DECISION PAPER RESULTS

FOR

NITROUS OXIDE EMISSION REDUCTION PROTOCOL

TO:

CLIMATE CHANGE CENTRAL
&
CANADIAN FERTILIZER INSTITUTE

July 23, 2009

Contents

1. Introduction

This document presents the background, context and decisions for Phase 3b of the Nitrous Oxide Emission Reduction Protocol (NERP) Webinar held June 30, 2009. The initial science coordination and consultation workshop on the NERP protocol was held in Calgary, Alberta, 28 & 29 October 2008. At this Workshop, participating experts approved the general design of the NERP according to the Right Product @ Right Rate, Right Time, Right Place™ stewardship model (4-R) of the Canadian Fertilizer Institute, and implementing the country-specific quantification method of Canada's National Inventory Report (see http://www.carbonoffsetsolutions.ca/offsetprotocols/workshops.html) for the participants, presentations, papers and results of the October workshop.

The experts participating in the Consultation Workshop approved the main elements of the implementation of the NERP. The eligibility requirements of the NERP will be designed according to the criteria of the Alberta Offsets System and Canada's Offset System. The scope of the NERP is limited to on-farm reductions of emissions associated with quantification categories of fertilizer, manure, residues, and irrigation. The GHG emissions for the baseline will be determined using the country-specific methodology from Canada's National Inventory Report according to three years of farm-level activity data. The GHG emissions for the project condition also will be determined with the country-specific methodology from Canada's National Inventory Report, using the data from the farm after participation in the NERP. The essential component for participation in the NERP was defined as the implementation of a 4-R 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, and (4) retaining services of an approved consulting professional. The fertilizer best management practices (BMPs) comprising the Basic, Intermediate, and Advanced levels of the NERP were listed for western Canada conditions.

Despite achieving consensus on the main elements of the NERP, the participants of the Consultation Workshop identified some gaps requiring further development. This Decision Paper is intended to facilitate consensus among scientific researchers and technical practitioners concerning the remaining decisions needed to complete the technical and operational framework of the NERP. To achieve this objective, the Decision Paper compiled the knowledge needed to address the gaps identified at the Consultation Workshop, and recorded the decisions of the Contract Steering Committee and other designated experts based on the compiled knowledge.

The members of the Contract Steering Committee are:

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

Keith Reid, Ontario Ministry of Agriculture, Food and Rural Affairs;
Esther Salvano, Manitoba Agriculture, Food, and Rural Initiatives;
Amanda Stuparyk, Climate Change Central; and
Bob Tadsen, The Fertilizer Institute.

This paper combines the initial Decision Paper used in the Webinar of June 30th, with the decisions recorded as the webinar proceeded. Consensus was defined as 80% agreement by the participating scientists and technical experts. The participants of the Webinar comprised technical experts from government/university research organizations, industry associations, as well as fertilizer manufacturers. A total of 47 individual received invitations to the Webinar, including the original invitees of the October 2008 workshop, and ~20 attended.

Name	Affiliation	Contact Information	Voting Participant[1, 3]
NERP Steering Committee			
Doug Beever	Agrium	dbeever@agrium.com	Did not attend
Clyde Graham	Canadian Fertilizer Institute	Cgraham@cfi.ca	Yes
Karen Haugen-Kozyra	Climate Change Central	karenhk@climatechangecentral.com	Yes
Tom Jensen	International Plant Nutrition Institute	tjensen@ipni.net	Yes
Len Kryzanowski	Alberta Agriculture & Rural Development	len.kryzanowski@gov.ab.ca	Yes
Keith Reid	Ontario Ministry of Agriculture Food and Rural Affairs	Keith.reid@ontario.ca	Yes
Ken Panchuk	Saskatchewan Agriculture and Food	Ken.panchuk@gov.sk.ca	Did not attend
Esther Salvano/Matthew Weins	Manitoba Agriculture and Agri-Food	Esther.salvano@gov.mb.ca Matt.Weins@gov.mb.ca	Yes
Amanda Stuparyk	Climate Change Central	astuparyk@climatechangecentral.com	No
Contractors and Workshop Facilitator			
Jessica Goforth	Blue Source Canada	jessicag@bluesourcecan.com	No
Rob Janzen	ClimateCHECK	rj@climate-check.com	Yes
Rigas Karamanos	Viterra	r.karamanos@westcoag.com	Yes
Canadian Researchers			
Eric Bremer	Symbio Ag	ericbremer@shaw.ca	Yes
David Burton	Nova Scotia Agricultural College	dburton@nsac.ns.ca	Yes
Ray Desjardins	Agriculture and Agri-Food Canada	desjardins@agr.gc.ca	Yes
Devon Worth	Agriculture and Agri-Food Canada	Devon.worth@agr.gc.ca	No

Elizabeth Pattey	Agriculture and Agri-Food Canada	Elizabeth.pattey@agr.gc.ca	No
Cindy Grant	Agriculture and Agri-Food Canada	cgrant@agr.gc.ca	Yes
Robert Grant	University of Alberta	Robert.grant@ualberta.ca	Yes
Kimlin Metivier	University of Alberta (Post Doctoral)	metivier@ualberta.ca	Yes
US / International Researchers			
Cliff Snyder	International Plant Nutrition Institute	csnyder@ipni.net	Yes
Industry Representatives			
Ray Dowbenko	Agrium	rdowbenk@agrium.com	Yes
Brian Gilbertson	Agrium	Bgilbert@agrium.com	No
Government			
Tom Goddard	Alberta Agriculture and Rural Development	tom.goddard@gov.ab.ca	Yes
Nancy Lease	Quebec Department of Agriculture	nancy.lease@mapaq.gouv.qc.ca	Yes
Sheilah Nolan	Alberta Agriculture and Rural Development	sheilah.nolan@gov.ab.ca	Yes

[1] All invited participants received a copy of the Decision paper, and were given the opportunity to provide written comments.

[3] Only participants with a graduate degree in soil science of a related discipline were given the privilege to vote on options to develop the NERP.

2. Enhanced Justification for Reduction Modifiers

The concept of reduction modifier was recommended to the participants of the October Consultation Workshop to acknowledge the full potential of the NERP to transform nitrogen (N) fertilizer management in achieving reductions of N_2O emissions. Although the quantification approach of the NERP will capture N_2O reductions associated with decreased inputs of N to a field, it is generally acknowledged that the management of the N fertilizer, as well as the rate, influences the emissions of N_2O. Also, the NERP encourages concurrent implementation of BMPs, thereby integrating the influence of a number of strategies to reduce N_2O emissions.

The relationship between integrated or 'stacked' BMPs and reduction of N_2O emissions has received relatively little research. With the exception of a few studies (such as the Case Study described in Section 2.3 below), empirical data are lacking concerning the cumulative reductions of a suite of BMPs based on 4-R principles. Therefore, at the October 2008 workshop it was recommended that the working group collect knowledge about emission reductions pertaining to single practices to inform expert judgement (through the Decision Paper and Webinar process on June 30th 2009) regarding the potential of integrated or 'stacked' practices to reduce N20 emissions.

The concept of the reduction modifier thus was proposed as a means to implement expert judgement informed by knowledge of single practice reductions, under the premise that credibility would be maintained by constraining the magnitude of the modifiers according to the ISO 14064 principle of conservativeness[1]. The rationale is that modifiers to generate token reductions can be assigned with current knowledge, with the understanding that more accurate and precise reduction modifiers will be derived as research advances. In other words, the reduction modifier reflects experts' confidence that increasingly sophisticated 4-R N stewardship plans will decrease N_2O emissions, but acknowledges experts' uncertainty of the precise magnitude of the decrease. The reduction modifier concept thus is a science-based standard to incentivize growers to intensify efforts to manage N fertilizer for reduction of N_2O emissions, and is not intended as an empirical prediction of N_2O dynamics, spatially or temporally.

At the NERP Consultation Workshop, the reduction modifiers associated with the levels of the NERP were approved in principle. This included approval of integration of these principles into Basic, Intermediate, and Advanced levels of the NERP, characterized by increasingly landscape-specific 4-R N stewardship plans and BMPs (Table 1). However, decisions concerning the values for the reduction modifiers were deferred, because the designated scientific experts with voting privilege were not comfortable voting on these values as yet. Therefore, the proposed reduction modifier values (Table 1) were retained as placeholders for further rationale and justification.

Table 1. Differentiation of 4-R N stewardship plans and BMPs for the levels of the NERP as revised by the decisions of the Consultation Workshop – last column were proposed placeholders.

	Right Product	**Right Rate**	**Right Time**	**Right Place**	**Proposed Modifier**
Basic	Ammonium-based formulation.	Apply N according to recommendation of 4-R 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	Apply in bands	0.8
Intermediate	Ammonium-based formulation Use slow / controlled release fertilizers or inhibitors or stabilized nitrogen.	Apply N according to qualitative estimates of field variability ((landscape position, soil variability)	Apply in spring, or split apply, or after soil cools in fall if using slow / controlled release fertilizer or inhibitors / stabilized nitrogen	Apply in bands	0.6
Advanced	Ammonium-based formulation Use slow / controlled release fertilizers or	Apply N according to quantified field variability (e.g. digitized soil maps, grid sampling, satellite	Apply in spring, or split apply, or after soil cools in fall if using controlled	Apply in bands	0.5

[1] Principle of Conservativeness — Use conservative assumptions, values and procedures to ensure that GHG emission reductions or removal enhancements are not over-estimated (Section 3.7. ISO 14064-2).

	inhibitors or stabilized nitrogen based on quantified field variability	imagery, real time crop sensors.) complimented by in season crop monitoring	release fertilizer or inhibitor / stabilized nitrogen		

2.1 General Scientific Rational for Reduction Modifiers

The participating experts at the October Consultation Workshop represented researchers from Canada and the United States, technical and extension specialists from federal and provincial industries of agriculture, and representatives from agri-business. Those who had voting privileges were identified as having a masters degree or higher in agronomy, agrology or soil fertility disciplines. In addition to the personal and professional experience these participants brought to the Workshop, each participant was also provided with the Science Discussion Document to summarize and to justify the approach described in the NERP. Based on the judgment of the participating experts, several conclusions were reached regarding the general scientific basis for the NERP.

