RESPONSE TO PEER REVIEW COMMENTS

A methodology for *Quantifying Nitrous Oxide (N_2O) Emissions Reductions in Agricultural Crops through Nitrogen (N) Fertilizer Rate Reduction* was developed by Michigan State University and the Electric Power Research Institute, and submitted to ACR for approval through the public consultation and scientific peer review process.

The methodology was submitted to ACR on March 10, 2011. ACR conducted its standard internal methodology screening and provided this to the authors on March 16. The authors submitted a revised methodology and supporting documentation on May 16.

The methodology was posted for public comment from May 23 – June 17, 2011. Public comments and responses by the authors are provided in a separate document.

The revised methodology was then submitted to three anonymous peer reviewers, experts in the field of fertilizer/nutrient management and GHG offset methodologies. Peer review comments and responses are given below.

General comments

	1^{ST} review	**Response**	**2^{nd} review**	**Response**
1	The methodology is very clearly written and I congratulate the authors to develop a methodology that balances scientific rigor with practicality. In this review, I have concentrated on the quantification approaches.	No response needed	N/a	N/a
2	I applaud the authors for the development of a protocol that is clear, concise and practical. I will confess that as an agriculturalist, I had considerable initial discomfort with the proposal of N rate reduction as a nitrous oxide reduction strategy. I do concur with the author's position regarding the current state of scientific knowledge. *"To date the vast majority of scientific evidence supports N input (annual N rate) as the most robust and reliable proxy for calculating N_2O emissions."* The corollary being that rate reduction is the best available strategy for reducing N_2O emissions. As I understand the author's conceptualization, a fundamental aspect is that a proposed project would only be eligible if an N application rate reduction can be implemented without a concomitant reduction in production (yield). I don't think this latter point can be stressed too strongly.	See specific responses below	N/a	N/a
3	The methodology for quantifying nitrous	No response needed	N/a	N/a

	1ST review	Response	2nd review	Response
	oxide emissions reductions in agricultural crops by decreasing N-fertilizer input is clearly written and should prove to be a useful, and used methodology. The simple and direct approach seems a good step in integrating N into the picture.			

1 Sources, Definitions and Applicability

	1ST review	Response	2nd review	Response	Final response
1	Even though it is appropriately discussed in Section 7, page 16, it would be good to note in the beginning of the methodology that decrease in N-fertilizer to decrease N2O emissions will not significantly decrease crop yield.	Agreed; sentence below added in section 1.3: *"A reduction in N rate during the project period will not significantly reduce crop yield (section 7)."*	Response accepted. However, this begs a follow up question. If no reduction in yield is an eligibility criterion – how will compliance be ensured (will project yield records be compared to baseline? If so, what happens if there actually was a yield reduction?	A zero reduction in project yield compared to baseline yield is not an eligibility criterion. Project crop yield is not a monitored parameter (see 11.1 Data and parameters monitored). Notwithstanding, the methodology is geared towards an increase in NUE and crop yield maintenance/increase. Although not mandatory, producers are encouraged to adopt N fertilizer rates for the project within an economically profitable N rate range determined, for example, using MRTN calculators. Reducing N rates by adopting N rates based on economic	Accepted

	1ST review	Response	2nd review	Response	Final response
				optimization does not reduce average crop yield (see 7 Leakage and Permanence). Any yield reduction during the project period, would not be attributable to reduced N rate. Yield is variable from year to year due to weather, pests, and factors other than N rate.	
2	Section 1.2 and throughout the methodology. I think that you need to be careful in your definition of indirect N2O emissions. Indirect emissions can occur within the project site as well as outside the project site. For example, N runoff from a field into a ditch at the end of the field can lead to N2O emissions that are not from the field itself.	Indirect emissions are currently defined as: "*Those emitted beyond the project site but resulting from N fertilizer applied to the project site.*" We appreciate that indirect emissions can result from fertilizer N lost to adjacent or even embedded ecosystems. However, as for IPCC methods, the protocol's calculation of indirect emissions is unaffected by where the emissions take place - the protocol does not distinguish among indirect emissions within, adjacent to, or far away from the field to which fertilizer was	Response accepted	N/a	N/a

	1ST review	Response	2nd review	Response	Final response
		applied. We thus have not further revised our definition of indirect emissions.			

2 Project Eligibility

	1ST review	Response	2nd review	Response	Final response
1	2.2.1 Best Management Practice: To accomplish a rate reduction without a yield penalty, the protocol requires that nitrogen additions be applied utilizing BMPs during the crediting period. The protocol states that "Project proponents shall describe and justify the GHG Project Plan how relevant BMPs have been adhered to." Here lies my major concern with the proposed protocol. Ensuring that the management practices employed are indeed appropriate is not always straightforward. Published BMPs generally provide guidelines that still need to be applied in a judicious manner	We agree with concerns regarding evaluating BMPs. The methodology requires that farmers keep records of agronomic practices relevant to BMPs. In the context of this methodology, these BMPs are related to N fertilizer formulation and dates and methods of application. As stated in section 2.2.1 "*Project Proponents shall describe and justify in the GHG Project Plan how relevant BMPs*	Response accepted	N/a	N/a

	1ST review	Response	2nd review	Response	Final response
	at the field level. My concern surrounding this approach really relates to how credible the assessment of BMPs will be. Will good N management plans be prepared and implemented for each parcel of land included in the project? Will the evaluation of these plans be made by someone(s) qualified, knowledgeable and thoroughly familiar with conditions and considerations pertinent to the land included in the project? I feel that this point is absolutely critical to the success of the protocol and needs to be clarified and strengthened. Further, I work in an agricultural area that has low loss potential and profit margins are very thin. Simple regional N balance calculations still indicate that more N is being exported (sold in the grain) than is being replaced with external N sources. I would submit that there is limited opportunity to reduce N application rates without a	*have been adhered to.*” With regards to enforcement and project verification, farmer records of these practices, consistent with project documents such as custom application contracts or fertilizer sales records are required and are sufficient to demonstrate methodology compliance. Project verifiers are expected to review these records in light of relevant state and federal programs based on the methodology. In addition, to clarify, a project is only eligible if it can reduce N rate. It is not eligible if it adopts or maintains N BMPs that do not include or lead to N rate reduction.			

