- Ensure consistency with other protocols — Tillage and Summerfallow

6.2 Practices and Technologies — BMPs to Reduce N_2O

Further description of the 4R N stewardship plan is required to:

- Provide details of how farmer/aggregator will determine recommended N fertilizer rate based on pH, salinity, soil texture, water status, rotation history, yield and protein content of previous crop, soil test levels of major nutrients (NPKS), and seeded crop (oilseed, cereal, or legume) — this instruction will be independent of degree of sophistication of data (i.e. same steps using data from concave/convex or from GIS-directed assessment. **NOTE! Tools such as AFFIRM (software from Alberta Agriculture and Rural Development) may provide guidance**.
- Provide details of sampling/testing plan for each level of the proposed NERP.
    - For the Simple level, guidance will be provided (1) for collecting soil or plant samples, (2) for analyzing the NPKS content of soil and plant samples, (3) for estimating the crop yield of the field, and (4) for determining the N use efficiency for each field.
    - For the Intermediate Level, guidance in addition to that for the Simple Level will be provided (1) for determining the concave and convex field sectors, and (2) for determining N recommendations and N efficiency for each the concave and convex sectors of each field.
    - For the Advanced Level, guidance in addition to that for the Simple Level will be provided (1) for defining the geomatic criteria to determine the relevant landscape sectors of the field, and (2) for determining N recommendations and N efficiency for the geomatically defined sectors of each field.

Further description of the individual Right Product, Right Rate, Right Time, Right Place BMPs is required to:

- Provide details of Right Time fertilizer management, including, for example, a definition of 'spring application' (e.g. after thaw/before seeding, before 01 June, after 15 Oct, etc.), and a specification for products having controlled release properties (e.g. specified brands, specified polymer characteristics, etc.).
- Provide details of Right Place fertilizer management, including, for example, a definition of 'banding' (e.g. with seed and/or below seed, allowable space between bands, allowable depth of band, procedure for measuring band dimensions, etc.).
- Provide details of Right Form fertilizer management, including, for example, a definition of 'ammonium formulation' (e.g. any ammonium salt, etc.)

Further description of the understanding concerning controlled release formulations is required:

- The consensus in unpublished research reports is clear that controlled release urea products tend to decrease the potential for N_2O emission. These reports, however, also point out that knowledge to date is insufficient to derive emission reduction coefficients associated with use of these technologies. Consultation with researchers is necessary to determine (1) whether sufficient knowledge exists to incorporate use of controlled release urea formulations in the context of the proposed NERP (for example, to allow fall application in the N stewardship plan if these are used), and (2) what further research is required to derive accurate coefficients.

6.3 Quantification — Reduction Factors per BMPs, per Simple/intermediate/Advanced Stewardship Plans

- Determine GHG reductions, with confidence, for each performance level (with uncertainty ranges) and to gain agreement on a preferred baseline to identify potential credits from reduction avoidance practices. In this task, the designated scientific advisors will need to step out beyond the limit of the published peer-reviewed literature.
- Finalize reduction factors for the Simple, Intermediate, and Advanced levels of the NERP. Again, in this task, the designated scientific advisors will need to step out beyond the limit of the published peer-reviewed literature.

6.4 Identification of Gaps — Attribute Priority and Strategy to Address Gaps.

- Clear identification of and priority for the areas where research gaps exist and must be addressed, including steps forward to address the gaps. Although knowledge exists concerning some BMPs in some conditions, knowledge is lacking concerning the reductions associated with implementing a number of BMPs ('stacked' BMPs) under diverse conditions.
- Initiate development of a science plan to address lack of data from studies to examine the integrated implementation of the 4R stewardship system.

7 References

Bouwman, A.F., L.J.M. Boumans, and N.H. Batjes. 2002. Emissions of N_2O and NO from fertilized fields: Summary of available measurement data. Global Biogeochem. Cycles 16(4): 6-1 to 6-13.

Brethour, C. B. Sparling, B Cortus, M Klimas, T-L. Moore, and J. Sadler Richards. 2007. An economic evaluation of beneficial management practices for crop nutrients in Canadian agriculture final report. Crop Nutrients Council.

Del Grosso, S.J., W. J. Parton, A. R. Mosier, M. K. Walsh, D. S. Ojima, and P. E. Thornton. 2006. DAYCENT National-scale simulations of nitrous oxide emissions from cropped soils in the United States. J. Environ. Qual. 35: 1451–1460.

Halvorson, A.D., S.J. Del Grosso, and C.A. Reule. 2008. Nitrogen, tillage, and crop rotation effects on nitrous oxide emissions from irrigated cropping systems. J Environ Qual. 37:1337-1344.

Grant, C.A. and R. Wu. 2007. Controlled release and alternate fertilizer materials use in conservation cropping systems. ETAA Final Report.

Grant, R.F., E. Pattey, T. W. Goddard, L.M. Kryzanowski, and H. Puurveen. 2006. Modeling the effects of fertilizer application rate on nitrous oxide emissions. Soil Sci. Soc. Am. J. 70:235-248.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4: Agriculture, Forestry and Other Land Use, Intergovernmental Panel on Climate Change. www.ipccggip.iges.or.jp/public/2006gl /vol4.htm.

Jaynes, D.B. and D.L. Karlen. 2005, Sustaining soil resources while managing nutrients: *In* Proceedings of the Upper Mississippi River Sub-Basin Hypoxia Nutrient Committee Workshop, September 26-28, 2005, Ames, Iowa, p. 141-150. http://www.umrshnc.org/files/Hypwebversion.pdf .

Kachanoski, R.G., I. O'Halloran, and P. Rochette. 2003. Site-specific application of fertilizer N for reducing greenhouse gas emissions. Climate change funding initiative in Agriculture, Canadian Agri-Food Research Council, Ottawa ON. (http://www.carc-crac.ca/ common/CCFIA%20Kachanoski%20Report.pdf)

Lemke, R.L., T.G. Goddard, F. Selles, and R.P. Zentner. 2002. Nitrous oxide emissions from wheat-pulse rotations on the Canadian prairies. p. 95–98. In Proc. of the 4th Annual Canadian Pulse Res. Workshop, 8–10 Dec. 2002, Edmonton, AB, Canada.