2.1.1 Relationship of N_2O Reduction and Nitrogen Use Efficiency

The experts participating in the Consultation Workshop agreed that, in general, (1) practices to increase nitrogen use efficiency would decrease N_2O emissions, and (2) the BMPs proposed in the three levels of the NERP would increase nitrogen use efficiency to the degree corresponding to the reduction modifiers proposed at the Consultation Workshop. The participating experts stated, however, that further justification was needed to determine the magnitude of the modifiers associated with the Basic, Intermediate, and Advanced levels of the NERP. The discussion in Sections 3 and 4 of this document addresses this request of the Workshop participants.

2.1.2 Canada's Country-specific N_2O Quantification Approach

The concept of a reduction modifier is part of the country-specific method used to quantify N_2O emissions in Canada's National Inventory Report (NIR 2008, Rochette *et al.* 2008). The following excerpt (p. 351, NIR 2008) describes the approach to quantifying N_2O emissions and removals resulting from adoption of no-till (NT) and reduced till (RT).

> This category is specific to Canada. It does not derive from additional nitrogen input such as fertilizer, manure, and crop residue nitrogen, but is rather like a "modifier" to several factors affecting N_2O emissions when tillage practices are modified. For example, compared with conventional or intensive tillage (IT), direct seeding or NT as well as RT affect the decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content. N_2O emissions or removals resulting from the adoption of NT and RT can be expressed as follows:
>
> **Equation A3-31:**

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

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 nitrogen consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	total amount of animal manure nitrogen applied as fertilizer to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	total amount of crop residue nitrogen 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 per year
$FRAC_{NT-RT,i}$	=	fraction of cropland on NT and RT in ecodistrict i, %
F_{TILL}	=	a ratio factor adjusting EF_{BASE} (*see "Determining Basic N_2O Emission Factor (EF_{BASE}) for an Ecodistrict"*) due to the adoption of NT and RT: F_{TILL} = 1.1 in eastern Canada; F_{TILL} = 0.8 in the Prairies (see below)
44/28	=	molecular weight ratio of N_2O to N_2

As a result of the integrated consequences of decreased tillage intensity for "decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content", the NIR uses a 'modifier', F_{TILL}, to calculate the N_2O emissions or removals associated with the practice of NT or RT, N_2O_{TILL}. In a similar manner, the proposed NERP uses modifiers to calculate the N_2O emission reductions achieved with the implementation of the comprehensive 4-R stewardship plan and associated BMPs. Clearly, a strong precedence exists for the use of reduction modifiers in the NERP.

The credibility of the Canada-specific N_2O quantification approach, and the precedence it provides for the use of modifiers, is pertinent to the development of a quantification approach for the NERP. Like the national inventory, the NERP is concerned with influences on emissions that transcend the scale of individual fields or farms. The NERP is expected to be implemented in aggregated projects comprised of implementation data from hundreds (perhaps thousands) of farms. In such expansive aggregation, the uncertainty of the NERP quantification approach and in the reduction modifiers can be expected to match that of the Canada-specific approach, described in the National Inventory Report as follows:

> Uncertainties associated with N_2O emission estimates from synthetic nitrogen fertilizer applications result from uncertainties associated with estimates of nitrogen fertilizer sales (±20%), of EF_{BASE} (±25%), and of $RF_{TEXTURE}$, a ratio factor adjusting EF_{BASE} for soil texture (±30%). These terms and emission calculations are explained in the methodological Section A3.3. The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be ±21% and ±19%, respectively (Hutchinson *et al.* 2007).

2.1.3 Development of Reduction Modifiers

The participants of the Consultation Workshop reiterated a foundational element of N_2O emission quantification; namely, the complexity of factors controlling N_2O emissions in the landscape must be acknowledged in the derivation of N_2O emission reductions modifiers associated with the BMPs prescribed for the various levels of the NERP. That is, despite the general applicability of the N_2O reduction approach of the NERP, individual studies exist to contradict the NERP approach. Ellert and Janzen (2008) recently described the complexity of predicting N_2O emissions, pointing out the variability of N_2O emissions measured by flux chambers from plots subjected to differing management practices. Zebarth *et al.* (2008) measured the N_2O emissions associated with various rates and times of application of N fertilizer on corn, and concluded that "improved fertilizer N management may not result in reduced N_2O emissions under some conditions". Kachanoski (Pers. Comm.), assessing the relationship of N_2O emissions and yield response in fields receiving variable rate N application, reported significantly higher N_20 flux from locations with the highest yield response. In agreement with the scientific literature, then, the participants of the Consultation Workshop stress that general relationships between BMPs and N_2O emission reductions can be determined by expert judgment based on integration of empirical data, but that these relationships, and the modifiers derived from them, will not hold under all time- and site-specific circumstances. Thus, the development of reduction modifiers for the NERP is similar to the derivation of coefficients for the Canada's National Inventory Report; namely, general trends evident in empirical data can be applied to achieve conservative and generally accurate assessment of N_2O emissions and reductions.

2.2 Data to Support Reduction Modifiers

A comprehensive summary and analysis of scientific literature pertinent to the relationship between N management practices and N_2O emissions and reductions is provided in a literature review published by the International Plant Nutrition Institute, *Greenhouse Gas Emissions from Cropping Systems and the Influence of Fertilizer Management* (Snyder *et al.* 2007). A pertinent excerpt of this literature review, describing N_2O emissions associated with management practices in the context of the 4-R model, is appended to this document (Appendix 1). To emphasize the potential to reduce N_2O emissions using single BMPs, this document expands on the summary in the IPNI literature review and adds knowledge from other sources to address N_2O reductions associated with 'Right Rate', 'Right Time', and 'Right Place' performance areas.

2.2.1 Reductions Associated with 'Right Rate' Practices

Although the 4-R model stresses the importance of a comprehensive approach to N fertilizer management, the literature provides evidence that substantive reductions to N_2O emissions can be achieved by applying N at the Right Rate. As described in the IPNI literature review (Snyder *et al.* 2008 — Appendix 1), strategies to achieve Right Rate N application include proper soil testing, and addressing within-field variability of N requirements.

Further studies reinforce the need for detailed assessment of N requirements. In a presentation to the participants of the NERP Consultation Workshop on 28 October 2008, Lemke described the relationship of pre-thaw soil nitrate concentration (which is correlated to over-application of fertilizer N) to N_2O emission estimated at research sites in Alberta (Figure 1). The linear relationship described by these data predicts a decrease of about 9% in N_2O emissions (from 0.899 to 0.809 kg ha^{-1}) for a 10% decrease in soil nitrate (from 10 to 9 ppm). Mulvaney *et al.* (2006), comparing yield-based and soil test-based N recommendations on 102 corn farms, estimated 13% of farmers under-fertilized (by average of 60 kg N ha^{-1}) and 69% over-fertilized (by average of 103 kg N ha^{-1}). By applying N to corn at the economically optimal rate, Hong *et al.* (2007) measured a decrease of 11 kg ha^{-1} of residual soil N to a depth of 90 cm compared to that in fields receiving N rates typical for the midwestern US.

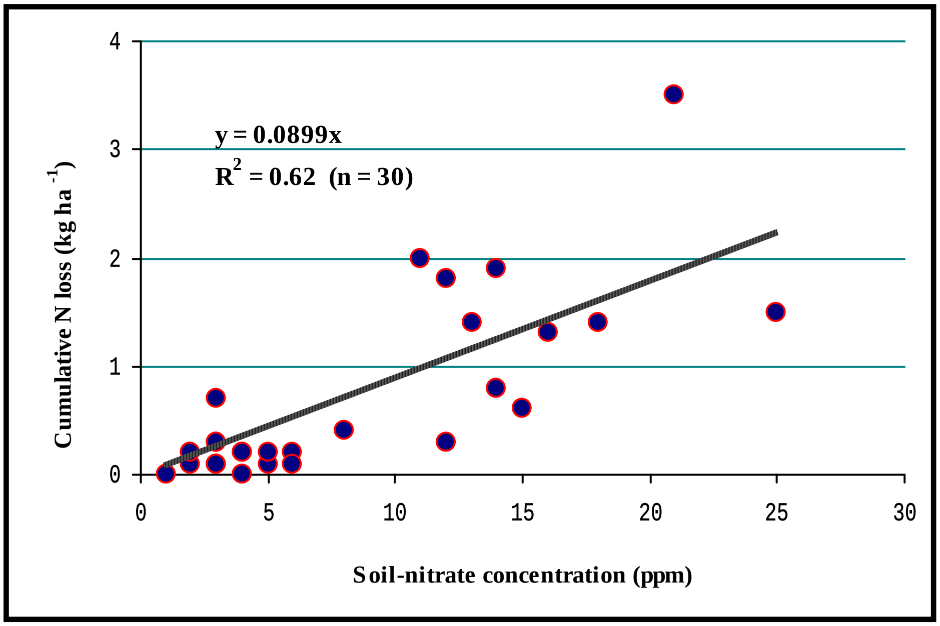

Figure 1. Mean "pre-thaw" soil-nitrate concentration vs. estimated N_2O-N loss at six locations in Alberta (Lemke Pers. Comm.).

