Nitrogen Management Project Protocol

Science Advisory Committee Meeting Report

Meeting Date September 7, 2011

Introduction

The Climate Action Reserve (Reserve) together with the Nicholas Institute of Duke University assembled a group of leading scientific experts to form a Science Advisory Committee (SAC). The purpose of the SAC is to help the Reserve interpret and apply the best available science into the Nitrogen Management Project Protocol (NMPP).

Committee membership was by invitation from the Reserve and the Nicholas Institute. Involvement in the Technical Working Group on Agricultural Greenhouse Gases (T-AGG), led by the Nicholas Institute, was a priority qualification as this is an established body of agricultural scientists with relevant scientific expertise, knowledge of GHG offset protocol development issues, and an explicit interest in translating research into GHG mitigation policy applications for agriculture. In addition, scientists must have met the following criteria to be eligible to participate in the committee: (1) a PhD in soil science or related field, (2) 10+ years of experience in research, with a research emphasis directly relevant to agricultural nitrogen management and N_2O emissions, and (3) multiple publications in soil science, ecosystem science, agronomy or related fields. The membership of the SAC is provided in Table 1.

The SAC will have multiple opportunities to provide input during the protocol development process, including by email and conference call. However, the most intensive opportunity for input was during an all-day workshop held at the Reserve offices in Los Angeles on September 7, 2011. This report summarizes the key findings of that meeting.

Table 1. NMPP Science Advisory Committee Members

Last Name	First Name	Affiliation
Del Grosso	Steven	USDA ARS, Colorado/ Natural Resource Ecology Laboratory
Desjardins	Ray	Agriculture and Agri-Food Canada
Groffman	Peter	Cary Institute of Ecosystem Studies
Halvorson	Ardell	USDA ARS, Colorado
Horwath	William*	UC Davis
Parkin	Tim	USDA ARS, Iowa
Robertson	Phil	Michigan State University
Snyder	Cliff	International Plant Nutrition Institute
Venterea	Rod	USDA ARS/ University of Minnesota
Lemke	Reynald	Agriculture and Agri-Food Canada

*Not present at September 7 meeting, however provided input to meeting report.

SAC Meeting Description

The in-person SAC meeting provided an opportunity for intensive discussion, consideration of research, and informal scientific consensus polling around the following:

- Interpretation of research on the GHG impacts of changes in nitrogen (N) management, specifically identifying the circumstances in which N_2O emission reductions from a change in agricultural N management can be consistently and accurately predicted;
- Evaluation of the technical and scientific merits of assumptions in the NMPP about GHG impacts from changes in nitrogen management; and
- Evaluation of quantification approaches for estimating net GHG reductions associated with changes in N management.

Prior to the meeting, each SAC member was sent a draft version of the NMPP and background information, and was asked to provide information on three key questions:

1. What is the "scientific validity" of providing GHG mitigation credits for the given nitrogen management practices? (An extensive list was provided.)
2. Which GHG sources, sinks, and reservoirs (SSRs) *must* be quantified to accurately and conservatively assess the net effect of a change in nitrogen management practice on GHG emissions?
3. What is a scientifically valid, economically practical, and ultimately verifiable approach to quantifying GHG reductions from nitrogen management offset projects? (For SAC consideration, this question presented four specific existing approaches from other similar offset protocols or GHG accounting tools.)

These questions and the draft protocol formed the basis of the meeting discussion.

Submissions of relevant information were provided by several SAC members and compiled by Reserve and Nicholas Institute staff prior to the meeting. In particular, two tables summarizing the current state of research on the effects of specific nitrogen management practices on N_2O emissions were compiled, forming a fairly comprehensive yet informal survey of the literature.

The morning of the workshop was spent orienting the SAC to the Reserve program and reviewing contents of the draft NMPP. Then, the members self-selected into two break-out groups. Group 1 was tasked with discussing Question 1, which entailed reviewing the compiled research resources and considering practice-by-practice whether the action would consistently and predictably lead to N_2O emission reductions and therefore would be scientifically valid to credit in an offset protocol. Group 2 was tasked with discussing Questions 2 and 3; however, the discussion focused primarily on Question 3 due to time constraints. Each group formulated preliminary recommendations/conclusions, which were reviewed by the full committee after the break-out sessions.