Lemke, R.L., Z. Zhong, C.A. Campbell, and R. Zentner. 2007. Can pulse crops play a role in mitigating greenhouse gases from North American agriculture? Agron. J. 99:1719–1725.

Malhi, S.S., R.L. Lemke, Z. Wang, R. Farrell, and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield and nutrient uptake, soil quality and greenhouse gas emissions. Soil Tillage Res. 90:171-183.

McSwiney, C.P. and G. P. Robertson. 2005. Nonlinear response of N_2O flux to incremental fertilizer addition in a continuous maize (*Zea mays* L.) cropping system. Global Change Biology. 11:1712–1719.

National Inventory Report, Greenhouse Gas Sources and Sinks in Canada (1990-2005). 2007. Greenhouse Gas Division, Environment Canada. (http://www.ec.gc.ca/pdb/ghg/inventory_report/ 2005_report/2005_report_e.pdf).

Rochette, P., D.A. Angers, G. Bélanger, M.H. Chantigny, D. Prévost, and G. Lévesque. 2004. Emissions of N_2O from alfalfa and soybean crops in eastern Canada. Soil Sci. Soc. Am. J. 68:493–506.

Rochette, P., D.E. Worth, R.L. Lemke, B.G. McConkey, D.J. Pennock, C. Wagner-Riddle, and R.L. Desjardins. In Press. Estimation of n_2o emissions from agricultural soils in Canada. I- Development of a country-specific methodology. Canadian Journal of Soil Science.

Schlegel, A.J., K. C. Dhuyvetter, and J. L. Havlin. 1996. Economic and environmental impacts of long-term nitrogen and phosphorus fertilization. J. Produc. Agric. 9:114-118.

Snyder, C.S., T.W. Bruulsema, and T.L. Jensen. 2007. Greenhouse gas emissions from cropping systems and the influence of fertilizer management — A literature review. International Plant Nutrition Institute, Norcross, Georgia, U.S.A.

Snyder, C.S. 2008. Fertilizer nitrogen BMPs to limit losses that contribute to global warming. International Plant Nutrition Institute. June 2008 Ref. # 08057 Item 30-3210.

Tiessen, K.H.D., D.N. Flaten, P.R. Bullock, C.A. Grant, R.E. Karamanos, D.L. Burton, and M.H. Entz. 2008. Interactive effects of landscape position and time of application on the response of spring wheat to fall-banded urea. Agron J. 100:557-563.

Zhong, Z., L.M. Nelson, and R. Lemke. 2004. Rhizobial denitrification and N_2Oemissions from soil profiles seeded with pulse crops. In Proc. Annual Meetings Abstracts 2004 [CD-ROM], Oct. 31– Nov. 4 2004, Seattle, WA. ASA, CSSA, and SSSA, Madison, WI.

8 ANNEX 1 — Excerpt from National Inventory Report 1990-2006 (2008)

The following excerpt from Canada's National Inventory Report describes the methodology used quantify N_2O emissions for agricultural soils. The peer-reviewed publications references listed in the text are not listed in this Science Discussion Document, but are available online in the original.

A3.3.6 N_2O Emissions from Agricultural Soils

Emissions of N_2O from agricultural soils consist of direct and indirect emissions as well as emissions from animal manure on pasture, range and paddock. The emissions of N_2O that result from anthropogenic Nitrogen inputs occur through direct (directly from the soils to which the N is added) and indirect pathways: i) through volatilization of synthetic fertilizer and manure N as NH_3 and NO_x and subsequent deposition ii) through leaching and runoff of N.

A3.3.6.1 Direct N_2O Emissions from Soils

Direct sources include synthetic fertilizers, animal manure applied as fertilizer, crop residue decomposition, modification of tillage practices, summerfallow, irrigation and cultivation of histosols. The methodologies for estimating emissions of N_2O for most of the direct emission sources from agricultural soils are country-specific and Intergovernmental Panel on Climate Change Tier 2 approaches.

It is known that moisture regimes and landscape impact on N_2O emissions (Rochette et al. 2008). Consequently, data on long-term climate normals and topographic characteristics are used to develop a base N_2O emission factor (EF_{BASE}).

Base N_2O Emission Factor (EF_{BASE})

The influence of local climatic conditions was assessed by the determination of regional EF_{BASE}. These factors were estimated using the same approach as for the determination of the Intergovernmental Panel on Climate Change Tier 1 emission factor by Bouwman (1996), i.e. EF_{BASE} = slope of the "N_2O emissions versus N fertilizer rate" relationship. EF_{BASE} was estimated for the three regions where field N_2O measurements are available: Quebec–Ontario; Brown and Dark Brown soil zones; and Grey and Black soil zones. The "EF_{BASE} versus fertilizer N" relationship determined for the Quebec–Ontario region has a similar slope (0.012 kg N_2O-N/kg N, excluding emissions during winter and spring thaw) (Gregorich et al. (2005) and fit ($r^2 = 0.43$) as the Intergovernmental Panel on Climate Change Tier 1 default emission factor derived by Bouwman (1996) using global data. In the Prairie region, low and variable N_2O emissions were measured across the range of N fertilizer rates (Brown-Dark Brown soils =0.0016 kg N_2O-N/kg N; Grey and Black soils = 0.008 kg N_2O-N/kg N). These observations suggest that soil N_2O production in the Prairie region is not limited by mineral N availability but rather by the low denitrification activity under well-aerated dry soil conditions.

N_2O is mostly produced during denitrification and, as a result, is greatly influenced by the soil oxygen status. Accordingly in moisture-limited conditions, N_2O emission factors have been shown to increase with increasing rainfall (Dobbie et al. 1999), and climate-variable emission factors have been used in estimating soil N_2O inventory (Flynn et al. 2005). A similar approach is proposed in this methodology by estimating emission factors at the ecodistrict level as a function of the ratio of the long-term normals (AAFC-archived database; S. Gameda, personal communication) of precipitation over potential evapotranspiration (P/PE) from May to October (Rochette et al. 2008). Despite the uncertainty in the determination of emission factors in the Prairie region, this approach is deemed a valid option to account for the influence of moisture limitations on N_2O emissions in that region. To account for the topographical effect, an EF_{BASE} was estimated at a P/PE = 1 (0.017 kg N_2O-N/kg N) for the lower sections of the landscapes. The fraction of the landscape to which this condition was applied differs among landscape types.