	1ST review	Response	2nd review	Response	Final response
	yield and/or quality penalty. If indeed this is the case, then I presume most producers would not be eligible (cannot reduce N rate without reducing yields) to participate in the protocol. I don't see this as a problem, it is consistent with the conceptualization of the protocol. However, eligibility would occur during the evaluation process for the proposed N management plan (BMP). This further highlights the importance of having a robust evaluation process.				
2	Section 2.4.2. Even after the thoughtful response to public comments, I still have some doubt that the tier 2 methodology is applicable across all of the Midwest. The soil/climate conditions in western Nebraska are considerably more different from those in Ohio than noted for the research sites in the Hoben et al. manuscript.	We appreciate concern regarding the extrapolation of the Tier 2 emissions factor to the NCR, and reiterate our response (below) detailed in section 6.3 of the public comments response document. Our study sites do not cover the entire range of possible conditions encountered in the NCR, nor even of	The new conservativeness factor introduced by the authors in section 8 / annex G helps address this concern. With this conservativeness factor, I agree the tier 2 emission factor is conservative in representing the range in soil types of the KBS study sites and weather conditions. However I remain unconvinced	We appreciate the reviewers continuing concern regarding extrapolation of the MI based field studies to the NCR. First, the reviewer seems to have the impression that the equation is based on results from only KBS. Rather, Hoben et al. (2011) represent on-farm results precisely to test whether the relationships established at KBS hold up in other environments. Below, we provide synopses of	Accepted

	1ST review	Response	2nd review	Response	Final response
		Michigan, but are nonetheless broadly representative of the NCR, are non-biased and conservative, and as such are validly extrapolated to the region. In particular: ◆ During years with normal precipitation, crop yields at our sites are typical of the NCR. ◆ The N rates we employed (0 to 225 kg N ha^{-1}) are within the range commonly required for optimum corn grain production and recommended for the NCR. ◆ There is no evidence that soil and climate variations of typical crop fields across the NCR will lead to	that the range of soils and weather conditions of the KBS study sites is representative for the whole NCR. I would have expected the authors to refer to other independent and primary N_2O measurements in the NCR. Are there really no other data that can be used for an independent check of the proposed equation? I find the arguments provided to indicate the representativeness of the study site relatively weak: ● Having similar yields is a relatively weak argument. Sites with similar yields may still have very different N2O emissions. ● The N range mentioned is very	results from independent studies in the peer reviewed literature that investigate N_2O emissions from crop experiments with at least two non-zero N rate treatments. Note that none of these studies are from the NCR because there are none available other than the MI based studies of Hoben et al. (2011) and McSwiney et al. (2005). In toto, studies show that N_2O emissions responses to increasing N input are non-linear and of a very similar magnitude to the MI studies across a range of agricultural systems, soil types, and environmental conditions that ‘exceed’ the range of conditions encountered in the NCR. For comparison of average daily N_2O emissions across these studies, note that for Hoben et al. (2011) (the data source for the derivation of the Tier 2 NCR EF and emissions uncertainty estimates), emissions of N_2O across the sites and years averaged between ~6 to ~26 g N_2O-N ha^{-1} day^{-1} for the lowest (45 kg N ha^{-1}) and	

	1ST review	Response	2nd review	Response	Final response
		any greater variation in N_2O emission rates than at our sites. ♦ There is no evidence that the soil and climate variations across the NCR are different from our sites in any way that is likely to lead to the methodology's making biased estimates of N_2O emissions. We consider our empirical results, in particular the N_2O response curve, to be representative of the NCR. This view was supported during the peer review process as part of the publications of Millar et al. (2010), Hoben et al. (2011), and Grace et al. (2011). Millar, N., G. Robertson,	large, so it would not be that discriminating to be within this range. - Instead of using the lack of evidence of an effect as an argument, I would like to see evidence of the lack of an effect. Are there studies from other areas in the NCR available that the authors can use to substantiate this? - I appreciate that the authors reiterate that the view was supported during a peer-review process. The peer review process definitely adds credibility. One could argue there is still a big difference between using these data to	highest (225 kg N ha^{-1}) non-zero N rate treatments, respectively. ♦ At a four level N gradient under corn at three sites in Ontario, Canada (cool and humid conditions with loam, silt and clay loams), ***Ma et al. (2009)*** found increasing fertilizer rates from 90 to 150 kg N ha^{-1} only marginally increased yield, but doubled cumulative N_2O emissions (16.3 vs. 37.1 g N_2O-N ha^{-1} day^{-1}, respectively). From the Discussion: *"Despite the influence of the variable weather conditions among the sites or years, it was clear that cumulative N_2O emission, averaged across all the site-years increased exponentially with increasing rate of N fertilization (Fig. 4a)."* ♦ In a three year study in spring barley in a cool maritime climate with humid soil moisture regimes (New Brunswick, Canada) and coarse loamy soils, ***Zebarth et al. (2008)*** found that N_2O emissions	