SAC Meeting Conclusions

Issues discussed by the SAC, but not specifically related to the key questions are noted immediately below. Further below, we report conclusions for each of the key questions.

General

The committee observed that there is some potential for N_2O emission reductions with improved management of nutrients other than nitrogen.[1] However, for clarity, since all of the proposed project practices in the protocol are related specifically to nitrogen management, "nitrogen management" may be a more appropriate name for the protocol. (The protocol was originally called the Nutrient Management Project Protocol; the title of the protocol has been changed in this document and elsewhere to the Nitrogen Management Project Protocol as a result of the above recommendation.)

The possibility for negative impacts on crop yield was discussed as related to some practices, and the committee agreed that this outcome should be avoided. The committee also encouraged the Reserve to consider whether and how to take into account changes in GHG intensity (i.e., GHG emissions per unit yield). The Reserve explained that a challenge with crediting decreases in GHG intensity in the context of offset projects is that there is the potential to include in the calculation decreases in GHG intensity or absolute emissions that result from a presumed change in practice or land use somewhere outside the GHG project area. As a general rule, indirect emission reductions are not counted towards offset credits. There may, however, be a way to credit decreases in GHG intensity at a project location relative to a "business as usual" GHG intensity baseline at the project site.

It was noted that there could be a risk of a farm or other entity misrepresenting the baseline management system – e.g., increasing nitrogen application for 3 to 5 years prior to starting a project. The Reserve agreed and indicated the protocol should include ways to minimize this risk.

The draft protocol states that each field much be "homogeneous"; however, it was noted that it is almost impossible to find a perfectly homogeneous field and the protocol will need to better operationalize that criteria – e.g., by setting the max difference in soil texture or soil carbon (C) content, or variability in soil classifications.

What is the "scientific validity" of providing GHG mitigation credits for the given nitrogen management practices?

The SAC refined the initial list of potential nitrogen management practices to better distinguish practices from one another. Using criteria such as the available number of side-by-side comparisons showing measured N_2O emission reductions in the field, whether these studies showed consistent results, and whether N_2O emission reductions were direct or indirect, they assigned a rough rating of "yes," "maybe" or "no" to each of the practices, denoting in a general sense which ones were ready for inclusion in the protocol based on the best available science. Resources affirming the science related to the practices were discussed. Cautions about situations where N_2O reductions could not reliably be expected from implementation of the practices were also noted. Table 2 summarizes the refined list of practices, ratings, and notes for each, as developed by Group 1 and reviewed by the whole committee. Practices receiving a "yes" or "maybe" rating will receive the highest priority from the Reserve for inclusion in the NMPP, in terms of developing performance standards for additionality and methods for quantifying GHG emission reductions that occur as a result of adopting the practice.

[1] This is mainly a result of limiting resources affecting growth potential or biomass accumulation. Any limiting factor like nutrients, pests, water or climate can affect N uptake. If growth potential is not realized then there is a likelihood of residual soil N and a potential for loss of N through gaseous or leaching pathways.

Table 2. Summary of Discussion of Potential Nitrogen Management Practices

Practice	Rating	General Comments	Regional Considerations
Reducing amount of N applied, without going below N uptake demand.	Yes	This practice is well-studied with consistent N_2O effects in terms of directional certainty. There are some challenges: e.g., management systems have different agronomic optimum N rates, which affect how much N can be reduced without exhibiting yield effects. Therefore, focusing on N use efficiency rather than N rates may be advisable. The relationship between N_2O emissions and N rate can be linear or non-linear depending on characteristics of specific crops and regions. However, these relationships can be described with the development of system-specific (as opposed to generic) Tier 2 emission factors.	All regions could be represented.
Avoiding Losses of Supplied N			
Synchronizing plant N uptake with N application through *increasing the number of applications*.	Maybe (for fertigation)	There are not enough studies to generate expectations of consistent direct N_2O emission reductions, because some studies have yielded conflicting results and may have simultaneously tested other management changes. The results of this practice are highly dependent on water management, placement of the increased number of applications, and how the applications are delivered. In some cases it could increase emissions as a result of a pulsing response (burst of N_2O emissions associated with application). However, more applications over the season with fertigation (i.e., applying N through sprinkler and drip irrigation systems) generally would be expected to reduce N losses and N_2O emissions (although it is not entirely known whether fertigation alone or the change in irrigation cause the effects). Also, by providing N to crops in a manner more synchronous to crop N uptake, it helps to limit the pool of N available at any given time. Generally, this will reduce nitrate runoff and leaching, leading to indirect emission reductions. In regions with a deep water table, the amount of N leached is generally less.	There may be potential for N_2O emission reductions from increasing number of N applications delivered via fertigation in irrigated western regions. However, rainfed systems would require many more studies, as results are unpredictable.
Synchronizing N	Maybe	Practice could have significant potential,	Likely to be regional