Landscape segmentation data were incorporated into the calculation of the national N_2O emission estimates, based upon the observations that N_2O emissions are greater in lower sections of the landscape where intermittently saturated soil conditions are favourable to denitrification (Corre et al. 1996, 1999; Pennock and Corre 2001; Izaurralde et al. 2004). The fraction of the landscape occupied by such lower sections, or FTOPO, was applied to concave portions of the landscape (i.e. lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and soils are imperfectly and poorly drained with mottles[101] within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower, and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine proportions of landforms in the Soil Landscapes of Canada (SLC), which was the basis for determining the proportion of the landscape to apply FTOPO for deriving N_2O emission estimates (Rochette et al. 2008).

To derive EF_{BASE} for an ecodistrict, the following equation was used:

Equation A3–14:

$$EF_{BASE} = EF_{CT,P/PE=1} \times F_{TOPO} + EF_{CT} \times (1 - F_{TOPO})$$

where:

EF_{CT} = emission factor, estimated at actual P/PE accounting for climate and topography in an ecodistrict, kg N_2O-N/kg N (See Figure A3–2)

$EF_{CT,\ P/PE=1}$ = emission factor estimated at P/PE = 1, 0.017 kg N_2O-N/kg N

F_{TOPO} = fraction of the ecodistrict area in the lower section of the toposequence *See Rochette* et al. *(2008)*

P = long-term mean precipitation from May to October in an ecodistrict, mm

PE = long-term mean potential evapotranspiration from May to October, mm

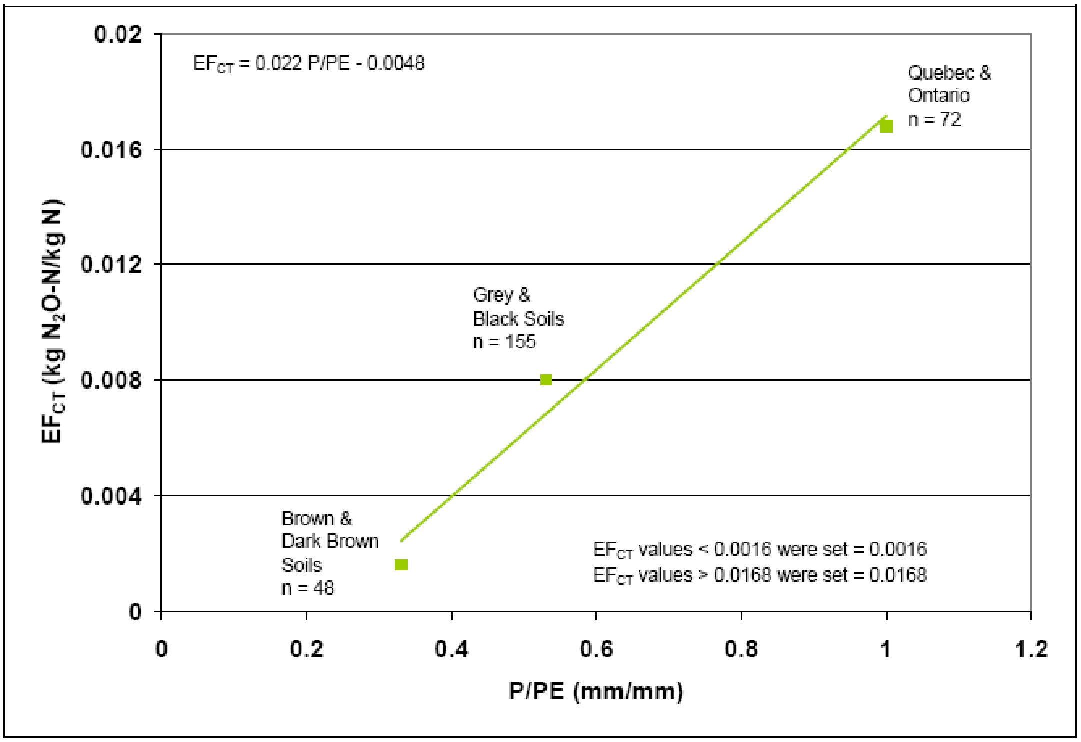

Figure A3–2: N_2O Emissions as a function of long-term ratio of precipitation over potential evapotranspiration (P/PE) from 1971 to 2000

N_2O Emissions during Winter and Spring Thaw

Average annual snowfall in eastern Canada varies between 1 and 4.5 m (Environment Canada 2002). Snowmelt water in the spring creates wet soil conditions that often stimulate N_2O production (Wagner-Riddle and Thurtel 1998). The intensity of soil freezing was also found to influence spring thaw emissions (Wagner-Riddle et al. 2007). Accordingly, results from micrometeorological studies showed that significant N_2O emissions can occur during winter and spring thaw in Ontario (Wagner-Riddle and Thurtell 1998; Grant and Pattey 1999) and limiting emission estimates to the snow-free period underestimates total annual N_2O emissions in that region. Rochette et al. (2008) reported mean N_2O emissions during winter and spring thaw in Southern Ontario to be 1.2 kg N_2O-N ha^{-1} (Wagner-Riddle et al. 2007; Wagner-Riddle and Thurtell 1998); these emissions were included for deriving the relationship between EF_{CT} and P/PE shown in Figure A3–2.

Spring thaw emissions also occur in the Prairies but are usually smaller than in eastern Canada (Lemke et al. 1999). Chamber flux measurements used to estimate EF_{CT} in the Prairies include spring thaw emissions, because low snow accumulation in that region allows chamber deployments during that period. Therefore, no adjustment to the EF_{CT} for the spring thaw emissions is required in the Prairies.

Soil Texture and N_2O Emissions

Soil texture does not directly influence N_2O production in soils. However, it correlates with several physico-chemical parameters that control N_2O production and transport in the soil profile (Arrouays et al. 2006; da Sylva and Kay 1997; Minasny et al. 1999). Accordingly, soil texturerelated variables often correlate with N_2O emissions from agricultural soils (Hénault et al. 1998; Corre et al. 1999; Chadwick et al. 1999; Bouwman et al. 2002; Freibauer 2003).