Also, other studies have identified the need for within-field variability of N requirements to minimize potential for N losses associated with improper rate of N application. Raun *et al.* (2002) reported that when optical sensor technology was used to recommend in-season variable rate of N application to winter wheat, N use efficiency increased >15% compared to typical and uniform application N rates. In three years of production of irrigated corn in Colorado, Koch *et al.* (2004) determined a 'site-specific management zone-variable yield goal' approach to fertilizer recommendation required 6-46% less N than 'typical farmer uniform rates' to achieve comparable yields.

There is growing evidence that N_2O emissions can increase disproportionately when a threshold level of N fertilizer application is exceeded (Grant *et al.* 2006, Mahli *et al.* 2006). This potential for increased emissions at higher rate of N application, however, is not addressed in the Canada-specific N_2O quantification approach. And, it is likely that such excessive application of N will occur at 'hot spots' within fields, because of localized decrease in N uptake capacity (e.g.

eroded sectors), or because of localized increase in potential for N_2O emission (e.g. waterlogged sectors). Thus, it is likely that the landscape-directed application of N in the Intermediate and Advanced levels of the NERP may result in emissions reductions larger than can be attributed to a simple decrease in rate of N application.

2.2.2 Reductions Associated with 'Right Time' Practices

Lemke provided data to the participants of the NERP Consultation Workshop comparing N_2O emissions from soils receiving fertilizer in fall or spring (Table 2). On average in 36 Canadian studies, emissions from fall-applied fertilizer exceeded by about 25% the emissions from spring-applied fertilizer. Further evidence to support this relationship is reported in Hultgreen and Leduc (2003).

Table 2. Emissions of N_2O from N Fertilizer Applied in Fall or Spring as Compared in 36 Studies in Canada (from Lemke Pers. Comm.).

APPLICATION TIME	MEAN	GEOMETRIC MEAN
	g N_2O–N ha^{-1}	
Fall	503	269
Spring	405	212

Coated fertilizer products and nitrification inhibitors are considered as 'Right Time' BMPs, since these products regulate the timing of availability of N for crop uptake. It is clear these products can increase N use efficiency, and short term N_2O emissions have been reported to decrease but more testing is needed to accurately quantify the N_2O reduction associated with these products (Snyder *et al.* 2007).

2.2.3 Reductions Associated with 'Right Place' Practices

Although there may be more factors involved than just placement, it is important to note the Canada-specific quantification approach for N_2O quantification assigns a reduction modifier of 0.8 for N_2O emissions from soils managed under No Till in the Canadian Prairies (Rochette *et al.* 2008). Also, Hultgreen and Leduc (2003) measured generally higher N_2O emissions from surface-applied urea as compared to band placement.

Indirect evidence to support the efficacy of band placement as a practice to reduce N_2O emissions comes from assessment of the value of band placement for increasing crop yield — the logic here is that increased yield relates to increased uptake efficiency of N, which in turn corresponds to decreased accumulation of nitrate in the soil. The Alberta Fertilizer Guide states that band placement supports greater crop yield as compared to broadcast and incorporated (Table 3).

Table 3. The relative effectiveness (%) of methods and time of nitrogen application for increasing crop yield.

	Soil-climatic categories			
Method and time of application	**Dry**	**Medium**	**Wet** [b]	**Irrigated**
Spring broadcast and incorporated	100	100	100	100
Spring banded [a]	120	110	105	110
Fall broadcast and incorporated	90	75	65	95
Fall banded [a]	120	110	85	110

[a] Although spring and fall banded nitrogen were equally effective in research trials, fall banding may be more practical under farm conditions. The extra tillage associated with spring banding may dry the seedbed and reduce yields.

[b] In research trials conducted in the higher rainfall areas, spring broadcast nitrogen was well incorporated and seeding and packing completed within a short period of time. Under farm conditions, shallow incorporation or loss of seedbed moisture resulting from deeper incorporation may cause spring broadcasting to be somewhat less effective than shown here.

2.3 Case Study Relating to Assignment of Reduction Modifiers

This case study is based on an experiment conducted on a corn, soybean, winter-wheat rotation from May 2000 to April 2005 at the Elora Research Station near Guelph, Ontario. The data from the experiment are reported in two peer-reviewed articles, with one article focused on N_2O emissions (Wagner-Riddle *et al.* 2007) and the other addressing N use efficiency and nitrate leaching (Jayasundara *et al.* 2007). The experiment assesses "the combined effects of multiple BMPs", and thus is pertinent to development of the reduction modifiers needed for the NERP. The Conventional System used ploughing and disking and determined fertilizer application rate based on general recommendations for each crop. The Best Management System used No Till (initiated in May 1999), fertilizer application based on soil tests and timed to crop uptake, and a cover crop when possible. For the purpose of this document, the management practices of the experimental systems are tabulated according to the Right Product @ Right Rate, Tight Time Right Place™ model (Table 4).

The experiment used micrometeorological methods to measure N_2O emission in fields of 1.4 ha in area, and applied fertilizer ^{15}N to track N transformations, so continuous and cumulative assessments N use efficiency and of N_2O and NO_3^- dynamics were possible for the five-year study (Table 5).

Table 4. Case study practices for each year of the Conventional System and Best Management System characterized according to a 4-R framework.

	Conventional System	**Best Management System**
	Plough and disk, fertilize to OMAFRA recommendation	No Till, fertilize to soil test and allow N credit for crop residue
2000 (Corn)		
Product	Urea	Urea-ammonium-nitrate
Rate	150 kg N ha^{-1}	50 kg N ha^{-1}
Time	05 June (planting)	04 July (6-leaf stage)
Place	Broadcast and disk	Inject as sidedress

2001 (Soybean)		
Product	none	none
Rate	none	none
Time	none	none
Place	none	none
2002 (Winter Wheat)		
Product	Urea	Urea
Rate	90 kg N ha^{-1}	60 kg N ha^{-1}
Time	23 April (seeding)	23 April (seeding)
Place	Broadcast and disk	Broadcast and disk
2003 (Corn)		
Product	Urea	Urea-ammonium-nitrate
Rate	150 kg N ha^{-1}	60 kg N ha^{-1}
Time	15 May (planting)	02 July (6-leaf stage)
Place	Broadcast and disk	Inject as sidedress
2004 (Soybean)		
Product	none	none
Rate	none	none
Time	none	none
Place	none	none

In each year, the soil managed under Conventional system had (1) lower fertilizer N uptake efficiency, (2) higher mineral N at harvest, and (3) higher direct N_2O emissions. These data thus support the foundation of the NERP; namely, BMPs to ensure 4-R management of N are generally expected to increase nitrogen use efficiency, decrease mineral N during the non-growing season, and decrease direct N_2O emissions from agricultural soil. The mean 36% reduction of direct N_2O emissions in the Best management system (0.786 kg N_2O-N ha^{-1} yr^{-1}) compared to direct emissions from the Conventional system equates to a reduction of 0.38 tCO_2e ha^{-1} yr^{-1}.

Table 5. Case study data of N_2O emission reductions and associated measurements of nitrogen dynamics.

	Fertilizer N Uptake Efficiency[1]	Total Mineral N at Harvest[2]	Total Annual N_2O-N	Reduction of Direct N_2O Emission
	%	kg N ha^{-1}	kg N ha^{-1}	%
2000 (Corn)				
Conventional	24	142.4	2.429 (0.021)	
Best	65	78.4	1.822 (0.058)	25
2001 (Soybean)				
Conventional		53.2	1.100 (0.059)	
Best		28.9	0.964 (0.103)	12

2002 (Winter Wheat)				
Conventional	45	35.7	3.318 (0.352)	
Best	61	21.1	0.888 (0.016)	73
2003 (Corn)				
Conventional	40	63.9	2.677 (0.115)	
Best	58	42.7	2.176 (0.051)	19
2004 (Soybean)				
Conventional			1.442 (0.218)	
Best			1.187 (0.136)	NS
Mean (All crops 2000 through 2004)				
Conventional			2.193 (0.075)	
Best			1.407 (0.046)	36

1 Fertilizer N uptake efficiency is the percentage of fertilizer N recovered in the aboveground crop biomass during the growing season.

2 Total mineral N at harvest represents the total NH_4^+-N and NO_3^--N to a depth of 90 cm extracted with 2 M KCl.

The country-specific approach to quantifying N_2O emissions from agricultural soils includes indirect emissions (Rochette *et al.* 2008). One component of the indirect N_2O emissions are those originating from N leached out of the rooting zone. Jayasundara *et al.* (2007) calculated N loss by leaching from NH_4^+-N + NO_3^--N concentrations (originating from both fertilizer and soil N) in the drainage water at 80 cm depth and from estimates of drainage volume. Over the five years of the experiment, the total mineral leached from the Conventional System was 132.6 kg NO_3^--N ha^{-1}, while that from the Best System was 67.6 kg NO_3^--N ha^{-1}. Canada's country-specific quantification approach calculates indirect N_2O emissions from N leached as 0.025 kg N_2O-N per kg N. Using this emission factor, the total mineral N leached in five years from the Conventional system would result in indirect N_2O emissions of 1.61 tCO_2e ha^{-1}, and that leached from the Best System would create indirect N_2O emissions of 0.82 tCO_2e ha^{-1}. Thus, if mineral N leached to 80 cm is considered a source of indirect N_2O emissions, the data from Jayasundara *et al.* (2007) support the conclusion that Best System would reduce indirect N_2O emissions 0.164 tCO_2e ha^{-1} y^{-1}. If this average estimate of indirect emission reductions is added to the direct N_2O emission reductions associated with the Best Management System, the total reduction is 43% relative to the Conventional System.