Practice	Rating	General Comments	Regional Considerations
plant uptake with N application through *switching from fall to spring application*.		particularly in regions with winter freeze/spring thaw but the number of studies is limited, with some conflicting results. Additional research is needed for spring-planted crops before strong conclusions can be drawn. Generally, nitrate leaching will be reduced, leading to indirect emission reductions. In regions with a deep water table, the amount of N leached is generally less.	variability in potential for this practice. Practice will have largest consistent reductions in northern and Corn Belt regions where there is typically a spring thaw.
Applying N closer to the root system (placement of fertilizer).	Maybe	Conflicting results from studies in different regions, but may have potential for limited regions. Some studies have shown banding applications to increase N_2O emissions.	Likely to be regional variability. May be potential in dry regions with irrigated systems, where reductions have been observed. Rainfed systems in humid climates (>500mm growing season precipitation) are less predictable.
Variable Rate (VR) technologies and precision farming.	No	VR technology may result in N rate reductions in areas of fields with lower yield potential or by leading to changes in N placement. However, no studies in North America quantify specifically how implementation of VR affects N_2O. May consider this a technology that enables N rate reductions, but not necessarily a N_2O-reduction practice in and of itself.	
Reducing the Conversion Rate of Supplied N to N_2O			
Use of nitrification inhibitors (A) *or* nitrification inhibitors combined with urease inhibitors (B).	Yes for (A) and (B)	(A) Akiyama et al. (2010)[2] (a literature review) showed positive results (i.e., emission reductions) for the use of nitrification inhibitors in certain regions. SAC was also confident about the combination of the two inhibitors (B). However, Akiayama et al. (2010) include few North American sites; other studies on U.S. sites show no or inconsistent effects. On the other hand, the practice could be an enabler for lower N rate. In some cases, nitrification inhibitors may have the adverse effect of decreasing yield potential and increasing residual soil N by maintaining immobile NH_4 in the soil during the critical crop development stage.	Likely to be regional variability in the effect of this practice on N_2O. Practice consistently reduces emissions in western climate and where water is intensively managed. However, results in rainfed regions are inconsistent, particularly for nitrification inhibitors by themselves. In mid-south, due to types of soils, activity could potentially increase N-losses.
Use of urease	No	Akiyama et al. extensive literature	

[2] Akiyama, H., X.Y. Yan, and K. Yagi. 2010. Evaluation of effectiveness of enhanced-efficiency fertilizers as mitigation options for N_2O and NO emissions from agricultural soils: Meta-analysis. *Global Change Biology* 16(6):1837–46.