The impact of soil texture on N_2O emissions from agricultural soils was estimated using a ratio factor ($RF_{TEXTURE}$) defined as the ratio of N_2O emissions on soils of a given textural class to the mean emissions from soils of all textures. A value of 0.8 was assigned to the $RF_{TEXTURE-COARSE}$, 1.0 for $RF_{TEXTURE-MEDIUM}$ and 1.2 for $RF_{TEXTURE-FINE}$ (Rochette et al. 2008). $RF_{TEXTURE}$ could not be estimated in regions other than Québec, Ontario, and the Atlantic Provinces. Small influence of soil texture on N_2O emissions ($RF_{TEXTURE}$ =1) is likely justified under dry climates such as in the Prairie region where low soil water content results in low N_2O emissions regardless of the soil texture.

Equation A3–15

$$RF_{TEXTURE,i} = \left(RF_{TEXTURE-FINE,i} \times FRAC_{TEXTURE-FINE,i}\right) + \left(RF_{TEXTURE-COARSE,i} \times FRAC_{TEXTURE-COARSE,i}\right) + \left(RF_{TEXTURE-MEDIUM,i} \times FRAC_{TEXTURE-MEDIUM,i}\right)$$

where

$RF_{TEXTURE,i}$ = a weighted soil texture ratio factor of N_2O for an ecodistrict i for Ontario, Quebec, and the Atlantic provinces
$RF_{TEXTURE-FINE,\,i}$ = a ratio factor of N_2O for fine-textured soils for an ecodistrict i
$FRAC_{TEXTURE-FINE,\,i}$ = fraction of fine-textured soils in an ecodistrict i
$RF_{TEXTURE-COARSE,\,i}$ = a ratio factor of N_2O for coarse-textured soils for an ecodistrict i
$FRAC_{TEXTURE-FINE,\,i}$ = fraction of coarse-textured soils in an ecodistrict i
$RF_{TEXTURE-MEDIUM,\,i}$ = a ratio factor of N_2O for medium-textured soils for an ecodistrict i
$FRAC_{TEXTURE-MEDIUM,\,i}$ = fraction of medium-textured soils in an ecodistrict i

Synthetic N Fertilizers

Canada's method to estimate N_2O emissions from synthetic N fertilizer application on agricultural soils takes into account local climate regimes and topographic conditions. Equation A3–16 is used to estimate N_2O emissions by ecodistricts[102]. Emission estimates at the provincial and national scales are obtained by aggregating estimates at the ecodistrict level.

Equation A3–16:

$$N_2O_{SFN} = \sum\left(N_{FERT,i} \times EF_{BASE,i} \times RF_{TEXTURE,\,i}\right) \times \frac{44}{28}$$

where:

N_2O_{SFN} = emissions from synthetic N fertilizers, kg N2O/year
$N_{FERT,i}$ = total synthetic fertilizer consumption at the ith ecodistrict, kg N/year. NFERT at an ecodistrict level is estimated using Equation A3–20.
$EF_{BASE,i}$ = a weighted average of emission factors at the ith ecodistrict, which is a function of local climate (ratio of precipitation over potential evapotranspiration) and landforms, kg N2O-N/kg N-year
$RF_{TEXTURE,i}$= a weighted soil texture ratio factor of N_2O emission for an ecodistrict, i
44/28 = weight ratio of N_2O to N

Data for synthetic N fertilizer sales are available by province only and needed to be disaggregated to the ecodistrict level. The approach was based on the assumption that the amount of synthetic N fertilizers applied (N_{APPLDP}) is equal to the difference between recommended N rates (N_{RCMD}) and manure N available for application on cropland ($N_{MAN\text{-}AV,CROPS}$):

Equation A3–17:

$$N_{APPLDP,i} = N_{RCMD,i} - N_{MAN\text{-}AV,CROPS,i}$$

where:

$N_{APPLDP,i}$ = total N fertilizer potentially applied in ecodistrict i, kg N/year
$N_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kg N/year
$N_{MAN\text{-}AV,CROPS,i}$ = available N from manure applied to crops in ecodistrict i, kg N/year
N_{RCMD} was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in that ecodistrict (Yang et al. 2007):

Equation A3–18:

$$N_{RCMD,i} = \Sigma\ (CROPA_{ij} \cdot N_{RECRT,j})$$

where:

$CROPA_{ij}$ = area of crop type j in ecodistrict i, ha
$N_{RECRT,j}$ = recommended annual N application rate for crop type j in ecodistrict i, kg N/ha-year

$N_{MAN\text{-}AV,CROPS}$ was calculated as the sum of all manure N from all farm animals in the ecodistrict as follows:

Equation A3–19:

$$N_{MAN\text{-}AV,CROPS,i} = \Sigma_{jik}[(AnimalNo_{ji} \cdot N_{EX,j})\ (1 - N_{PRPj})\ (1 - FRAC_{(LossMS)jk} - UNAV)]$$

where:

$AnimalNo_{ji}$ = animal population of category j in ecodistrict i, number of heads (see section A3.3.1)
$N_{EX,j}$ = annual N excretion rate for animal category j, kg N/head-year (see Table A3–25 and Table A3–26)
N_{PRPj} = fraction of manure N that is deposited on pasture by grazing animals for animal category j (see Table A3–22).
$FRAC_{(LossMS)jk}$ = fraction of manure N that is lost during manure storage and handling in manure management system k for animal category j (See Table A3–27)
UNAV = fraction of manure N that is either in organic form or unavailable for crops: 0.35 (Yang et al. 2007).

Table A3–27: Total N and NH_3- and NO_x-N Losses Associated with Various Livestock and Manure Management Systems

Animal Category	Manure Management Systems	Total Manure N Loss (%)[1] ($FRAC_{(LossMS)}$)	NH_3-N and NO_x-N Loss (%)[1] ($FRAC_{GASM}$)
Dairy Cow	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	35 (10–55)	25 (10–40)
	Pasture and Range		20 (5–50)
Non-Dairy Cattle	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	40 (20–50)	30 (20–50)
	Pasture and Range		20 (5–50)
Swine	Liquid	48 (15–60)	48 (15–60)
	Solid Storage	50 (20–70)	45 (10–65)
Sheep, Lamb, Llamas and Alpacas	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range		20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range		20 (5–50)
Poultry	Liquid	50	50
	Solid Storage	53 (20–80)	48 (10–60)
	Pasture and Range		20 (5–50)

Notes:
1. Numbers in parentheses indicate a range.
2. Data sources: Hutchings et al. (2001); EPA (2004); Rotz (2004).