The primary difference in management between the Conventional and Best systems involved more sophisticated practice to determine rate of N application. The total N fertilizer applied over the 5 growing seasons of the experimental period in the Conventional System (390 kg ha^{-1}) was substantially higher than that added in the Best Management System (170 kg ha^{-1}). The use of the cover clover crop and the greater yield of soybean in 2001 in the Best Management System indicate N input by biological fixation was lower in the Conventional System. And, the no till practice included in the Best Management System is considered to increase N_2Oemisisons per unit of N input by 10 % (i.e. RF_{Till} = 1.1 for eastern Canada), according to the Canada-specific N_2O quantification approach. Thus, more comprehensive and detailed analysis of the case study data are necessary to assess whether differences in rate of N application can account for all of the difference in N_2O emissions reported from the two management systems. Also, it is important to note that this case study did not include landscape-directed strategies for N management, and thus this case study represents only the Basic level of implementation of the NERP.

2.4 Revised Reduction Modifiers - NERP Prairie

This Decision Paper has reiterated the importance of rate of N application as a factor in controlling N_2O emissions from agricultural land in Canada. In addition, evidence has been presented to support the assertion that other fertilizer management practices, encompassed in the 4-R stewardship model, can contribute to mitigation of N_2O emissions. N_2O reductions from 10 to 20% associated with these BMPs of Right Product, Right Time, and Right Place are documented. However, the integrated contribution of the non-Right Rate BMPs in the suite of BMPs included in the levels of implementation of the NERP is not completely certain. Thus, it remains for the experts participating in the development of the NERP to seek consensus concerning appropriately conservative reduction modifiers for the Basic, Intermediate, and Advanced levels.

Although empirical evidence to address the N_2O emission reductions associated with a suite of integrated or stacked BMPs within each level of the NERP is lacking, reductions from individual BMPs have been quantified. Listing examples of the emission reductions from single BMPs illustrates the potential to achieve N_2O reductions in addition to simple rate-related reductions thorough implementation of the levels of the NERP (Table 6).

Table 6. 4-R N stewardship plans and BMP/Performance Levels for NERP Prairie

	Right Rate	Right Time	Right Place	Proposed Modifier[2]
Basic	• Decreased emission per lower N input, if assessment of N requirement leads to decreased N application.	• 20 to 25 % decrease in emissions associated with spring vrs fall application.	• About 10% decrease in emissions with band placement. • 20 % decrease in emissions associated with no till[3].	0.8
Intermediate	• Decreased emission per lower N input, if assessment of N requirement leads to decreased N application. • Potential for greater emission reduction if 'hot spots' eliminated by	• 20 to 25 % decrease in emissions associated with spring vrs fall application. • Potential for emission reduction with use of coated products and nitrification inhibitors.	• About 10% decrease in emissions with band placement. • 20 % decrease in emissions associated with no till.	0.7

[2] Proposed modifiers changed on the Webinar prior to voting – see below

[3] The Tillage System Management Protocol attributes offsets associated with lower N_2O emission associated with reduced till and no till. The potential for double counting of these offsets will be addressed in the development of final requirements of the NERP.

	landscape-directed N application.			
Advanced	• Decreased emission per lower N input, if assessment of N requirement leads to decreased N application. • Potential for greater emission reduction if 'hot spots' eliminated by landscape-directed N application.	• 20 to 25 % decrease in emissions associated with spring vrs fall application. • Potential for emission reduction with use of coated products and nitrification inhibitors.	• About 10% decrease in emissions with band placement. • 20 % decrease in emissions associated with no till	0.7

WEBINAR RESULTS:

INITIAL PROPOSAL:

> **Decision point 2.4.a:** The appropriate reduction modifier for the Basic Level of the NERP Prairies is 0.8.

MODIFIED PROPOSAL AFTER DISCUSSION:

> **Decision point 2.4.a:** The appropriate reduction modifier for the Basic Level of the NERP Prairies is **0.85.**
>
> Agree __16___ Disagree __2___

Total Voting: 18
89% Agree

OUTCOME:
Consensus achieved - that the Basic NERP Modifier for the Prairies is **0.85**.

INITIAL PROPOSAL:

> **Decision point 2.4.b:** The appropriate reduction modifier for the Intermediate Level of the NERP Prairies is 0.7.

MODIFIED PROPOSAL AFTER DISCUSSION:

> **Decision point 2.4.b:** The appropriate reduction modifier for the Intermediate Level of the NERP Prairies is **0.75**.
>
> Agree ___14__ Disagree __4___

Total voting: 18
78% Agree[4]

OUTCOME:
Consensus achieved - that the Intermediate NERP Modifier for the Prairies is **0.75**.

INITIAL PROPOSAL:

Decision point 2.4.c: At present, the reduction modifier for the Advanced Level of the NERP Prairies should be the same as the Intermediate reduction modifier. Agree __14___ Disagree __4___

Total voting: 18
78% Agree[5]

OUTCOME:
Consensus achieved – that the advanced and intermediate level be **the same**.

To promote the development of reduction modifiers of greater accuracy and precision, the NERP Team urges all levels of government and all participants in the fertilizer sector to encourage research concerning the quantification of N_2O emissions under conditions of the 'stacked' BMPs of the NERP, particular with respect to the more landscape-specific 4-R stewardship plans and BMPs characterizing the Intermediate and Advanced levels of implementation.

3. Reduction Modifiers and BMPs for NERP Humid

Although the 4-R framework and three levels of implementation of the NERP is expected to be universally applicable, the BMPs in the original version of the NERP are focused on reduction of N_2O in cereal and oil seed crops of the Canadian Prairies ('NERP Prairies'). To initiate development of the NERP Humid, three levels of implementation are presented with BMPs and place-holder reduction modifiers (similar to the Table 9).

---

[4] Note, when the polling was done by phone 14% disagreed. When the nature of the disagreement was investigated post Webinar call, it was determined that several scientists thought the intermediate/advanced modifier too conservative. On this basis the Steering Committee made the decision that 78% consensus was adequate to accept the 0.75 modifier.

[5] Note, when the polling was done by phone 14% disagreed. When the nature of the disagreement was investigated post Webinar call, it was determined that several scientists thought the intermediate/advanced modifier too conservative. On this basis the Steering Committee made the decision that 78% consensus was adequate to accept the 0.75 modifier.

To design the NERP Humid, two fundamental differences between the Prairies and the humid regions of Canada must be acknowledged in the choice of BMPs. First, fall application of N fertilizer is NOT part of normal practice, and would therefore be eliminated during an assessment of baseline conditions in any case. Second, N soil tests seem to be much less reliable at predicting N requirements of crops in humid than in sub-humid areas.

Also, it may be more important to prescribe manure management practices in NERP Humid than in NERP Prairies, since some estimates put the amount of manure N in Ontario equal to the fertilizer N applied. The inclusion of manure has been limited to accounting for it in the rate calculations, and applying a restriction on time of application.

Table 7. 4-R N stewardship plans and BMP/Performance Levels for NERP Humid.

	Right Product	Right Rate	Right Time	Right Place	Proposed Modifier
Basic	Ammonium-based formulation.	Apply N according to recommendation of 4-R N stewardship plan*, using annual soil testing** and/or N balance to determine application rate.	Apply fertilizer in spring, or split apply. Apply liquid or solid manure in spring or after soil cools in fall	Apply in bands	0.8
Intermediate	Ammonium-based formulation	Apply N according to 4-R N stewardship plan*, modified by qualitative estimates of field variability (landscape position, soil variability)	Apply fertilizer or liquid manure in spring, or split apply. Apply solid manure in spring or after soil cools in fall	Apply in bands	0.7
Advanced	Ammonium-based formulation. Use slow / controlled release fertilizers or inhibitors or stabilized nitrogen.	Apply N according to 4-R N stewardship plan*, modified by quantified field variability (e.g. digitized soil maps, grid sampling, satellite imagery, real time crop sensors.), and complemented by in season crop monitoring	Apply controlled release fertilizer or inhibitor / stabilized nitrogen fertilizer or liquid manure in spring, or split apply. Apply solid manure in spring or after soil cools in fall.	Apply in bands	0.7

*4-R N Stewardship Plan must account for all sources of N, including previous crop residues, fertilizer, manure or biosolids applications. Plan also prescribes assessment of N in crop, so this serves to supplement or replace information from soil testing.
**where appropriate for the crop, and calibration data is available

WEBINAR RESULTS:

Decision point 3a: The BMPs listed in Table 7 are appropriate for the levels of implementation of the NERP Humid.

Agree __13___ Disagree __3___

Total voting: 16
81% Agree

OUTCOME:
Consensus achieved – Table 7 is appropriate for the NERP humid.

INITIAL PROPOSAL:

Decision point 3b: The appropriate reduction modifier for the Basic Level of the NERP Humid is 0.8.

MODIFIED PROPOSAL AFTER DISCUSSION:

Decision point 3b: The appropriate reduction modifier for the Basic Level of the NERP Humid is **0.85**. Agree __14___ Disagree ___2__

Total voting:
88% Agree

OUTCOME:
Consensus achieved - that the Basic NERP Modifier for Humid soils is **0.85**.

INITIAL PROPOSAL:

Decision point 3c: The appropriate reduction modifier for the Intermediate Level of the NERP Humid is 0.7.

MODIFIED PROPOSAL AFTER DISCUSSION:

Decision point 3c: The appropriate reduction modifier for the Intermediate Level of the NERP Humid is **0.75**. Agree __13___ Disagree ___3__

Total voting: 16
81% Agree

OUTCOME:
Consensus achieved - that the Intermediate NERP Modifier for Humid soils is **0.75**.