Practice	Rating	General Comments	Regional Considerations
inhibitors (stand alone).		review showed no significant effect of urease inhibitors, except for one (hydroquinone) that reduced N_2O emissions. The article did not show a significant increase in N_2O emissions with other urease inhibitors, but a high degree of variability in data used.	
Changing fertilizer composition (source) [specifically, switch from anhydrous ammonia to urea].	Yes (for certain fertilizer sources)	Effects are mostly consistent, but depend on rate (before and after switch). Practice change will have less N_2O emission reduction effect at lower N-rates than at higher N-rates. Other fertilizer source switches may also have potential, but were not directly addressed during the meeting. Production of urea fertilizer results in significantly more emissions than production of anhydrous ammonia, however, so the trade-off may need to be considered for conservativeness. One other issue that may require attention (for other environmental impact reasons) is that switching to urea from anhydrous ammonia may increase nitric oxide emissions.	Directional certainty consistent regardless of region. However, results from Canada showed no difference in N_2O emissions between Aqua Ammonia and urea, demonstrating potential regional differences.
Changing to use slow-release fertilizer.	Yes	Although high N_2O emissions can occur when slow-release fertilizer application is followed by big precipitation events, GHG reductions are assessed relative to a project's "business as usual" baseline in which the precipitation event would also have happened. Therefore, factoring the precipitation effect into the baseline and project emissions estimates means there would be a net N_2O reduction when slow-release fertilizer is applied. It should be noted that the use of slow-release fertilizer could have an adverse effect of decreasing yield potential and increasing residual soil N, if the activity limits available N in the soil during the critical crop development stage.	Less consistent emission reductions in wetter regions due to greater volatilization. Slow release fertilizers are more consistent at reducing emissions in a no till system than a conventional till system.
Supplying N in organic form through manure application.	No	Most studies show an increase or no change in N_2O emissions with manure. However direct N_2O emissions are highly dependent on manure type and application method. If soil C storage were the primary intended GHG effect, then manure application could lead to a net GHG benefit.	Not recommended for any regions.

Practice	Rating	General Comments	Regional Considerations
		The net or landscape scale GHG effects should be considered, to ensure that emissions and sequestration are not simply being moved from one part of the landscape to another. Net reductions from to soil carbon stock changes would occur when readily oxidized organic matter under “business as usual” is converted to or replaced by resistant organic matter by the project activity. By providing N in the form of organic material (manure) instead of fertilizer, residual mineral N in the soil can be reduced, thus having potential to reduce indirect N_2O emissions. However, available N during critical crop development stage may also be lowered (and insufficient), reducing yield and making such systems less desirable.	
Supplying N in organic form through legume incorporation.	No	Leguminous cover crops may reduce N_2O, but only if properly managed with cover crop varieties and changes in irrigation. Over time, these practices can increase soil fertility, which may enable an N rate reduction. However, leguminous cover crops can also potentially result in no change or an increase in emissions. Emissions also depend on how far cover crops are allowed to mature. Not enough research or consistent results to include at this time.	Switching from continuous corn to corn/soy would reduce emissions (due to not growing corn as frequently), but it would be challenging to assess the net GHG effects of such a switch because of changes in the amount of corn produced and potential leakage effects.
Supplying N in organic form through composting.	No	Not enough studies available at this time to indicate consistent N_2O reductions occur. According to available studies, the practice could potentially reduce or increase emissions, depending on soil type, management methods, and the composition of composted materials. However, even in cases where N_2O may increase, if soil C sequestration is the intended primary GHG effect, there could be net GHG reductions due to increased soil C sequestration. As with manure, a life cycle or landscape scale analysis of the net-GHG emissions from the compost may be necessary. Studies are underway for this practice and should be reexamined once more research results are published.	Not recommended for any regions.
Scavenge Residual N			
Adding N	Maybe	Highly dependent on cover crop mixture	Not discussed.

Practice	Rating	General Comments	Regional Considerations
scavenging cover crops.		and fertilizer management, but if managed properly, has the potential to reduce N_2O emissions and increase yield, but studies show no or small reductions in indirect N_2O emissions. May enable an N rate reduction. Cover crops consistently reduce nitrate leaching.	
Adding deep rooting plants to the rotation.	No	Effects unknown. Not enough data. Indirect N_2O emissions likely to be consistently reduced, but the baseline management is hard to establish as are the potential leakage implications.	Not discussed.

Which GHG SSRs must be quantified to accurately and conservatively assess the net effect of a change in nitrogen management on GHG emissions?

In defining the scope of this protocol, the Reserve has determined that direct N_2O emissions from soil is the primary GHG source intended for quantifying GHG reductions. While there may be soil carbon benefit from some practices, all of the practices recommended for inclusion in the protocol should primarily have the potential to reduce direct N_2O emissions; they may also incidentally reduce indirect N_2O emissions from leaching, run off, and volatilization. Soil carbon impacts would need to be included in the GHG accounting boundary, only for practices that could decrease soil carbon stocks and generate higher CO_2 emissions.