	1^{ST} review	Response	2^{nd} review	Response	Final response
		P. Grace, R. Gehl, and J. Hoben. 2010. Mitigation and Adaptation Strategies for Global Change 15:185-204. Hoben, J. P., R. J. Gehl, N. Millar, P. R. Grace, and G. P. Robertson. 2011. Global Change Biology 17:1140-1152. Grace, P. R., G. P. Robertson, N. Millar, M. Colunga-Garcia, B. Basso, and S. H. Gage. 2011. Agricultural Systems 104: 292–296. Note, too, precedence in the peer-reviewed literature for Michigan based empirical field measurements of N_2O emissions extrapolated to the NCR. In Grace et al. (2011), the annual fertilizer induced N_2O emissions from corn production in each NCR county were calculated from the average daily	estimate a regional estimate of GHG emissions within a scientific paper (e.g., Grace et al. 2011) and a system where carbon credits are issued and money will change hands. The stringency of the latter must be considerably greater. I can see two potential ways to address this concern: (1) Compare the range in soil texture and SOC in the study sites with the texture and SOC of the NCR and/or (2) provide N_2O measurements from independent studies that indicate the N_2O emissions predicted by the tier 2 factors are not totally off.	increased by ~5 g N_2O-N ha^{-1} day^{-1} (18 to 23 g N_2O-N ha^{-1} day^{-1}) following an increase in N fertilizer rate from 0 to 75 kg N ha^{-1}, but increased by 12 g N_2O-N ha^{-1} day^{-1} (23 to 35 g N_2O-N ha^{-1} day^{-1}) following an increase from 75 to 150 kg N ha^{-1}. From the Discussion: *"The calculated value for fertilizer N induced N_2O emissions was approximately twice as high when fertilizer N rate was increased from 75 to 150 kg N ha^{-1} compared with when fertilizer N rate was increased from 0 to 75kg N ha^{-1}. This indicates that the effect of fertilizer N addition on N_2O emissions was more pronounced when fertilizer N application was in excess of that required to optimize crop yield."* ♦ In a two year study at three grazed grassland sites in the UK in varying loam soils (N rates of 0, 75, 175 and 350 kg N ha^{-1}) Cardenas et al. (2010) found that a *"nonlinear response of N_2O*	

	1^{ST} review	Response	2^{nd} review	Response	Final response
		N_2O flux derived from data collected from the five Michigan field sites of Hoben et al. (2011).		*emissions to fertiliser N application rates was observed.”* Average daily emissions ranged from 7 to 65 g N_2O-N ha^{-1} day^{-1} for the 75 and 350 kg N ha^{-1} treatments respectively (note the highest N rate in this study is considerably higher [125 kg N ha^{-1}] than the highest N rate in the Hoben et al. (2011) study). ♦ At a five level N gradient (0, 50, 75, 100, and 200 kg N ha^{-1}) in a smallholder farm system under corn (high clay soil of basaltic origin) in western Kenya (1600m asl, with ~1750 mm annual rainfall), Hickman et al. (2012) measured varying emissions rates of between 8 to 19 g N_2O-N ha^{-1} day^{-1} and found that *“Emissions of N_2O following the second fertilizer application increased only when fertilization rates exceeded a threshold between 100 and 200 kg N ha^{-1}, at which point emissions doubled”* As our Tier 2 non-linear relationship	

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				(and magnitude of N_2O emissions) holds across these diverse systems, we argue that it is valid and appropriate to extrapolate our MI based study to the NCR (indeed, if not to the entire U.S). As discussed previously, conditions and row-cropping practices in the NCR are similar to those in the MI studies, and are relatively homogeneous compared to the diversity of conditions presented in the above studies. Please also note that although the Bouwman et al. (2002) meta-analysis provides the basis for the IPCC constant Tier 1 EF of 1.0%, (along with the follow-up Stehfest and Bouwman (2006)), the overall relationship between N_2O emissions and N inputs in this global study was non-linear (exponential) across a very wide and diverse range of conditions (Bouwman et al. (2002); Figures a-d on page 28-6). From these graphs, if we take the maximum N_2O emissions (at 250 kg N ha^{-1}) as 7.9 kg N ha^{-1} (Fig. b), and	

	1^{ST} review	Response	2^{nd} review	Response	Final response
				the minimum (at 50 kg N ha^{-1}) as 0.9 kg N ha^{-1} (Fig. a) we can calculate average emissions of 4 – 34 g N_2O-N ha^{-1} day^{-1}. This calculation makes the reasonable assumption that the N_2O emissions were measured over the average experimental period for crop and grassland studies as presented in the Stehfest and Bouwman (2006) dataset, of which the Bouwman et al. (2002) data is a subset. This calculated exponential global range (4 – 34 g N_2O-N ha^{-1} day^{-1}) for N rates of between 50 and 250 kg N ha^{-1} is remarkably similar to the range of emissions found across the MI sites in Hoben et al. (2011) that averaged between 6 – 26 g N_2O-N ha^{-1} day^{-1} for N rates between 45 and 225 kg N ha^{-1}.	

3 Project Boundary

	1^{ST} review	Response	2^{nd} review	Response
1	3.3 Greenhouse Gases: It is conceivable that an N management adopted when moving from the baseline to	The reviewer is correct that the methodology does not take into account the GHG emissions resulting from a	Response accepted	N/a