Decision point 3d: At present, the reduction modifier for the Advanced Level of the NERP Humid should be the same as the Intermediate reduction modifier.

Agree __9___ Disagree __5___

Total voting: 14
64% Agree

Steering Committee Decision – to accept this as consensus since it is consistent with the previous question in NERP Humid. After discussion with Committee members, many felt that there should be a difference between intermediate and advanced, advanced being higher, but that there is not enough science-base evidence to support an 'Advanced' level of management as described in the BMPs

OUTCOME:
Move forward as an accepted decision that intermediate and advanced be one performance level for now but that the Advanced level would serve as a placeholder when more evidence is available to support the rate and form improvements (precision application and controlled release products).

4. Regional N_2O Emission Factors — Provided by Devon Worth and Ray Desjardins, Agriculture and Agri-Food Canada

At the Consultation Workshop, the working group was tasked with determining the appropriate level of emission factor application. In the methods used for the national inventory accounting, researchers from Agriculture and Agri-Food Canada, along with Devon worth and Ray Desjardins, integrate the site-specific controls on N_2O emission to provide EcoDistrict-level factors (EF_{eff}) for the agricultural regions of Canada. The EcoDistrict–level EF_{eff} values are tabulated in an Excel workbook file, Soil N2O Emission Factors.xls. The EF_{eff} were calculated from the database used to estimate nitrous oxide emissions from agricultural sources in Canada as a part of Canada's National Inventory Report, 1990-2007.

Ecodistricts have relatively homogenous biophysical and climatic conditions and have an average area of approximately 150,000 ha (see http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html for more details). They have been consistently used as a common analytical unit in Agri-Environmental Indicators work at a national level. There are about 1,000 Ecodistricts across Canada, of which about 400 are considered agricultural. Consistent with the methodology used in the National Inventory Report, any Ecodistrict that crosses a provincial boundary has been subdivided along that boundary.

Provincial Designations are as follows:

Provincial Abbreviation	Province
NF	Newfoundland and Labrador
PE	Prince Edward Island
NS	Nova Scotia
NB	New Brunswick
PQ	Québec
ON	Ontario
MB	Manitoba
SK	Saskatchewan
AB	Alberta
BC	British Columbia

Geographic location of Ecodistricts can be determined through the online tool located at: http://nlwis-snite1.agr.gc.ca/eco/index.phtml?lang=en-CA.

Explanation of Data Columns in File: Soil N2O Emission Factors.xls

P/PE: This is the average (1970-2000) ratio of precipitation to potential evapotranspiration (expressed as mm/mm or unitless) for the growing season (May to October).
$Frac_{Leach}$: This is the fraction of nitrogen (expressed as % of available N) that is estimated to be lost through leaching and runoff. This value is estimated as a function of the P/PE ratio as follows. $Frac_{Leach}$ = 0.3247*P/PE-0.00247. $Frac_{Leach}$ cannot be lower than 5% or higher than 30%.
EF_{base}: This is the average base nitrous oxide emission factor (expressed as kg of N_2O-N per kg of N) that is estimated as a function of the P/PE ratio as follows: EF_{base} = 0.022*P/PE – 0.0048. EFbase reaches a minimum possible value of about 0.0016 kg N_2O-N per kg N when P/PE = 0.23 and reaches a maximum possible value of about 0.017 kg N_2O-N per kg N when P/PE = 1.0.
EF_{eff}: This is the "effective" nitrous oxide emission factor (expressed as kg N_2O-N per kg N), once consideration for position in the toposequence, irrigation, tillage and soil texture has been accounted for. Factors that affect soil moisture, such as the fraction of area in an Ecodistrict that falls in a low position in the toposequence and the fraction of area that is irrigated, are accounted for by weighting the area that they occupy with the maximum base emission factor of 0.0168 kg N_2O-N per kg N. Factors that affect the rate of N_2O emissions such as tillage practices and soil texture are accounted for by calculating Ratio Factors (RFs) that weight the amount of area in an Ecodistrict subject to a tillage practice or soil texture that can influence N_2O emissions.

This can be summarized mathematically as follows:

$$EF_{eff} = \left[\left(0.0168 \times \frac{A_{irrig} + A_{low}}{A_{ag}}\right) + \left(EF_{base} \times \frac{A_{ag} - A_{irrig} - A_{low}}{A_{ag}}\right)\right] \times RF_{till} \times RF_{text}$$

Where,

A_{irrig} = irrigated area in an Ecodistrict (ha)
A_{low} = low lying area in an Ecodistrict (ha)
A_{ag} = total agricultural area in an Ecodistrict (ha)
RF_{till} = ratio factor for tillage (unitless)
RF_{text} = ratio factor for soil texture (unitless)

The ratio factor for tillage can be determined as follows:

$$RF_{till} = \left[\frac{A_{NT}}{A_{NT} + A_{MT} + A_{CT}}\right] \times C_{NT} + \left[\frac{A_{MT}}{A_{NT} + A_{MT} + A_{CT}}\right] \times C_{MT} + \left[\frac{A_{CT}}{A_{NT} + A_{MT} + A_{CT}}\right] \times C_{CT}$$

Where,

A_{NT} = area in an Ecodistrict under no-tillage (ha)
A_{MT} = area in an Ecodistrict under minimum tillage (ha)
A_{CT} = area in an Ecodistrict under continuous tillage (ha)
C_{NT} = tillage coefficient for no-tillage, 0.8 for chernozemic soils under no-tillage in western Canada, 1.0 for all other soils under no-tillage in western Canada (Manitoba and west), 1.1 for all soils under no-tillage in eastern Canada (Ontario and east).
C_{MT} = tillage coefficient for minimum tillage, 0.8 for chernozemic soils under no-tillage in western Canada, 1.0 for all other soils under no-tillage in western Canada (Manitoba and west), 1.1 for all soils under no-tillage in eastern Canada (Ontario and east).
C_{CT} = tillage coefficient for all soils under no-tillage conventional tillage, 1.0 for all soils nationwide.

The ratio factor for texture can be determined as follows:

$$RF_{text} = \left[\frac{A_{C}}{A_{C} + A_{M} + A_{F}}\right] \times C_{C} + \left[\frac{A_{M}}{A_{C} + A_{M} + A_{F}}\right] \times C_{M} + \left[\frac{A_{F}}{A_{C} + A_{M} + A_{F}}\right] \times C_{F}$$

Where,

A_C = area in an Ecodistrict of annually cultivated soils with a coarse soil texture (ha)
A_M = area in an Ecodistrict of annually cultivated soils with a medium soil texture (ha)
A_F = area in an Ecodistrict of annually cultivated soils with a fine soil texture (ha)
C_C = texture coefficient for coarse soils, 0.8 for all soils in eastern Canada (Ontario and east), 1.0 for all of western Canada (Manitoba and west)
C_M = texture coefficient for medium soils, 1.0 for all soils in eastern Canada (Ontario and east), 1.0 for all of western Canada (Manitoba and west)

C_F = texture coefficient for fine soils, 1.2 for all soils in eastern Canada (Ontario and east), 1.0 for all of western Canada (Manitoba and west)

WEBINAR RESULTS:

PROPOSAL:

Decision point 4: The ecodistrict-level emission factors as listed in the accompanying Excel workbook are appropriate for the NERP Prairie and Humid.

Agree __13___ Disagree __1___

Total voting: 14
93% % Agree[6]

OUTCOME:
Consensus achieved – ecodistrict level emission factors are appropriate.

NOTE: The EF_{eff} values received from Worth and Desjardins integrate natural controls (topography, texture) as well as management controls (tillage, irrigation) on N_2O emissions. To increase the site-specific flexibility and applicability of the NERP, Worth and Desjardins have agreed to provide the Canada Census data necessary to separate the influence of natural and management controls on EF_{eff}. These revisions are expected before the end of the Phase 3 development of the NERP, and will be incorporated in the NERP during the final approval process for the Alberta Offset System.

Performance Standard Baseline: In the interaction with the Agriculture and Agri-Food Canada researchers, the possibility has emerged to determine the predicted N_2O emissions for various crops in the ecodistricts of Canada. If this ecodistrict-level estimation of crop-specific N_2O emissions is available, the NERP Team could consider developing a Performance Standard baseline in alternative to the currently required farm-specific baseline using three years of management data for each crop on the farm. Worth and Desjardins are willing to attempt this estimation, but they are unable to complete such an undertaking until after the Phase 3 efforts of the NERP development.

5. Resolution of 'Banding' or 'Concentrated Nitrogen Placement' Issue

The participants of the Consultation Workshop determined that further explanation was required concerning the BMP of applying fertilizer in bands. The Technical Working Group has considered this issue, and has developed the following recommendations for decisions.

[6] Responses coordinated by email.

The rationale for fall application is that when fertilizer is applied in bands in the soil, the chemical conditions associated with the concentrated placement of fertilizer inhibits microbial activity, and thus slows or prevents mineralization to nitrate of the applied ammonium-based nitrogen. The challenge is to define the various types of fertilizer application which can achieve banded or concentrated placement of ammonium-based fertilizer.

Seedbed Utilization (SBU)

Seedbed Utilization (SBU) can be used as a measure of the fertilizer band concentration. The width of fertilizer, relative to the row spacing, reflects the relative concentration of fertilizer in the band (Table 8). The lower the SBU, the more concentrated is the fertilizer band. Whereas, for the maximum safe rates of nitrogen fertilizer application at the time of seeding without damage to crop seedlings, the higher the SBU, the more fertilizer that can safely be applied with the seed. For example a 7.5 cm spread with a 15 cm row spacing is 50% SBU (7.5/15 x 100 = 50%).