With that in mind, the SAC was asked to discuss which GHG SSRs must be quantified to accurately and conservatively assess the net effect of a change in N management. It should be noted that this question did not receive comprehensive coverage by the SAC during the meeting; however, it was discussed briefly in the break-out group and some preliminary conclusions can still be gleaned. Specifically:

> Notwithstanding the potential of some nitrogen management practices to increase soil carbon sequestration, it is “conservative” to exclude the soil carbon pool from the quantification methodology. In this case, conservative means that GHG reductions are most likely to be underestimated. While some practices (e.g., cover crops) have the potential to both decrease N_2O emissions and increase soil carbon sequestration, none of the practices are likely to substantially *decrease* soil carbon stocks or sequestration rates as a result of project activities. Any such decreases would be slight (less than 5 percent of the total estimated emission reductions) if they were to occur. In particular, if yield declines as a result of lower available nutrients, then the resulting decrease in plant matter inputs could decrease soil carbon over time. However, as noted, these negative soil carbon effects are small and inconsistent, and the inclusion of mechanisms to mitigate or prevent yield declines would further ensure that such effects would be small.
>
> Quantifying soil carbon increases, particularly for the practices known to affect soil carbon, could increase the mitigation potentials for these practices. However, as noted above, it is preferable (and conservative) to underestimate GHG reductions.

Doing so will also keep the methodology practical and avoid the need to develop requirements for ensuring the permanence of changes in soil carbon stocks.

There was general agreement that it is important to include indirect N_2O emissions from volatilization, leaching, and runoff in the GHG accounting boundary for completeness. Please see the discussion below for the SAC recommendations on how to quantify *direct* N_2O emissions. Indirect N_2O emissions result from the transport of N away from the project site via air or water (surface and groundwater) and eventual conversion to N_2O somewhere else. The ability to directly monitor the movement of N and the eventual indirect N_2O emissions is fairly limited, making the development of Tier 2 or Tier 3 type methods difficult. Therefore, the SAC felt the IPCC methodology for estimating indirect N_2O emissions for national GHG inventory reporting purposes (Tier 1) was generally sufficient and is the best available option for capturing these effects. This recommendation was made presuming that other methodologies, as discussed below, were used to estimate direct N_2O emissions.

It was also noted that biogeochemical process models are capable of estimating the fraction of nitrogen that is leached or volatilized, perhaps more accurately than the IPCC default coefficients, and estimates of indirect N_2O emissions may be improved by using modeled fractions of N leached and volatilized as inputs to the IPCC methodology for indirect N_2O emissions. However, larger scale studies of indirect GHG emissions related to agricultural N use are consistent with results using the IPCC methodology.

What is a scientifically valid, economically practical, and ultimately verifiable approach to quantifying GHG reductions from nitrogen management offset projects?

Quantification approaches were categorized into three tiers, following a similar approach adopted by the IPCC, where:

- Tier 1 refers to a general emission factor developed for broad scales (e.g., the IPCC emission factor recommended for national scale GHG inventories; EF = 0.01 N_2O-N/N input).
- Tier 2 refers to regionally specific emission factors or simplified multivariate statistical models, derived from field data or biogeochemical process model runs based on changes in cropping practices such as, but not limited to, changes in N application rate (e.g., model to quantify N_2O emissions from N rate reduction derived from field studies in Michigan and potentially applicable to corn rotations throughout the North Central Region; $EF = 0.0072 * \exp [5.2(F_{syn} + F_{org})]$, where F_{syn} and F_{org} refer to the amount of synthetic and organic fertilizer applied, respectively).
- Tier 3 refers to the use of biogeochemical process models with site-specific inputs or to site-specific measurement of N_2O emissions (the latter of which is too costly given current technology and therefore impractical for offset projects).

Each tier is represented in existing nitrogen management offset protocols and GHG accounting tools (see Appendix A for more information).

The SAC discussed the trade-offs of the various approaches and indicated a low level of confidence in the application of DNDC for field-level quantification of N_2O emission reductions. In particular, concerns were raised about the reliability of using yield to calibrate the model (an approach used in one of the existing N management offset protocols). The group also felt that validation of the model to a broad enough range of relevant cropping systems and regions was still incomplete.