	1^{ST} review	Response	2^{nd} review	Response
	the project condition may result in an increase in GHG emissions that are not addressed in the current form of the protocol. An overall emission reduction would likely still be realized, but it should be "net" of the accompanying increase. For example, if a single N application was utilized in the baseline condition and a split N application (a BMP for some production systems) is utilized in the project condition, then the additional fossil fuel used would not be accounted for as I understand the current protocol. I propose that the project proponent be required to provide evidence that the N management strategies employed in the project condition have a fossil fuel usage that is less or equivalent to those in the baseline condition. If there is an increase, then an appropriate adjustment (discount) needs to be made to the ERTs generated.	practice change to adhere to BMPs. There are few if any BMPs for farmed cropland that might result in additional net GHG emissions for practices related to fertilizer applications. In the example provided (an additional field pass to apply side dress fertilizer) the additional fuel usage would be de minimis, in any case – less than 3% of the ex ante calculation of emission reductions enhancements. See Gelfand et al. (2010) for an example of fuel GHG costs. • Gelfand, I., S.S. Snapp, and G.P. Robertson. 2010. Energy Efficiency of Conventional, Organic, and Alternative Cropping Systems for Food and Fuel at a Site in the US Midwest. Environmental Science & Technology 44: 4006-4011.		
2	The spatial and temporal boundaries are appropriate. I have one minor question concerning the greenhouse gases considered, section 3.3. Why is CO2 from urea fertilizer addition not considered in the mix? Please see the IPCC 2006, methodology, Vol. 4, Chapter 11, Section 11.4 Co2 emissions from urea fertilization.	Following further discussion, we have removed the equations that calculate GHG emissions from fertilizer production from the baseline and project period. We believe that the project developer does not have jurisdiction over these emissions reductions. Please note that the emissions factor for urea (1.54 Mg CO_2e, (Mg fertilizer applied)$^{-1}$) is based on IPCC default values	Response accepted	N/a. [ACR comment: Note that since this methodology requires a reduction in N rate, the only directional effect on upstream emissions from fertilizer production should be to reduce those emissions.

	1^{ST} review	Response	2^{nd} review	Response
		that takes into account the overall net GHG emissions from urea production, storage and release due to application (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3: Industrial Processes, and Product Use; Chapter 3.2 Ammonia Production). Therefore, CO_2 emissions from urea addition to the soil are inherently included when this default factor is used in calculations.		However, ACR policy would not be to credit those upstream emission reductions to the farmer since it would be difficult to establish clear and uncontested title to these indirect emission reductions 'belonging' to the owners of fertilizer production facilities; without which it would be difficult to ensure no double-counting.]

4 Selection of Baseline Scenario

	1^{ST} review	Response	2^{nd} review	Response
1	No comments	N/a	N/a	N/a

5 Assessment of Additionality

	1^{ST} review	Response	2^{nd} review	Response
1	No comments	N/a	N/a	N/a

6 Emission Measurements (Baseline Emissions and Project Activity Emissions)

	1^{ST} review	Response	2^{nd} review	Response

	1^{ST} review	**Response**	**2^{nd} review**	**Response**
1	From the Response to Public Comments: In the original derivation of the protocol, the FracLEACH term was discounted (removed) prior to calculation of direct emissions. As the authors indicate, this was not consistent with the IPCC approach but is "conservative" in that it minimizes the predicted N_2O emissions. In the revised protocol, and in response to public comments, the authors have opted to remove the FracLEACH factor from the relevant equations to provide further consistency with the IPCC approach and remove potential confusion with terminology and definition. However, the authors further comment that *"The absolute reductions and credits generated will not change, as use of the same method for calculation is required for both project and baseline."* I believe this comment is incorrect. At least for situations where the NCR emission factor is used, the absolute credit resulting from a N-rate decrease will be greater when the FracLEACH term (for regions where leaching does occur) is not removed prior to calculation of the direct emissions. Using a very simple example where the baseline rate is 100Kg N ha^{-1} which is reduced to 90 kg N ha^{-1} in the project condition. Then the credit generated is ~ 0.06 Mg CO_2eq ha^{-1} if FracLEACH is removed compared to ~0.07 Mg CO_2eq ha^{-1}	The reviewer is correct for the Tier 2 situation. However, because this comment is relevant only to our public comments response (section 6.1), no further revision to the methodology is required.	Response accepted	N/a

	1ST review	Response	2nd review	Response
	when FracLEACH is included. I do not disagree with the revised form of the calculations, I just think it important that the implications are clear.			
2	See comment 1.2 on the definition of indirect emissions.	Please see our response to comment 1.2.	N/a	N/a
3	As noted above in comment 3.2, does CO2 from urea need to be included, where urea is the N-fertilizer source?	Please see our response to comment 3.2	N/a	N/a

7 Leakage and Permanence

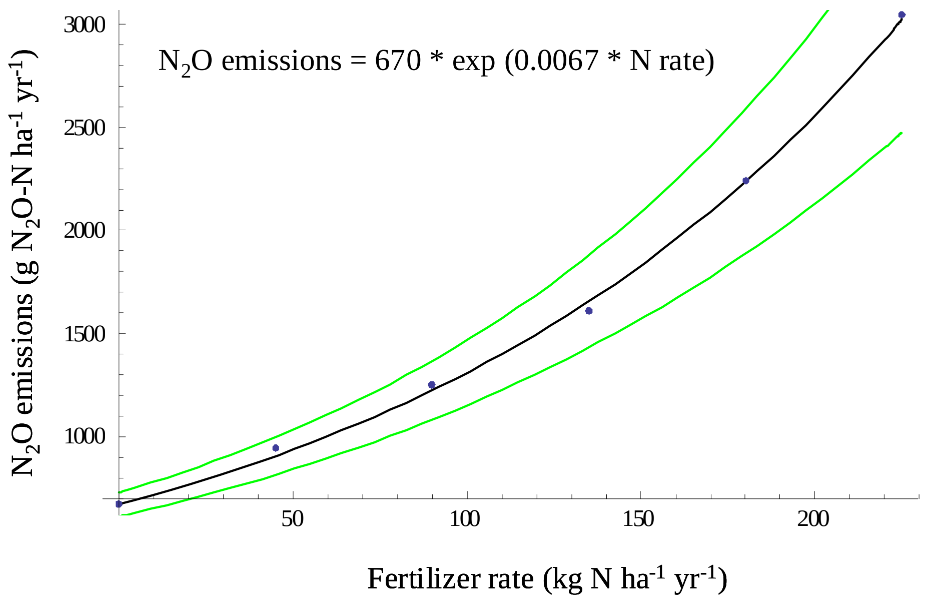
	1ST review	Response	2nd review	Response
1	No comments	N/a	N/a	N/a