Because the potential amount of fertilizer needs to be reconciled with the total amount sold in the province (N_{SALES}) to estimate the actual amount applied (N_{FERT}), N_{APPLDP} is adjusted in each ecodistrict as follows:

Equation A3–20:

$$N_{FERT,\,i} = N_{APPLDP,\,i}\,(\Sigma_{ip}\,N_{APPLDPp} / N_{SALESp})$$

where:

$N_{FERT,i}$ = total fertilizer N actually applied to all crops in ecodistrict i, kg
$N_{APPLDP,i}$ = total fertilizer N applied to all crops in ecodistrict i, kg
$\Sigma_{ip}\,N_{APPLDPp}$ = sum of all fertilizer N potentially applied in province p, kg
N_{SALESp} = total amount of fertilizer N sold in province p, kg

In ecodistricts where $N_{MAN\text{-}AV,CROPS}$ exceeded N_{RCMD}, N_{FERT} was set to 0. For years between two consecutive Census years (e.g. 1991, 1996 and 2001), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLDP} and N_{FERT} at the ecodistrict level.

The Farm Input Markets Unit of the Farm Income and Adaptation Policy Directorate of Agriculture and Agri-Food Canada collected annual fertilizer N consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade* from 1990 to 2002 (Korol 2003). Since 2003, fertilizer N data have been collected and published by the Canadian Fertilizer Institute (Available online at: http://www.cfi.ca/Publications/Statistical_Documents.asp.).

There are 958 weather stations in the AAFC-archived weather database. These stations (80º00′N–41º55′N, 139º08W–52º40W) across Canada (758 stations) and the United States (200 stations) were used to interpolate monthly precipitation and potential evapotranspiration from May to October from 1970 to

2000 to the ecodistrict centroids. AAFC-archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

Manure Applied as Fertilizer

Emissions of N_2O from manure applied as fertilizer include N_2O produced from the application of manure from drylot or solid storage, liquid and other waste management systems on agricultural soils. Similarly to synthetic fertilizer N_2O emissions, a country-specific Tier 2 methodology is used for estimating N_2O emissions from manure applied as fertilizer. The methodology is based on the quantity of manure N produced by domestic animals and country-specific EF_{BASE} taking into account local climate moisture and topographic conditions at the ecodistrict level. N_2O emission estimates from this source are calculated using Equation A3–21.

Equation A3–21:

$$N_2O_{MAN} = \sum \left(N_{MAN,CROPS,i} \times EF_{BASE,i} \times RF_{TEXTURE,\,i} \right) \times \frac{44}{28}$$

where:

N_2O_{MAN} = emissions from animal manure applied to cropland as fertilizers, kg N_2O/year
$N_{MAN,CROPS,i}$ = total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year (*see Equation A3–22)*
$EF_{BASE,i}$ = a weighted average emission factor for ecodistrict i accounting for climate and topography, kg N_2O-N/kg N-year
$F_{TEXTURE,i}$ = a weighted average of soil texture ratio factor of N_2O emission for an ecodistrict, i
44/28 = weight ratio of N_2O to N

Equation A3–22:

$$N_{MAN,CROPS,i} = \sum_{T} \left[\left(N_T \times N_{EX,T} \right) \times \left(1 - N_{PRP,T} \right) \times \left(1 - FRAC_{(LossMS,T)} \right) \right]$$

where:

$N_{MAN,CROPS,i}$ = animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year
N_T = population for the Tth animal category or subcategory (*see section A3.3.1*)
$N_{EX,T}$ = N excretion rate for the Tth animal category or subcategory (*Table A3–25 and Table A3–26)*
$N_{PRP,T}$ = fraction of manure N on pasture, range, and paddock for each animal category T in ecodistrict i (*See Table A3–22)*
$FRAC_{(LossMS,T)}$ = fraction of total losses of manure N for each animal category T excluding pasture, range, and paddock in ecodistrict i (*See Table A3–27)*

Animal population data sources and population accounts are detailed in section A3.3.1.

Biological N Fixation

Biological N fixation by the legume–rhizobium association, a major source of N_2O in the Revised 1996 Intergovernmental Panel on Climate Change Guidelines (IPCC/OECD/IEA 1997), is not included in the 2006 Intergovernmental Panel on Climate Change Guidelines (IPCC 2006). This decision is supported by the findings of Rochette and Janzen (2005) that there is no evidence that measurable amounts of N_2O are produced during the N fixation process itself.

Therefore, Canada decided to report this source as “not occurring.” However, the contribution of legume N to N_2O emissions is included as a source of N_2O emissions from crop residue decomposition on agricultural soils (N_{RES}).

Crop Residue Decomposition

The transformations (nitrification and denitrification) of the N released during the decomposition of crop residues result in N_2O emissions into the atmosphere. A country-specific Tier 2 methodology similar to that for fertilizer and manure applied as fertilizer is used to estimate N_2O emissions from crop residues, based on Equation A3–23, Equation A3–24 and Equation A3–25:

Equation A3–23:

$$N_2O_{RES} = \sum \left(N_{RES,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right) \times \frac{44}{28}$$

where:

N_2O_{RES} = emissions from crop residue decomposition, kg N_2O/year
$EF_{BASE,i}$ = a weighted average of emission factors for ecodistrict i, kg N_2O-N/kg N-year
44/28 = weight ratio of N_2O to N
$N_{RES,i}$ = total amount of crop residue N that is returned to the cropland annually for ecodistrict i, kg N/year *(See Equation A3–24)*
$RF_{TEXTURE,i}$ = a weighted average of soil texture ratio factor of N_2O emission for an ecodistrict, i

Equation A3–24:

$$N_{RES,i} = \sum_T \left[P_{T,i} \times FRAC_{RENEW,T,i} \times \left(R_{AG,T} \times N_{AG,T} + R_{BG,T} \times N_{BG,T}\right)\right]$$

where:

$FRAC_{RENEW,T,i}$ = fraction of total area under crop T that is renewed annually in ecodistrict i
$R_{AG,T}$ = ratio of above-ground residues to harvested yield for crop T, kg dry matter (DM)/kg
$N_{AG,T}$ = N content of above-ground residues for crop T, kg N/kg DM
$R_{BG,T}$ = ratio of below-ground residues to harvested yield for crop T, kg DM/kg
$N_{BG,T}$ = N content of below-ground residues for crop T, kg N/kg DM
T = crop/forage type
$P_{T,i}$ = total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM/year (*See Equation A3–25).*

Equation A3–25:

$$P_{T,i} = \frac{A_{T,i} \times Y_{T,i}}{\sum_{i=1}^{N}\left(A_{T,i} \times Y_{T,i}\right)} \times P_{T,p} \times \left(1 - H_2O_T\right)$$

where:
$A_{T,i}$ = area under crop type T in ecodistrict i, ha
$Y_{T,i}$ = average crop yield for crop type T in ecodistrict i, kg/ha-year
H_2O_T = water content of harvested crop T, kg/kg
$P_{T,p}$ = total crop production for crop type T in province p, kg DM/year

Statistics Canada (2006, #22-002) collects and publishes annual field crop production data by province. Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chick peas, and lentils. Area and production of each crop are reported at the Census Agricultural Region and provincial levels, and yields have been allocated to SLC polygons through area overlays by Agriculture and Agri-Food Canada. Specific parameters for each crop type are listed in Janzen et al. (2003).

Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop production produces N_2O. The Intergovernmental Panel on Climate Change Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils (Equation A3–26).

Equation A3–26:

$$N_2O_H = \sum \left(A_{os,i} \times EF_{HIST}\right) \times \frac{44}{28}$$

where:

N_2O_H = N_2O emissions from cultivated histosols, kg N_2O-N/year
$A_{os,i}$ = total area of cultivated organic soils in each province, ha
EF_{HIST} = IPCC default emission factor for mid-latitude organic soils, 8.0 kg N_2O-N/ha-year (IPCC 2000)
44/28 = weight ratio of N_2O to N

Areas of cultivated histosols at a provincial level are not collected as part of the Census of Agriculture. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils from 1990 to 2006 in Canada was 16 200 ha (G. Padbury and G. Patterson, AAFC, personal communication).

N_2O Emissions or Removals from Adoption of No-Till and Reduced Tillage

This category is specific to Canada. It does not derive from additional N input such as fertilizer, manure, and crop residue N, but reflects how changes in tillage practices affect N_2O emissions. For example, compared with conventional or intensive tillage (IT), direct seeding (NT) and reduced tillage (RT) affect the decomposition of soil organic matter, soil carbon and N availability, soil bulk density, and water content, and thus N_2O emissions.

Field studies in Quebec and Ontario showed that NT practices increased N_2O emissions, whereas in the Prairies the opposite was observed. To quantify the impact of tillage practices on N_2O, a tillage ratio factor (F_{TILL}) defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), is used as follows (Rochette et al. 2008):

Equation A3–27:

$$N_2O_{TILL} = \sum \left[\left(N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}\right) \times \left(EF_{BASE,i} \times FRAC_{NT-RT,i} \times \left(F_{TILL} - 1\right)\right)\right] \times \frac{44}{28}$$

where:

N_2O_{TILL} = N_2O emissions or removals resulting from the adoption of NT and RT, kg N_2O/year

$N_{FERT,i}$ = total synthetic fertilizer N consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$ = total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year
$N_{RES,i}$ = total amount of crop residue N that is returned to the cropland annually for ecodistrict i, kg N/year
$EF_{BASE,i}$ = a weighted average emission factor for ecodistrict i, kg N_2O-N/kg N-year
$FRAC_{NT-RT,i}$ = fraction of cropland on NT and RT in ecodistrict i, %
F_{TILL} = a ratio factor adjusting EF_{BASE} due to the adoption of NT and RT: F_{TILL} = 1.1 in eastern Canada; F_{TILL} = 0.8 in the Prairies (Rochette et al. 2008)
44/28 = weight ratio of N_2O to N

The fraction of cropland under NT and RT ($FRAC_{NT-RT}$) for each ecodistrict originated from the Census of Agriculture and is identical to that used in the LULUCF Cropland Remaining Cropland category for NT and RT practices (Statistics Canada 1992; 1997; 2002). These data are published at the Census Agricultural Region, Census Division, provincial, and national levels. Annual $FRAC_{NT-RT}$ between the two consecutive Census years is adjusted through interpolation.

N_2O Emissions Resulting from Summerfallowing

Summerfallowing is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, temperature, and available carbon and N (Campbell et al. 1990). Experimental studies have shown that N_2O emissions in fallow fields are similar to emissions from continuously cropped fields (Rochette et al. 2008). In order to account for these emissions not captured by the default Intergovernmental Panel on Climate Change input-driven approach, the following country-specific methodology is used to estimate the effect of summerfallowing on N_2O emissions with the assumption that during a crop year, direct N_2O emissions from a given field are summarized as follows:

Equation A3–28:

$$N_2O_{CROP} = N_2O_{BACK} + N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES}$$

where N_2O_{SFN}, N_2O_{MAN}, and N_2O_{RES} are defined in the previous sections. N_2O_{BACK} are the background soil N_2O emissions that are not due to crop residue-N, fertilizer-N or manure-N additions.