It was noted that Tier 3 models have the capacity to capture the effects of a range of practices, for example, N application rate, use of N inhibitors, and placement of fertilizer. Tier 2 methods can also potentially account for multiple practices depending on the underlying data (e.g., if the experimental data are testing the effects of multiple practices on N_2O emissions). Tier 3 models are able to estimate the interactive effects of multiple practices as well; however, it was noted that the assumptions within the models regarding interactions have not been well tested to date. While there may be some circumstances where using the DNDC model is appropriate, there is not a good understanding today of when and where this may be the case. It was generally thought that there are not enough practice-based trials of DNDC to develop it into an offset protocol quantification methodology at this point in time.

It was noted by the Reserve that a large-scale DNDC validation study is underway for California (funded by California Air Resources Board or "CARB"). The SAC felt this could be useful for advancing the development of DNDC for use in California, particularly if the validation included side-by-side tests comparing the effects of N management practices. They also indicated it was advisable to find a way to update methodologies and equations in the NMPP as more research becomes available. In short, while Tier 3 models such as DNDC or DAYCENT would be desirable goals and perhaps increase efficiency of quantification, further calibration and testing is needed to achieve reliable field level estimates. Some SAC members expressed concerns about realistically being able to validate models for this purpose. The CARB-funded DNDC validation study plans to develop Tier 2 emission factors for California based on Tier 3 model results, serving possibly as a model for an emission factor development method for other practices and regions.

Given the cautions about using DNDC, the SAC generally felt most confident in the use of Tier 2 approaches based on current understanding of predictable N_2O effects. They felt that Tier 2 methods are likely the ideal at this point in time because data are available to develop Tier 2 models for several practices while also accounting for soils and climate; the potential practices include N-rate reduction, use of nitrification inhibitors, switching from fall to spring application, and fertilizer formulation (note this corresponds closely with the "yes" list from Table 2).

A remaining question with Tier 2 approaches is how to account for interactive effects when multiple practices are adopted. It is unknown the exact degree to which effects estimated with separate Tier 2 equations are additive (or "stackable") or how they interact. However, the interactive effect is generally thought to be low, with the practice with the largest effect dominating. Again, as with any Tier 3 model, the scientists suggested the inclusion of an allowance within the protocol for improvements in quantification as more information becomes available. Alternatively, Tier 2 emission factors could be developed which specifically quantify these interactive effects for practices that are commonly implemented together.

The Committee also noted that USDA has a process underway to update GHG accounting methodologies and under that process, experts are aiming to generate Tier 2 emission factors for certain regions of the U.S. with respect to N management. It was thought that perhaps the Reserve process could incorporate outcomes from and possibly engage more directly with this effort.

The SAC encouraged the Reserve to develop minimum “data standards” as a reference against which to evaluate potential Tier 2 and Tier 3 approaches. Such standards would specify, for example, minimum number of field trials with side-by-side comparisons measuring N_2O fluxes directly, with a certain proportion that demonstrate consistent N_2O effects, and minimum acceptable uncertainty bounds around the change in N_2O emissions resulting from those studies. There must also be a clear standard for determining the cropping systems and climate conditions to which the assumptions or outcome of the studies can be reasonably applied (i.e., how far can you extrapolate the results).

The SAC also noted that GHG projects are concerned primarily with achieving the best possible estimate of the *change* in emissions (the “delta”) as opposed to estimating absolute emissions. It was noted that it may be possible to achieve tighter confidence intervals around the “delta” than around the absolute emissions. The one aspect in which the absolute emission quantification is important is when a change in emission is calculated as a proportion of the absolute value. Even in these cases, though, there could be much more uncertainty around the absolute value than around the change. This suggests a potential for tighter confidence intervals around the delta when there is a good understanding of the effects of a practice change on reducing N_2O, even if the understanding of absolute N_2O emissions is less well understood.