Table 8. Seed Bed Utilization for Fertilizer Application

	Width of spread of fertilizer in the row [a]											
	2.5 cm			5.0 cm			7.5 cm			10.0 cm		
	(Disc or knife)			(Spoon or hoe)			(Sweep)			(Sweep)		
Row spacing (cm)	15	23	30	15	23	30	15	23	30	15	23	30
Seed bed utilization (SBU)[b]	17%	11%	8%	33%	22%	17%	50%	33%	25%	67%	44%	33%

[a] The width of spread of fertilizer and seed depends on the type of opener, soil type and moisture content, air flow, etc. Some openers give less than 2.5 cm (1") spread (e.g., double disc).

[b] SBU (Seed bed Utiation) is the width of spread of fertilizer and seed relative to the row spacing. For example a 7.5 cm spread with a 15 cm row spacing is 50% SBU (7.5/15 x 100 = 50%). If the same rate of fertilizer is applied with a 7.5 cm spread and a 30 cm row spacing, the concentration of fertilizer in the seed row is doubled (7.5/30 x 100 = 25% SBU). Some openers spread seed and fertilizer vertically. SBU does not take vertical spread into account.

WEBINAR RESULTS:

NO VOTE - REQUIRES MORE WORK

Decision point 5: The Seedbed Utilization value of 33% or less provides sufficient horizontal concentration of fertilizer to constitute a band placement.

Agree __x___ Disagree ___x__

6. Determine Verifiable Definition of ‘Fall’ Application

The participants of the Consultation Workshop pointed out that further explanation was required concerning the BMP of applying fertilizer in the fall “after the soil cools”. The plenary at the Workshop recommended that a 10 °C soil temperature threshold was a ‘safe’ fall application temperature. The Technical Working Group was tasked with how to implement this recommendation. The Technical Working Group has considered this issue, and has developed the following recommendations for decisions.

The rationale for fall application is that microbial activity slows with decrease of soil temperature, and thereby mineralization to nitrate of the applied ammonium-based nitrogen is minimized or prevented in a ‘cool’ soil. The challenge is to determine a soil temperature at which soil microbial activity is sufficiently slowed, but which allows sufficient time to complete applications before onset of winter.

Based on existing agronomic recommendation for the Prairies, and supported by peer-reviewed science (Tiessen *et al.* 2008), the Technical Working Group recommends 10 °C as the threshold soil temperature. This soil temperature is agreed to represent a condition which generally occurs when soils are beginning to cool in fall, but also provides sufficient time to complete fall fertilizer application.

Although a best practice for the NERP may be to encourage farmers to measure soil temperature, the Technical Working Group also recommends an alternative to actual on-farm measurement of fall soil temperatures. This approach involves (1) using an empirical relationship to predict soil temperature based on sir temperature, and (2) assigning dates for which soil temperatures are predicted to decrease to 10 °C in the different EcoRegions of the Prairies.

Two different equations, which provide similar results, are available to describe the relationship between air temperature and soil temperature:

Equation1:

- From data collected footslope position of low relief hummocky moraine in the Black soil zone E of Edmonton to predict soil temp at 5 cm as a function of air temperature (Tom Goddard, Personal Communication).
- Derived from monthly means for 2 years, with soil temperatures taken every 20 minutes and averaged for the hour.
- Y = 0.8079X + 0.0032 (R^2 =0.97)
  Where, Y is the predicted soil temperature; and
  X is the measured air temperature.

Equation 2:

- From data collected in Alaska in soils where soil T_{ave} > 0 (Zheng *et al.* 1993).
- Derived from daily temperatures.
- Y = 0.99X - 1.40 (R^2 = 0.86)
  Where, Y is the predicted soil temperature; and
  X is the measured air temperature.

The Technical Working Group asked Devon Worth and Ray Desjardins of Agriculture and Agri-Food Canada to map the dates at which soil temperatures are predicted to decrease to 10 °C in the different ecoregions of the Prairies. Worth and Desjardin used 30-year average temperature data from Environment Canada to predict the date when soil temperature declines and remains at or below 10 °C for three consecutive days in each agricultural ecodistrict in the Canadian Prairies. They then derived the weighted average dates for the ecoregions according to the areas of ecodistricts in the ecoregions (Figure 2).

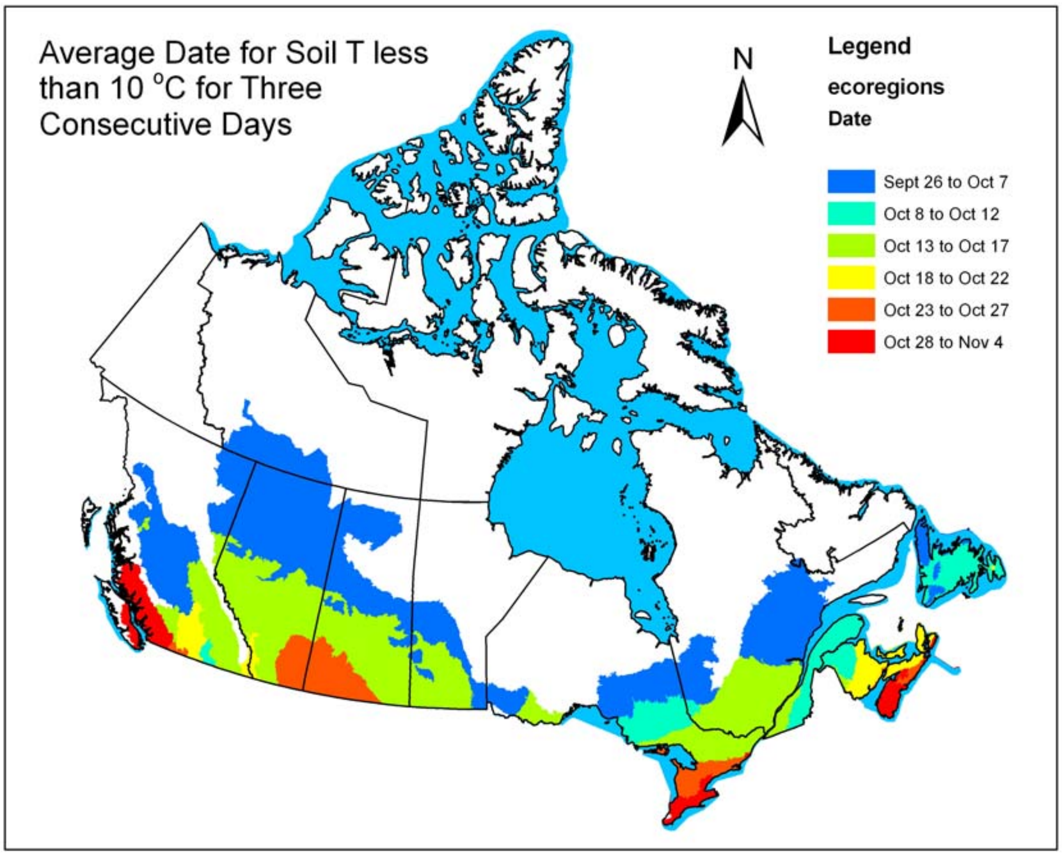

Figure 2. Soil temperature map to indicate day of year (DOY) at which soils can be considered sufficiently cool to allow fall application of fertilizer under the requirements of the NERP. Provided by Devon Worth and Ray Desjardins of Agriculture and Agri-Food Canada.

WEBINAR RESULTS:

PROPOSAL:

Decision point 6: The ecoregion-level of soil temperature map (Figure 2) provides a verifiable method to define the time after which fall banding is allowable under the requirements of the implementation levels of the NERP.

Agree __11___ Disagree ___3__

Total voting: 14
80% Agree

OUTCOME:
Consensus achieved – the map provides a way for verifiers to ensure that the requirements of the NERP have been met.

7. Preliminary Steps to Increase Capacity of Professional Advisors

The participants of the NERP Consultation Workshop agreed that a qualified professional should be involved in designing and implementing the 4-R N stewardship plans of the NERP. If such professionals signed off on the plans, subsequent verification could rely on the assurance of the professional rather than examining each individual plan. The International Plant Nutrition Institute (IPNI), with the Canadian Fertilizer Institute (CFI) and The Fertilizer Institute (TFI), is developing and distributing information resources to train Certified Crop Advisors and other professional farm advisors concerning the application of 4-R Best Management Practices (BMPs). The preparation and delivery of these professional development initiatives are included in this Decision Paper for the information of the scientific experts.

7.1 Introduction of 4-R Stewardship Strategy to Certified Carbon Advisors

To instruct to advisors who will design and validate the N stewardship plans for the NERP, IPNI is developing a series of articles for Crops and Soils[7], a publication of the American Society of Agronomy. Each article will include a self study quiz, worth one Continuing Education Unit (CEU) (Table 9).

The following excerpt from Paul Fixen of IPNI describes the project:

> This project will generate a series of five or possibly six articles on fertilizer best management practices structured around the 4 R strategy — application of the right source at the right rate, at the right time, and in the right place. The Certified Crop Adviser (CCA) will be the primary audience. The objective of the series is to increase the 4 R comfort level of the CCA to the point where it becomes an automatic part of his or her thought process as existing fertilizer practices or products are being reviewed or new practices or products are being considered. The focus will be on concepts behind practices rather than practices themselves. A sixth article on tools for implementation of the 4 R strategy might be added by Tom Jensen (IPNI).
> All articles will be reviewed and the word count needs to be at least 2,000 words but not more than 2,500 for one CEU. Quiz needs to be 10, multiple choice questions with 4 choices. No T/F or all of the above questions are accepted.