8 Uncertainty Assessment

	1ST review	Response	2nd review	Response	Final response
1	You note that the Hoben et al. (2011) reference provides a statistical evaluation of uncertaint	We have revised our uncertainty analysis to include a more formal calculation of the % uncertainty in N_2O emissions reductions associated with a reduction in N fertilizer rate. The uncertainty is calculated from the empirical data collected for Hoben et al. (2011). The uncertainty analysis is now presented in Annex G of the methodology document, and is detailed below. **Uncertainty assessment** Methodologies and procedures adopted to calculate emissions of N_2O have	This section is a very good addition to the protocol. Two minor questions/issues: (1) I understand how the emissions reductions	In response to (1) and (2). The conservativeness factors in the methodology (Table 2) are	Accepted

	1ST review	Response	2nd review	Response	Final response
	y of N2O emissions, what is the amount of expected uncertainty?	been refined over many years, and are conservative in nature. Here we outline assumptions, parameters and procedures that relate to uncertainty in N_2O emissions in the methodology. We focus on the derivation of the regional NCR emissions factor used in equation (6) and (15) in sections 6.1.1 and 6.2.1, respectively. More detailed information on field-sampling and laboratory analytical techniques is given in Hoben et al. (2011). **Application of N fertilizer** The methodology monitors five parameters during the project period. Four of these relate directly to the calculation of N rate applied at the project site. These are detailed along with their measurement in section 11.1 of the methodology. All of these parameters are assumed to have negligible uncertainty. **Derivation of regional (NCR) emissions factor** *Daily N_2O emissions* Values for daily N_2O emissions have negligible uncertainty; field and laboratory sampling and analytical techniques have been refined over many years to standardize methodologies and minimize analytical uncertainty. We used standard methods to measure daily emissions as described in Hoben et al. (2011). *Annual N_2O emissions* We determined total annual emissions by interpolating daily emissions between sampling days. This was carried out using linear interpolation – a broadly accepted mechanism in the scientific peer reviewed literature. In brief, the sum of the rate of N_2O emissions on two successive sampling days was divided by two (averaged), and this average rate was multiplied by the period (in days) between the two measurements, then added to the previous cumulative emissions total. This can be represented by:	uncertainties are calculated, but how were the conservativeness factors calculated? I may be missing something really obvious, but can't find the relation. (2) Why is the uncertainty range put in buckets, why not just provide the formula for the conservativeness factor in case the uncertainty is >15%?	identical to the suggested CDM project values for acceptable limits for random uncertainty as reported in the CDM 32nd Meeting Report, Annex 14, and that were adapted from 2006 IPCC Guidelines. Use of these specific values for confidence deductions in the AFOLU sector are standard, and for example, recommended in the current	

	1ST review	Response	2nd review	Response	Final response
		$C_B = C_A + [(D_A + D_B) / 2] * (B-A)$ (G1) Where: C_B = Cumulative N_2O emission as of day B (g N_2O-N ha^{-1}); C_A = Cumulative N_2O emission as of day A (g N_2O-N ha^{-1}); D_A = Daily gas flux on day A (g N_2O-N ha^{-1} d^{-1}); D_B = Daily gas flux on day B (g N_2O-N ha^{-1} d^{-1}); B = Day of latest emissions measurement (day of year); A = Day of previous emissions measurement (day of year). Annual emissions (g N_2O-N ha^{-1} yr^{-1}) of N_2O for each field replicate were calculated from daily N_2O emissions (g N_2O-N ha^{-1} d^{-1}) measured in each block (4) at each N rate (6, including zero) at each site during the year for all site years (8), to give a total of 192 cumulative annual N_2O emissions data points (4 * 8 * 6). These individual cumulative annual emissions, calculated directly from daily N_2O emissions with negligible uncertainty, are also assumed to have negligible uncertainty. The best-fit line that defines the mathematical relationship between N rate (kg N ha^{-1} yr^{-1}) and N_2O emissions (g N_2O-N ha^{-1} yr^{-1}) for all 192 data points is: N_2O emissions = 670 * exp (0.0067 * N rate) (G2) *Where*: N rate is the equivalent of $F_{B\ SN,\ t} + F_{B\ ON,\ t}$ for baseline N input (equation [2] and [5]) and $F_{P\ SN,\ t\ +\ FP\ ON,\ t}$ for project N input (equation [11] and [14]). The standard error (SE) associated with N_2O emissions, is: N_2O emissions $_{(SE)}$ = 58 * exp (0.010 * N rate) (G3) Figure G1 (below) shows this relationship.		Verified Carbon Standard Methodology Requirements (section 4.1).	