During a fallow year, no fertilizer or manure is applied. In the absence of external N inputs, N_2O emissions during the fallow year (N_2O_{FALLOW}) can be seen as consisting of 1) background" emissions that would have occurred regardless of fallow (N_2O_{BACK}) and 2) emissions due to the modifications to the soil environment by the practice of summerfallow ($N_2O_{FALLOW-EFFECT}$):

Equation A3–29:

$$N_2O_{FALLOW} = N_2O_{BACK} + N_2O_{FALLOW-EFFECT}$$

Since N_2O emissions are assumed equal during fallow and cropped years ($N_2O_{CROP} = N_2O_{FALLOW}$) and assuming that N_2O_{BACK} is the same in cropped and fallow situations, $N_2O_{FALLOW-EFFECT}$ can be estimated as follows:

Equation A3–30:

$$N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES} = N_2O_{FALLOW-EFFECT}$$

The N_2O emissions due to the practice of summerfallow are therefore calculated for each ecodistrict by applying emissions from N inputs to annual crops (crop residues, fertilizers and manure) to the area of that ecodistrict under summerfallow:

Equation A3–31:

$$N_2O_{FALLOW} = \sum\left[\left(N_2O_{SFN,i} + N_2O_{RES,i} + N_2O_{MAN,i}\right) \times FRAC_{FALLOW,i}\right]$$

where:

N_2O_{FALLOW} = emissions due to the effect of summerfallow
$N_2O_{SFN,i}$ = emissions from synthetic N fertilization in ecodistrict i, kg N_2O-N
$N_2O_{RES,i}$ = emissions from crop residue decomposition in ecodistrict i, kg N_2O-N
$N_2O_{MAN,i}$ = emissions from animal manure applied as fertilizers to cropland in ecodistrict i, kg N_2O-N
$FRAC_{FALLOW,i}$ = fraction of cropland in ecodistrict i that is under summerfallow, %

Estimates of N_2O_{SFN}, N_2O_{RES} and N_2O_{MAN} at an ecodistrict level are those derived from synthetic fertilizers, manure applied as fertilizers and crop residues. $FRAC_{FALLOW}$ is derived from the Census of Agriculture for each ecodistrict (Statistics Canada 1992; 1997; 2002) and is identical to that used in the LULUCF Cropland Remaining Cropland category for the summerfallow practice. Annual $FRAC_{FALLOW}$ between the two consecutive Census years is adjusted through interpolation.

N_2O Emissions from Irrigation

Higher soil water content under irrigation increases N_2O emissions by increasing biological activity and reducing soil aeration (Jambert et al. 1997). Accordingly, highest N_2O emissions from agricultural soils in the northwestern United States (Liebig et al. 2005) and western Canada (Hao et al. 2001) were observed on irrigated cropland, followed by non-irrigated cropland and rangeland. Field studies directly comparing N_2O emissions under irrigated and non-irrigated situations are lacking in Canada. Therefore, an approach was used based on the assumptions that 1) the irrigation water stimulates N_2O production in a way similar to rainfall water, and 2) irrigation is applied to eliminate any moisture deficit such that "precipitation + irrigation water = potential evapotranspiration." Consequently, the effect of irrigation on N_2O emissions from agricultural soils was accounted for using an EF_{BASE} estimated at a P/PE = 1 (e.g. EF_{BASE} = 0.017 N_2O-N/kg N) for the irrigated areas of an ecodistrict:

Equation A3–32:

$$N_2O_{IRRI} = \sum\left[\left(N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}\right) \times \left(0.017 - EF_{BASE,i}\right) \times FRAC_{IRRI,i}\right] \times \frac{44}{28}$$

where:

N_2O_{IRRI} = emissions from irrigation, kg N_2O/year
$N_{FERT,i}$ = total synthetic fertilizer N consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$ = total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year
$N_{RES,i}$ = total amount of crop residue N that is returned to the cropland annually for ecodistrict i, kg N/year
0.017 = value attributed to EF_{BASE} for irrigated land, kg N_2O-N/kg N-year
$EF_{BASE,i}$ = a weighted average emission factor for ecodistrict i, kg N_2O-N/kg N-year for ecodistrict i
$FRAC_{IRRI,i}$ = fraction of irrigated cropland in ecodistrict i,

44/28 = weight ratio of N_2O to N

$FRAC_{IRRI}$ is derived from the Census of Agriculture for each ecodistrict (Statistics Canada 1992; 1997; 2002). Annual $FRAC_{IRRI}$ between the two consecutive Census years is adjusted through interpolation.

A3.3.6.2 Manure on Pasture, Range, and Paddock from Grazing Animals

The Intergovernmental Panel on Climate Change Tier 1 methodology is used to estimate N_2O emissions from manure on pasture, range, and paddock. The Intergovernmental Panel on Climate Change methodology is based on the quantity of manure N produced by domestic animals on pasture, range, and paddock, and N_2O emissions are calculated using Equation A3–33.

Equation A3–33:

$$N_2O_{PRP} = \sum_T \left(N_T \times N_{EX,T} \times N_{PRP,T} \times EF_{PRP,T}\right) \times \frac{44}{28}$$

where:

N_2O_{PRP} = emissions from manure on pasture, range, and paddock from grazing animals, kg N_2O/year
N_T = animal population of the animal category T in a province, head (*see section A3.3.1).*
$N_{EX,T}$ = annual N excretion rate for the animal category T, kg N/head-year (*Table A3–25 and Table A3–26)*
$N_{PRP,T}$ = fraction of manure N excreted on pasture, range, and paddock by animal category T (*See Table A3–22).*
$EF_{PRP,T}$ = emission factor for manure N deposited by animals on pasture, range, and paddock: 0.02 kg N_2O-N/kg N for dairy cattle, non-dairy cattle, buffalo, swine, and poultry, and 0.01 kg N_2O-N/kg N for sheep, llamas, alpacas, lamb, goat, and horse (IPCC 2006) (*See Annex 12)*
44/28 = weight ratio of N_2O to N

Animal population data and data sources are detailed in section A3.3.1.