---

[7] *Crops & Soils*, the magazine of choice for practicing professionals in agronomy, crops, and soils, is published six times a year. It focuses on solutions to the daily challenges facing those working in the field and features information on new technology and products, company strategies, CEU articles and quizzes, and regulatory and industry news. *Crops & Soils* is a benefit for all holding CCA, CPAg, CPSS, and CPSC certifications.

The International Plant Nutrition Institute (IPNI) will publish the complete set as a collection of reprints from the Crops and Soils series. The project is being sponsored jointly by The Fertilizer Institute (TFI) and the Canadian Fertilizer Institute (CFI) through an agreement between the American Society of Agronomy and the sponsors. The time table for preparation and publication of the articles follows.

Table 9. Know Your Fertilizer Rights: A series of articles developed by IPNI for *Crops and Soils*. From Paul Fixen, IPNI.

Title	Authors	Due Brook.	Due ASA	Comments
Know Your Fertilizer **Rights**	Tom Bruulsema (IPNI), Jerry Lemunyon (NRCS), Bill Herz (TFI)	1/23/09	2/1/09 March issue	General concept and relevance in working with clients & communicating with public. Explain how rights cannot be considered independently but will be treated singularly in this series to facilitate organization of content. Could link article to the story on the FAR/IPNI CIG project on BMPs.
Know Your Fertilizer Rights: Right **Source**	Greg Schwab (U of KY), Gylles Randall (U of MN), Rob Mikkelsen (IPNI)	3/15/09	4/1/09 May issue	Start with an explanation of how the rights cannot be considered independently but are treated singularly in this article series to facilitate organization of content.
Know Your Fertilizer Rights: Right **Rate**	Dale Liekam (FFF), Jim Camberato (Purdue), Steve Phillips (IPNI)	5/15/09	6/1/09 July issue	Start with an explanation of how the rights cannot be considered independently but are treated singularly in this article series to facilitate organization of content.
Know Your Fertilizer Rights: Right **Time**	Mark Alley (VT), John Sawyer (ISU), Mike Stewart (IPNI)	7/15/09	8/1/09 Sept. issue	Start with an explanation of how the rights cannot be considered independently but are treated singularly in this article series to facilitate organization of content.
Know Your Fertilizer Rights: Right **Place**	Tony Vyn (Purdue), Guy Lafond (AAFC), Scott Murrell (IPNI)	9/15/09	10/1/09 Nov. issue	Start with an explanation of how the rights cannot be considered independently but are treated singularly in this article series to facilitate organization of content.

7.2 Resources to Develop 4-R Stewardship Plan for the NERP

The Canadian Fertilizer Institute and the International Plant Nutrition Institute are cooperating to develop resources to help professional crop advisors to apply the principles and BMPs of the 4-R stewardship strategy for reduction of nitrous oxide emissions from cereals and oil seed crops in western Canada (Table 10).

Table 10. Guidance documents from Canadian Fertilizer Institute to implement the 4-R nutrient stewardship framework in the N stewardship plans for the NERP.

Title	Comments
A Guide to Implementing the 4-R Nutrient Stewardship Framework for Sustainability	Provides steps to follow when developing a nutrient management plan using the 4-R nutrient stewardship framework for sustainability. Step One, identify economic, social, and environmental goals specific to each field and operation. Step Two, select BMPs that are specific to the soil, climate, cropping system, and goals identified by the grower — the guide provides additional suggestions to consider for each of the 4-Rs. Step three, integrate BMPs for all goals and adjust as needed. Step Four, document the 4-R nutrient management plan.
4-R Nutrient Management Plan — Worksheet For Crop Advisors	Provides template to assist in gathering information to develop a nutrient management plan for a field. The template prompts advisors to identify various sustainability goals, to describe boundaries and to set target yields for sub-fields, and to list the 4-R BMPs to be implemented for management of NPKS.
4-R Sustainability Goals	Assists advisor and grower to select sustainability goals for each field, according to a reference guide. The reference guide identifies and describes the various types of economic, social, and environmental goals the grower might select for a field. Addressing losses of N_2O is one type of environmental goal available to the grower.
4-R Nutrient Management Best Management Practices (BMPs) — Goal: Reduce Nitrous Oxide Emissions	Describes in detail the BMPs for each of the 4-Rs prescribed for the three levels of implementation to achieve the goal of reducing nitrous oxide emissions from cereal and oil seed crops in western Canada. Using this format emphasizes the crop- and region-specific nature of the listed BMPs and introduces the intention to develop guides for other crops and for other regions. This guide also tabulates the BMPs and proposed reduction factors corresponding to each of the three implementation levels of the NERP.

8. References (including references cited in Appendix 1)

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: 6-1 to 6-13.

Breitenbeck, G.A and J.M. Bremner. 1986b. Effects of rate and depth of fertilizer application on emission of nitrous oxide from soil fertilized with anhydrous ammonia. Biol. Fert. Soils 2:201–204.

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.

Drury, C.F., W.D. Reynolds, C.S. Tan, T.W. Welacky, W. Calder, and N.B. McLaughlin. 2006. Emissions of nitrous oxide and carbon dioxide: Influence of tillage type and nitrogen placement depth. Soil Sci. Soc. Am. J. 70:570–581.

Ellert, B. H. and H. H. Janzen. 2008. Nitrous oxide, carbon dioxide and methane emissions from irrigated cropping systems as influenced by legumes, manure and fertilizer. Can. J. Soil Sci. 88: 207-217.

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.

Hong, N., P.C. Scharf, J.G. Davis, N.R. Kitchen, and K.A. Sudduth. 2007. Economically optimal nitrogen rate reduces soil residual nitrate. Journal of Environmental Quality. 36:354-362.

Hultgreen, G. and P. Leduc. 2003. The Effect of Nitrogen Fertilizer Placement, Formulation, Timing, and Rate on Greenhouse Gas Emissions and Agronomic Performance. Final Report, Project No. 5300G, ADF#19990028, Saskatchewan Department of Agriculture and Food, Regina, SK. http://www.agr.gov.sk.ca/apps/adf/adf_admin/reports/19990028.pdf.

Hutchinson, J. J., B.B. Grant, W. N. Smith, R. L. Desjardins, C. A. Campbell, D. E. Worth, and X.P. Vergé. 2007. Estimates of direct nitrous oxide emissions from Canadian agroecosystems and their uncertainties. Can. J. Soil Sci. 87: 141–152.

Jayasundara, S. C. Wagner-Riddle, G. Parkin, P. von Bertoldi, J. Warland, B. Kay, P. Voroney. 2007. Minimizing nitrogen losses from a corn–soybean–winter wheat rotation with best management practices. Nutr. Cycl. Agroecosyst. 79: 141-159.

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 Accessed 7 August 2007.

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 , verified August 10, 2007)

Kachanoski, G. Personal Communication. Based on presentation to the 2006 ASA Meetings, Indianapolis. Field Scale Spatial Covariance of Nitrous Oxide Emissions and Crop Yield Response to Applied N Fertilizer.

Koch, B., R. Khosla, W. M. Frasier, D. G. Westfall, and D. Inman. 2004. Economic Feasibility of Variable-Rate Nitrogen Application Utilizing Site-Specific Management Zones. Agron. J. 96:1572-1580.

Legg, J.O. and J.J. Meisinger. 1982. Soil nitrogen budgets. p. 503-566. *In* F.J. Stevenson (ed.) Nitrogen in Agricultural Soils. Agron. Monogr. 22. ASA, CSSA, and SSSA. Madison, WI.

Lemke, R. Personal Communication. Based on presentation to the 2008 Nitrous Oxide Emission Reduction Protocol Consultation Workshop, Calgary. IPCC Methodology and International Guidance on Nitrous Oxide Reduction; Canada's Quantification Approach.

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.

Matson, P.A., R. Naylor, and I. Ortiz-Monasterio. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. Science 280: 112-115.

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.

Mosier, A.R., A.D. Halvorson, C.A. Reule, and X.J. Liu. 2006. Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. J. Environ. Qual. 35:1584–1598.

Mulvaney, R. L., S. A. Khan, and T. R. Ellsworth. 2006. Need for a Soil-Based Approach in Managing Nitrogen Fertilizers for Profitable Corn Production. Soil Sci Soc Am J 70:172-182.

National Inventory Report, Greenhouse Gas Sources and Sinks in Canada (1990-2006). 2008. Greenhouse Gas Division, Environment Canada. http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/tdm-toc_eng.cfm.

Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, R.W. Mullen, K.W. Freeman, W.E. Thomason, and E.V. Lukina. 2002. Improving Nitrogen Use Efficiency in Cereal Grain Production with Optical Sensing and Variable Rate Application. Agron. J. 94:815–820.

Rochette, P., D.E. Worth, E.C. Huffman, J.A. Brierley, B.G. McConkey, Jingyi Yang, J.J. Hutchinson, R.L. Desjardins, R. Lemke, and S. Gameda. 2008. Estimation of N_2O emissions from agricultural soils in Canada. II. 1990-2005 Inventory. Can. J. Soil Sci. 88: 655-669.

Sehy, U., R. Ruser, and J.C. Munch. 2003. Nitrous oxide fluxes from maize fields: relationship to yield, site-specific fertilization, and soil conditions. Agricultural Ecosystems and Environment. 99: 97–111.

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.

Thornton, F.C. and R.J. Valente. 1996. Soil emissions of nitric oxide and nitrous oxide from no-till corn. Soil Sci. Soc. Am. J. 60:1127–1133.

Tiessen, K., D. Flaten, P. Bullock, C. Grant, R. Karamanos, D. Burton, and M. Entz. 2008. Interactive effects of landscape position and time of application on response of spring wheat to fall-banded urea. Agronomy Journal. 100: 557-563.