	1^{ST} review	Response	2^{nd} review	Response	Final response
		 **Figure G1. Relationship between N_2O emissions (g N_2O-N ha^{-1} yr^{-1}) and N fertilizer rate (kg N ha^{-1} yr^{-1}) for baseline and project N fertilizer rates (black line). Standard errors (± 58 * exp [0.010 * N rate]) are also shown (green lines). Calculated using Mathematica (v. 8, Wolfram Research Inc., 2011).** *N_2O emissions reductions* Raw N_2O emissions reduction values were obtained by subtracting cumulative annual emissions of lower N application rates from cumulative annual emissions of higher N application rates (i.e., 0, 45, 90, 135, 180, and 225 kg N ha^{-1} yr^{-1}) within the same block, site, and year. This emissions difference was then divided by the difference in rate between the N rate pairs. Thus, we obtained 32 values (4 blocks * 8 site years) for the emission			

	1^{ST} review	Response	2^{nd} review	Response	Final response
		reductions for each of the 15 pairs (e.g., 45 → 0, 90→ 0, 90 → 45, etc.). To best define the interpolation of the empirical data for emissions reductions - N_2O emissions $_{(RED)}$ - many types of function were tested, including linear and exponential functions with various parameter combinations. The function below (Equation [G4]) derived from equation [G2] above) was also tested. N_2O emissions $_{(RED)}$ = $0.67 * \{\exp(6.7 * N_{Base}) - \exp(6.7 * N_{Proj})\} / (N_{Base} - N_{Proj})$ (G4) *Where*: N_2O emissions $_{(RED)}$ = N_2O emissions reductions, g N_2O-N ha^{-1} yr^{-1}; N_{Base} = $F_{B\ SN,\ t} + F_{B\ ON,\ t}$ baseline N input, Mg N ha^{-1} yr^{-1}; N_{Proj} = $F_{P\ SN,\ t} + F_{P\ ON,\ t}$ project N input, Mg N ha^{-1} yr^{-1}. Equation (G4) outperformed all linear functions and works as effectively as more complex exponential functions. *Emissions factors* The emissions factor for N_2O is defined as the fraction of N applied that is released as nitrogen in N_2O (N_2O-N) at a non-zero N rate minus the N_2O-N emitted at zero N rate. The emissions factors for baseline and project calculations were obtained by dividing the reduction function (equation G4) by $1 * 10^6$ (to convert g N_2O-N / Mg N rate to Mg N_2O-N / Mg N rate). We then formatted the equation to compare baseline and project N rates to zero N rate. Therefore we have: EF_{Base} = $6.7 * 10^{-4} * \exp([6.7 * N_{Base}] – 1) / N_{Base}$ (G5) EF_{Proj} = $6.7 * 10^{-4} * \exp([6.7 * N_{Proj}] – 1) / N_{Proj}$ (G6) *Where*:			

	1^{ST} review	Response	2^{nd} review	Response	Final response
		EF_{Base} and EF_{Proj} are equivalent to EF_{BDM2} (Equation [6]) and EF_{PDM2} (equation [15]), respectively. *Emissions reduction uncertainty* The standard error equation (G3) is useful for describing uncertainty in annual emissions but cannot be used to accurately describe uncertainty for emissions reductions in the range of smaller N rate reductions (10 – 20 kg N ha^{-1} yr^{-1}). Instead the 32 values (4 blocks * 8 site years) for the emission reductions for each of the 15 pairs (e.g., 45 → 0, 90→ 0, 90 → 45, etc.) were used to obtain variability of the mean using the Bootstrap method (Monte Carlo algorithm with case re-sampling, Mathematica – v. 8, Wolfram Research Inc., 2011). For each pair of N fertilizer rate reductions a random sample of 32 baseline values was taken and replaced with a random sample of 32 project values to compute a mean reduction. This process was repeated 100,000 times and the overall standard error of the means were calculated. The standard error of the means was then multiplied by 1.645 (the critical value of normal one-sided test at 95% confidence) and divided by the average emissions reduction to give the fraction of the average that is within the 95% confidence interval. These values plotted against N rate are represented by Equation (G7), which calculates the uncertainty associated with a reduction in N rate during the project period: N_2O Emissions $_{(RED\ UNC)}$ $[1 – \{0.63 * \exp(-40 * [N_{Proj}]^2)\}] * 100$ (G7) *Where*: N_2O Emissions $_{(RED\ UNC)}$ Uncertainty in N_2O emissions reductions, %; N_{Proj} $F_{P\ SN,\ t} + F_{P\ ON,\ t}$ project N input, Mg N ha^{-1} yr^{-1}. Equation (G7) is identical to equation (19) in section 8 of this methodology. Within the empirical N rate data range (0 – 225 kg N ha^{-1} yr^{-1}) the highest			

<table>
<tr><th></th><th>1ST review</th><th>Response</th><th>2nd review</th><th>Response</th><th>Final response</th></tr>
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<p>uncertainty was ~90%. There is no evidence to suggest that higher N rates would generate uncertainties above 100%, therefore the Gaussian function was used to constrain uncertainty below 100%.</p>
<p>Project proponents will use equation (G7 / 19) to calculate emissions reductions uncertainties (%) for a project. Credit award deductions as a result of uncertainty will use the uncertainty deductions in Table G1 (below, and Table 2 – section 8).</p>
<p>Table G1. Conservativeness factors and uncertainty deduction for N_2O emissions reductions based upon uncertainty at 95% confidence level.</p>
<table>
<tr><th>Uncertainty range at 95% confidence level of project emissions reductions[#]</th><th>Conservativeness factor</th><th>Uncertain deductio</th></tr>
<tr><td>< ± 15%</td><td>1.000</td><td>0.000</td></tr>
<tr><td>> ± 15% ≤ ± 30%</td><td>0.943</td><td>0.057</td></tr>
<tr><td>> ± 30% ≤ ± 50%</td><td>0.893</td><td>0.107</td></tr>
<tr><td>> ± 50% ≤ ± 100%</td><td>0.836</td><td>0.164</td></tr>
</table>
<p>[#] Where uncertainty in emissions reductions is < ± 15%, no deductions will be applied. Uncertainty in emissions reductions does not exceed 100% (see Annex G). * Uncertainty deduction (UNC) = (1 – Conservativeness factor). See equation (20) in section 9.</p>
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9 Emission Reductions and Calculation of ERTs