The SAC generally agreed that by allowing for unlimited numbers of fields to join together in an aggregate and act as a single project, the protocol would generate improved accuracy of GHG reduction estimates at the aggregate scale. They noted that a key consideration is making sure the fields within the aggregate represent a diversity of situations so as to avoid propagating systematic biases in estimation methods, which would skew the aggregate total. It was suggested that if aggregates were made up of a variety of climates and practices, this particular risk could be addressed. The SAC discussed how a minimum aggregate size could be constructed from rough estimates of what is an economically viable quantity of GHG emission reduction credits for a project.

In summary, the SAC concluded the following about prioritizing approaches to quantifying N_2O reductions in the NMPP:

- In general, it is advisable to use the highest tier possible, provided that the methodology meets a minimum data standard (and ideally that additional costs of using higher tiers are balanced by the value of being able to more accurately estimate reductions).
- Tier 3: It is believed that not enough practice-based trials have been conducted to develop DNDC into a comprehensive protocol methodology at this point in time. However, there may be potential for using DNDC to develop Tier 2 emission factors based on Tier 3 model results, in circumstances where the model is known to perform well.
- Tier 2: Ideal for this point in time and data are available to develop Tier 2 models for N-rate reduction accounting for soils and climate as well as other practices like inhibitors, fall to spring, and formulation. The “stackability” of interactions is not known, though the practice with the largest effect is generally expected to dominate. However, a methodology could presumably be developed address “stackability” when the interactive effects are well understood.
- Tier 1: May be appropriate, especially at regional and national scales and when Tier 2 is not available (e.g., indirect emission quantification). However they should be used with care and it is preferable to work towards developing Tier 2 approaches. Most appropriate for quantifying indirect emission reductions.

Appendix A

Summary of Quantification Methods Used in Existing Methodologies

Protocol	Methodology
EPRI-MSU protocol	Tier 2 for Corn-systems in North Central Region, derived from empirical field measurements in Michigan Tier 1 (using IPCC factors) for everything else
Alberta Offsets protocol	Tier 2 factor calibrated for Canadian eco-regions, derived from Canada's national inventory
American Carbon Registry protocol	Tier 3: Uses DNDC biogeochemical process model at a field level
COMET VR or COMET Farm tools	Tier 2/3: COMET uses a simplified version of the DAYCENT biogeochemical process model, with certain parameters constrained so it is not completely site specific

EPRI-MSU protocol (Tier 1 and 2): Uses region-specific emission factors that estimate N_2O as a function of annual amount of fertilizer applied; emission reductions are estimated based on the change in fertilizer use compared to either recommended rates or site specific historic practice. An exponential emission factor for corn systems in the North Central Region (NCR) of the U.S. was developed from empirical field measurements in Michigan (details on how the NCR emission factor was derived can be found in Millar et al. 2010). Outside of the NCR, this methodology applies the Tier 1 (linear) IPCC emission factor.

Alberta Offsets protocol (Tier 2): Uses an emission factor specifically calibrated for Canadian eco-regions. The factor takes into account the ratio of precipitation and irrigation to potential evapotranspiration. The factors were derived from Canada's National GHG Inventory Report quantification method, which is based on N_2O flux measurements in three regions with different precipitation characteristics.

American Carbon Registry protocol (Tier 3): Uses the DNDC process model at the field scale to estimate N_2O emission reductions. The model must be calibrated to optimal yield parameter and parameters related to heat or water stress. The model is run for each individual field in the project. Monte Carlo analysis is required to assess input parameter uncertainty, and the total model uncertainty (at the 90 percent confidence level for individual model runs) is calculated to determine the magnitude of an uncertainty deduction that must be applied to the emission reduction estimates. If total uncertainty is less than or equal to 10 percent, no uncertainty deduction is required. Input parameters except the "critical inputs" remain the same when running the model to estimate baseline and project emissions. Critical inputs relate to nitrogen management practices and are adjusted between baseline and project model runs to reflect the implementation of specific nitrogen management practices under the offset project.

COMET VR or COMET Farm tools (Tier 3): The COMET tools simplify the use of the DAYCENT biogeochemical process model by constraining the model input parameters to a limited number of management schedules, crop parameters, and soil parameters. COMET estimates N_2O emissions at the parcel scale and uncertainty values based on analysis at the national scale. The COMET tools were developed for voluntary GHG emission reporting, not necessarily for offset quantification.