Wagner-Riddle, C., A. Furon, N.L. Mclaughlin, I. Lee, J. Barbeau, S. Jayasundara, G. Parkin, P. von Bertoldi, and J. Warland. 2007. Intensive measurement of nitrous oxide emissions from a corn–soybean–wheat rotation under two contrasting management systems over 5 years. Global Change Biology. 13: 1722-1736.

Zebarth, B. J., P. Rochette, D. L. Burton, and M. Price. 2008. Effect of fertilizer nitrogen management on N_2O emissions in commercial corn fields. Can. J. Soil Sci. 88: 189-195.

Zheng, D, Hunt, E.R and Running S.W. 1993. A daily soil temperature model based on air temperature and precipitation for continental applications. Clim. Res. 2: 183-191.

9. Appendix — Excerpt from IPNI Literature Review (Snyder *et al.* 2007). The figures referenced in this excerpt are not shown.

• N Rate Impact on N_2O Emissions from Soil

NO_3-N can accumulate in soils when the N rate exceeds crop demand and the point of crop response (Legg and Meisinger, 1982). Use of appropriate N rates can help minimize soil accumulation of NO_3-N. Jaynes and Karlen (2005) noted that merely cutting applied N rates to reduce the potential for increases in residual soil NO_3-N is not considered an appropriate management action because N rates below the economic optimum could result in "mining" of SOC and cause a decline in long-term soil productivity.

In a 3-year study in southwest Michigan with corn comparing split-applied, injected UAN or post-emergence, surface broadcast granular urea at rates from 0 to 292 kg N/ha (9 rates), N_2O emissions were measured biweekly (McSwiney and Robertson, 2005). The authors reported grain yields (5 to 9 t/ha, depending on the year) were maximized with 101 kg N/ha, which also resulted in moderately low emissions (ca. 20 g N_2O-N/ha/day. At N rates above 134 kg N/ha, N_2O emissions were observed to increase sharply to about 450 g N/ha/day and then decline somewhat once grain yields maximized. The greatest percentage (calculated) of fertilizer N lost as N_2O (7%) occurred with 134 kg N/ha. The authors found that the percentage of applied N lost as N_2O dropped to 2 to 4% with N rates above 134 kg N/ha. The authors stated, "This threshold N_2O response to N fertilization suggests that agricultural N_2O fluxes could be reduced with no or little yield penalty by reducing N fertilizer inputs to levels that just satisfy crop needs." The distribution in patterns of N_2O emission were governed by soil N availability, and the magnitude of emissions was related to the interaction of soil water content and N availability.

Grant *et al.* (2006) noted that taken together, the effects of past and current fertilizer use on N_2O emissions suggest that emission factors attributed to fertilizer use should rise to the extent applications exceed ecosystem N uptake capacity over time. This capacity could be estimated from pre-planting measurements of residual N, and from annual estimates of gains or losses in soil organic N and of removals in harvest N, much as estimates of N fertilizer requirements are made currently. Applications in excess of uptake capacity would be allocated larger N_2O emission factors.

This reference to managing N-fertilizer rates to an appropriate amount is challenging because each agro-ecosystem and specific growing season will differ as to what is appropriate. There are many examples where when a threshold level is exceeded, N_2O emissions can increase dramatically. For example, Malhi *et al.* (2006) observed that when N rates exceeded 80 kg/ha in a specific cropping study, N_2O emissions increased. Similarly, N_2O emissions began to increase significantly compared to unfertilized check treatments with N rates above 100 kg/ha in an irrigated corn study (Kachanoski *et al.*, 2003 and Grant *et al.*, 2006).

In on-farm practical terms, a grower can minimize the potential for N_2O emissions by following a nutrient management plan (NMP) which includes soil testing to determine residual NO_3^- in the soil (where appropriate and calibrated by research), taking into consideration the normal N mineralization potential from SOM for soils in a field, and then filling in the deficit between the sum of these two N-inputs and reasonable crop yields with an appropriate amount of timely and well-placed N fertilizer.

Both the DAYCENT N_2O emission model (Del Grosso *et al.*, 2006) and measured data (Bouwman *et al.*, 2002) show a relationship between the amount of N fertilizer added and N_2O emissions. Without fertilizer N addition, however, there is a baseline level of N_2O emission from N mineralized from SOM (Del Grosso *et al.*, 2006). As fertilizer additions increase, N_2O emissions also increase, emissions also increase, but the rate of increase may slow at higher rates, as seen in Tennessee corn data (Thornton and Valente, 1996) and in data from irrigated corn cropping in Colorado (Mosier *et al.*, 2006). Generalizing across multiple sites, years, sources, and cropping systems, Bouwman *et al.* (2002) showed that N_2O emissions appear to remain relatively static across a broad range of rates (perhaps near the crop demand levels) and then tend to increase with higher rates (**Figure 5**). This relationship is in agreement with nonlinear N_2O emission response measured by McSwiney and Robertson (2005), but contrasts with the linear emission factor approach assumed by the IPCC (2006).

Grant *et al.* (2006) measured and modeled N_2O-N emissions in a temperate humid climate. They reported a nonlinear rise in N_2O-N emissions with fertilizer N rate once the rate exceeded crop and soil ecosystem uptake capacities. These results are in agreement with the trendline in **Figure 5** and results reported by Kachanoski e*t al.* (2003). In contrast, Sehy *et al.* (2003) found no significant increase in N_2O emissions with increasing fertilizer N rates (ranging up to 175 kg N/ha/yr) in high-yielding areas, on a site where corn yields were not responsive to increased N rate. The authors found that site-specific application of lower N rates in the low-yielding areas did result in 34% less N_2O emitted in 10 months following their differentiated fertilization, which was attributed to differences in soil NO_3– contents in the lower-yielding areas of their study site.

- **N Placement**

Breitenbeck and Bremner (1986b) found that N_2O emissions from soil fertilized with anhydrous NH_3 (112 kg N/ha) injected at a depth of 30 cm were 107% and 21% greater than injections at depths of 10 cm and 20 cm, respectively. The effect of depth of application of anhydrous NH_3 on emission of N_2O was less when this fertilizer was applied at a rate of 225 kg N /ha.

Drury *et al.* (2006) compared N_2O emissions following the application of 160 kg N/ha as ammonium nitrate as a side-dress to corn grown with three tillage treatments. They found low emissions (2.8 kg N_2O-N/ha/yr) with fertilizer placed 2 cm deep, averaged over three years. With placement depth at 10 cm, however, emissions increased to 3.0, 3.7 and 4.8 kg N/ha/yr for zone-tillage, no-tillage, and moldboard plow tillage, respectively. The authors concluded "Zone tillage and shallow N placement consequently appear to be management practices that reduce N_2O emissions from corn crops on fine-textured soils in cool, humid climates." Tillage and N placement depth did not affect CO_2 emissions in this study. Corn yields, however, were 4% higher with the deeper placement (7.5 vs 7.2 t/ha), and peak levels of soil NO_3^- were lower with shallow placement. While soil pH data were not provided, it is possible that higher NH_3 loss with shallow placement provides a partial explanation for these results. In addition, N_2O emissions varied more strongly with site-year than with any of the imposed treatments.

When N is applied on the soil surface and not incorporated, particularly in humid environments, a substantial proportion can be lost to the air as NH_3, especially with manure or urea as sources. While NH_3 is not a GHG, its ultimate fate is to be deposited back on the soil elsewhere. It is generally assumed that the proportion emitted as N_2O is the same, whether the applied N stays available in the soil for plant uptake or it goes elsewhere as NH_3. For this reason, BMPs that reduce NH_3 volatilization also reduce N_2O emission in the same proportion as the amount of N conserved.

Research comparing surface-applied urea to urea placed in a band below and to the side of the seed-row showed that N_2O emissions were higher from broadcast compared to band placement, in 2 years of a 3-year study at two sites in Saskatchewan (Hultgreen and Leduc, 2003).

• Timing

In an intensive wheat production system in the Yaqui Valley near Sonora, Mexico, Matson *et al.* (1998) evaluated three alternative practices that were based on agronomist recommendations and that added fertilizer later in the crop cycle, or less fertilizer N, or both, compared to the standard farmer practice of applying 250 kg N/ha; 75% as urea one month before planting, and 25% as anhydrous NH_3 one month after planting. The agronomist-recommended fertilizer BMP involving later applications of N and a reduced N rate (180 kg N/ha; 33% at planting and 67% 6 weeks after planting) resulted in no reduction in grain yield (6.1 t/ha), better economic returns, less residual soil NO_3-N, and 50% less emission of N_2O and NO compared to the standard farmer practice.

In addition to lower N_2O emissions observed with band placement of urea near the seed-row compared to surface applications, as noted above in the section on **N Placement**, the study by Hultgreen and Leduc (2003) in Saskatchewan showed lower N_2O emissions from spring compared to fall N fertilizer applications. The closer soluble N fertilizer such as urea can be applied to the time crop N uptake begins, the less potential for losses as N_2O emissions.

Zebarth *et al.* (2007) reported that in a study where no corn grain or silage response was observed to N application (indicating that all N applications were at or in excess of crop N requirement), changing fertilizer application to side-dress and reducing the N rate reduced "nitrate intensity", (an index of soil NO_3^- availability calculated as the summation of daily soil NO_3-N concentration for the 0 to 15 cm soil depth). However, they observed no significant effect of N fertility treatment on cumulative N_2O emissions, and found that NO_3^- intensity explained little of the variation in cumulative N_2O emissions. This study provides evidence that N rate reductions and split applications may not result in direct reductions of N_2O emissions under some conditions.