	1ST review	Response	2nd review	Response
1	No comments	N/a	N/a	N/a

10 Data and Parameters

	1^{ST} review	Response	2^{nd} review	Response
1	I think that there is a typing error in NC (subscript B OF).	Yes. We have corrected C subscript for $NC_{B\ SF}$ and $NC_{B\ OF}$ parameters.	Response accepted	N/a
2	Baseline Crop Area: Why could the baseline crop area be greater than the project crop area?	We agree that this comment is unclear. Our intention was to indicate that the baseline crop area must encompass the project crop area in order to ensure that the same land area is used in emission reduction calculations. We have removed the text from the table to avoid further confusion.	Response accepted	N/a

11 Monitoring Procedure

	1^{ST} review	Response	2^{nd} review	Response
1	No comments	N/a	N/a	N/a

Annexes

	1^{ST} review	Response	2^{nd} review	Response	Final response
1	Annex F: The methodology developers have set EF_{BDM1} and EF_{PDM1} to the average default factor of the IPCC, namely 1%. However, the authors indicate that this value has an uncertainty range from 0.003 until 0.03. Therefore, requiring to use the average does not seem conservative, as required	1. The uncertainty values around the default emissions factor for N_2O (EF_1) presented in Annex F are from Table 11.1 in the IPCC document linked by the reviewer (left). With offset projects, we are interested in the uncertainty associated with the decrease in N_2O emissions (delta) and	I appreciate the elaborate justification of the conservative nature of the EF. I accept the reasoning and am comfortable with the conservative nature of the IPCC EF.	We agree. The IPCC Tier 1 and Tier 2 inventory approaches include terms for the inputs from crop residues and	Accepte d

	1ST review	Response	2nd review	Response	Final response
	in the ACR Standard v2.1 Section F. In addition, the IPCC 2006 GL admits that the EF1 is, in fact closer to 0.9%: “The mean value for fertiliser- and manure-induced emissions calculated in these reviews is close to 0.9%; however, it is considered that, given the uncertainties associated with this value and the inclusion in the inventory calculation of other contributions to the nitrogen additions (e.g., from crop residues and the mineralisation of soil organic matter), the round value of 1% is appropriate.” (document available from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf p 11.11) Even though a value of 1% may represent a global average, it is not too hard to find studies that indicate a (much) lower emission factor than 1%. Hoben et al. (2011), for example, references an N2O emission factor of as small as 0.6%. I understand Method 1 should not be applied for the conditions of Hoben et al. (2011), and this value represents a small fertilizer application rate, this is an illustration of the	not in the emissions factor(s) per se. Therefore, uncertainty around the emissions factor used is not the same as uncertainty associated with N_2O emissions reductions during the project period. As noted in our response to comment 8.1 above, we have described in detail how uncertainty is calculated for N_2O emissions reductions in the NCR region (Method 2). For Method 1 our methodology assumes there is no uncertainty in N_2O emissions reductions. We make this assumption, due to the conservative nature of the IPCC Tier 1 emissions factors used for both direct and indirect emissions. More details of this conservativeness are given in points 3 and 4 below. This systematic ‘underestimation’ of emissions, and therefore emissions reductions calculated using the IPCC Tier 1 EFs constitutes a conservative approach and can be viewed as a fully compensatory emissions reduction ‘mechanism’ for the increasing variability of N_2O emissions at higher N rates and the decreasing confidence in N_2O emissions at these rates. 2. We are aware of the discrepancy	One issue that is also related to another comment: I still think the IPCC explicitly includes mineralization and crop residues in the N2O calculation: see equation 11.2 on p 11.10. The rounding of the EF from 0.9% and 1% is not meant to compensate the lack of including crop residues, but to make the EF more representative F_SN, F_ON, as well as F_CR and F_SOM. Can the authors point to a resource that shows EFs that are based on emissions that were normalized over one year?	(where soil carbon changes) N mineralization. The equation noted by the reviewer (11.2) refers to Tier 2, and is one possible disaggregation of the Tier 1 equation (11.1 on page 11.7). The Bouwman et al. (2002) and Stehfest and Bouwman (2006) papers from which the global EF value of ~0.9 was primarily derived do indicate that the influence of crop residues and leguminous crops were not	

	1ST review	**Response**	**2nd review**	**Response**	**Final response**
	potential non-conservative nature of the default IPCC emission factor. Likewise, http://nitrogen.ceh.ac.uk/solothurn/presentations/4_up-scaling/8_Lesschen.pdf on p 4 indicates the variability of the Stehfest and Bouwman dataset. In light of the statement in the IPCC 2006 GL document and observations made by Hoben et al. (2011), I would suggest that the authors use at most an EF of 0.9% for Method 1 of the direct emissions quantification, but preferably even smaller so that the conservative nature of the EF can be assured with 90% confidence, as specified by the ACR within the context of sampling (Section E in ACR Standard v2.1).	between the IPCC default value and the values for synthetic and animal manure N fertilizer induced direct N_2O emissions, reported for example in the global meta-analyses of Bouwman et al 2002, and Stehfast and Bouwman 2006. From the IPCC document: "The mean value for fertiliser- and manure-induced emissions calculated in these reviews is close to 0.9%; however, it is considered that, given the uncertainties associated with this value and the inclusion in the inventory calculation of other contributions to the nitrogen additions (e.g., from crop residues and the mineralisation of soil organic matter), the round value of 1% is appropriate." We believe the use of 1% is appropriate in our methodology, as well, for the same reasons. During the baseline and project period, a farmer will take N inputs, other than the external application of synthetic and organic N into account. For example, the N credit associated with soybean residue when applying N to a subsequent corn crop. Also, N mineralization is accounted for when soil N tests are taken and results are incorporated into yield goal		represented in their analyses. From Bouwman et al. (2002) Paragraph 7: *"The first step in data handling consisted of the rational exclusion of several factors and factor classes: ….(2) soil type and crop-residue management, because of the scanty data from the literature for these factors;.."* From Stehfest and Bouwman (2006): *"The mean global FIE is*	