A3.3.6.3 Indirect N_2O Emissions from Soils

Volatilization and Redeposition of Nitrogen

The Intergovernmental Panel on Climate Change Tier 1 methodology is used to estimate indirect N_2O emissions due to volatilization and redeposition of fertilizer and manure N applied to agricultural soils. The emission calculation is shown in Equation A3–34:

Equation A3–34:

$$N_2O_{VD} = \sum\left[\left(N_{FERT,i} \times FRAC_{GASF}\right) + \left(N_{MAN,CROPS,i} \times FRAC_{GASM}\right) + N_{MAN-VOLAT,i}\right] \times EF_{VD} \times \frac{44}{28}$$

where:

N_2O_{VD} = emissions due to volatilization and redeposition of N, kg N_2O/year
$N_{FERT,i}$ = synthetic N fertilizer consumption in ecodistrict i, kg N/year
$FRAC_{GASF}$ = fraction of synthetic fertilizer N applied to soils that volatilizes as NH_3- and NO_x-N: 0.1 kg (NH_3-N + NO_x-N)/kg N (IPCC 2006)
$N_{MAN,CROPS,i}$ = total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year

$FRAC_{GASM}$ = fraction of volatilized manure N applied as fertilizers to cropland: 0.2 kg (NH_3-N + NO_x-N)/kg N (IPCC 2006)
EF_{VD} = emission factor due to volatilization and redeposition: 0.01 kg N_2O-N/kg N (IPCC/OECD/IEA 1997)
44/28 = weight ratio of N_2O to N
$N_{MAN\text{-}VOLAT,i}$ = total manure N lost as NH_3-N and NO_x-N from livestock excretion in ecodistrict i, kg N (*Equation A3–35)*

Equation A3–35:

$$N_{MAN-VOLAT,i} = \sum_{mT}\left(N_T \times N_{EX,T} \times AWMS_{m,T} \times FRAC_{GASMm,T}\right)$$

where:

N_T = animal population for animal category T, head
$N_{EX,T}$ = N excretion from animal category T, kg N/year (*Refer to Section A3.3.5.1.*
$AWMS_{m,T}$ = fraction of manure N from animal category T managed under manure management system m (*See Table A3–22)*
$FRAC_{GASMm,T}$ = fraction of manure N excreted by animal category T and managed under manure management system m that volatilizes as NH_3-N and NO_x-N (*See Table A3–27)*

Data sources for estimating N_{FERT} and $N_{MAN\text{-}VOLAT}$ at an ecodistrict level are provided in the previous sections (section 3.3.6.1 and Table A3–27).

Leaching, Erosion and Runoff

A modified Intergovernmental Panel on Climate Change Tier 1 methodology is used to estimate N_2O emissions from leaching, runoff, and erosion of fertilizer, manure, and crop residue N from agricultural soils:

Equation A3–36:

$$N_2O_L = \sum\left[\left(N_{FERT,i} + N_{MAN,CROPS,i} + N_{PRP,i} + N_{RES,i}\right) \times FRAC_{LEACH,i} \times EF_{LEACH}\right] \times \frac{44}{28}$$

where:

N_2O_L = emissions due to leaching and runoff, kg N_2O/year
$N_{FERT,i}$ = synthetic N fertilizers applied for ecodistrict i, kg N
$N_{MAN,CROPS,,i}$ = manure N applied as fertilizers for ecodistrict i, kg N
$N_{PRP,i}$ = manure N on pasture, range, and paddock for ecodistrict i, kg N
$N_{RES,i}$ = crop residue N for ecodistrict i, kg N
$FRAC_{LEACH,i}$ = fraction of N that is lost through leaching and runoff for ecodistrict i, as defined below
EF_{LEACH} = leaching/runoff emission factor: 0.025 kg N_2O-N/kg N (IPCC 2000)
44/28 = weight ratio of N_2O to N

Determining the Fraction of Nitrogen that is Leached (FRACLEACH) at the Ecodistrict Level in Canada

In Canada, leaching losses of N vary widely among regions. High N inputs in humid conditions may lead to losses greater than 100 kg N/ha-year in some farming systems of southern British Columbia (Paul and Zebarth 1997; Zebarth et al. 1998). Such losses, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0–37 kg N ha^{-1}, accounting for 0–20% of N inputs from seed, fertilizer, manure, animals, N fixation, and atmospheric deposition. Leaching losses in most of the Prairie region may be smaller due to lower precipitation and lower N inputs on an areal basis. Based on a long-term experiment in central Alberta, Nyborg et al. (1995) suggested that leaching losses were minimal, and Chang and Janzen (1996) found no evidence of N leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The default value for $FRAC_{LEACH}$ in the Revised 1996 Intergovernmental Panel on Climate Change Guidelines (IPCC/OECD/IEA 1997) was 0.3. $FRAC_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (Intergovernmental Panel on Climate Change 2006), such as in the Prairie region of Canada. Accordingly, it was assumed that $FRAC_{LEACH}$, depending on the ecodistrict, would vary from a low of 0.05 to a high of 0.3.

For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum $FRAC_{LEACH}$ value recommended by the 2006 Intergovernmental Panel on Climate Change Guidelines (IPCC 2006) of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.23), a minimum $FRAC_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.23 and 1, $FRAC_{LEACH}$ was estimated by the linear function that joins the points (P/PE, $FRAC_{LEACH}$) = (1,0.3; 0.23,0.05) (Figure A3–3).

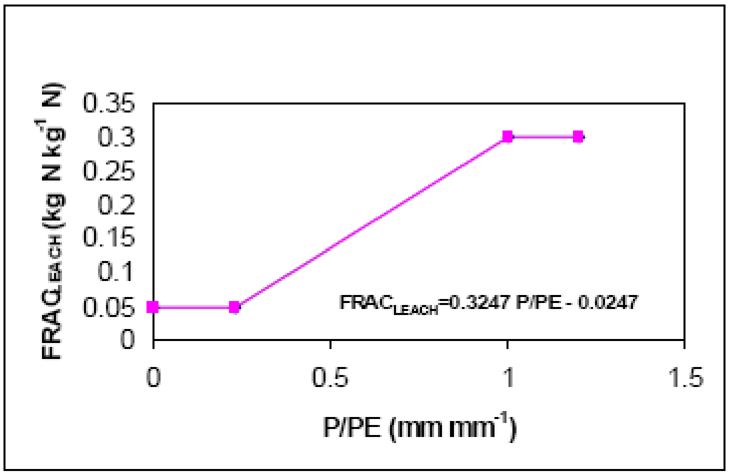

Figure A3–3: Determination of the Ecodistrict $FRAC_{LEACH}$ Values

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Data sources for N_{FERT} (section A3.3.6.1), $N_{MAN,CROPS}$ (section A3.3.6.1), N_{PRP}(section A3.3.6.2), and N_{RES} (section A3.3.6.1) at an ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1971–2000 (AAFC-archived database; S. Gameda, personal communication), were used to calculate $FRAC_{LEACH}$ at an ecodistrict level.