	1ST review	Response	2nd review	Response	Final response
		equations for recommended N rate. Therefore the use of 1%, as opposed to 0.9% (that omits crop residue N and N mineralization), is appropriate. Slide 4 of the presentation by Lesschen and others (link in reviewer comment) shows the variation in EFs calculated from the N_2O emissions dataset used by Stehfest and Bouwman. One of the major contributing factors to variation in EF is the duration of the period over which N_2O emissions are made. EFs 'increase' with increasing measurement period. In the Stehfest and Bouwman dataset, 71% of the N_2O emissions data points used to calculate the average EF were measured over a period of less than one year (365 days), and ~30% were measured over 3 months or less. These short measurement periods will tend to lower the average calculated EF. Normalizing the experimental period to one year and recalculating EFs over one year results in an average EF substantially greater than 1%. 3. Regarding the conservativeness of global EFs, there is recent published evidence from a number of studies (below) using a variety of		*0.91% of the N applied in cropland (excluding legumes)..*" Also the Stehfest and Bouwman dataset shows that in the vast majority of cropland and grassland studies from which the global FIE is derived, no crop residues were incorporated. The 1.0% EF for crop residues appears to be primarily derived from the meta-analysis of Novoa and	

	1ST review	Response	2nd review	Response	Final response
		methodological approaches to indicate that using the IPCC Tier 1 default values results in conservative estimates of global and regional N_2O emissions. • Beaulieu, J.J., J.L. Tank, S.K. Hamilton et al. 2011. Nitrous oxide emission from denitrification in stream and river networks. Proceedings of the National Academy of Sciences 108: 214-219. • Berdanier, A. B. and R. T. Conant. 2011. Regionally-differentiated estimates of cropland N_2O emissions reduce uncertainty in global calculations. Global Change Biology: • Crutzen, P.J., A.R. Mosier, K. Smith, and W. Winiwarter. 2008. N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics 8: 389-395. • Davidson, E. A. 2009. The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860. Nature Geoscience 2: 659-662. In Berdanier and Conant (2011, Table		Tejeda (2006), where *"An emission factor (EF) equal to 1.055% of N applied in plant residues – derived from a simple linear regression of emitted N_2O-N (kg ha^{-1}) on N applied in crop residues (kg ha^{-1}) – represent an estimate that explains about 60% of emission variations."* Irrespective, the IPCC Tier 1 global default EF of 1.0% is applied to synthetic fertilizer (F_{SN}), organic additions (F_{ON}),	

	1^{ST} review	Response	2^{nd} review	Response	Final response
		2), the global weighted average mean EF for direct N_2O emissions from cropland is calculated to be 1.33%, with a standard deviation of 0.16%. This EF is in better agreement with the earlier global EF estimate of 1.25% (Bouwman, 1996). In this analysis, all regions of the world (other than Canada at 0.95%) have a calculated EF of > 1.0%. In Davidson (2009), regression modeling showed that 2.0% of manure N and 2.5% of fertilizer N are converted to N_2O (direct + indirect emissions). In Crutzen et al. (2008), top down modeling indicated that default IPCC estimates of global N_2O emissions associated with N application in agriculture were too low by about a factor of two. In Beaulieu et al. (2010), the results of whole-stream ^{15}N-tracer additions conducted in dozens of headwater streams draining multiple land-use types across the U.S. showed that river N_2O emissions are three times greater than estimated by the IPCC default value. Please also note that 1% can also be considered conservative with regards		crop residues (F_{CR}) and (when soil carbon changes) N mineralized (F_{SOM}). The dataset for Stehfest and Bouwman (2006) can be found at: http://www.pbl.nl/en/publications/2006/N2OAndNOEmissionFromAgriculturalFieldsAndSoilsUnderNaturalVegetation This data set does not normalize N_2O emissions to a one year period, but contains information on N_2O emissions	

	1^{ST} review	Response	2^{nd} review	Response	Final response
		to the Stehfest and Bouwman dataset. Here the control emissions corrected EFs (n = 352) range from 0.0% to 10.8% with an average of 1.1% (Lesschen et al. (2011). Please also see our response above regarding experimental time periods and conservative EF calculations. 4. With regard to the Hoben et al. (2011) paper, the reported range of EFs was 0.6 to 1.5 as N rate increased. However, as discussed in the paper, these estimates were very conservative for the reasons detailed below. a) The best-fit exponential model response curve from which the emissions factor relationship was derived calculates lower values for N_2O fluxes, as compared to the raw average N_2O fluxes at each N rate (diamonds in Figure 6a of Hoben et al 2011). For example the raw average flux from all site years for the highest N rate investigated (225 kg N ha^{-1} yr^{-1}) is ~ 26 g N_2O-N ha^{-1} day^{-1}, whereas the actual model data used to help determine the emissions factors in the paper is ~ 18 N_2O-N ha^{-1} day^{-1}, a reduction of ~ 30%. The higher the N rate, the larger this reduction in N_2O emissions calculated using the model when compared to the		measurement periods from the numerous studies that can easily be modified.	

	1ST review	Response	2nd review	Response	Final response
		raw field data. This systematic underestimation in using the model data constitutes a conservative approach. b) The calculation for estimating annual N_2O emissions at each N rate from which the emission factors are calculated is conservative for the following reasons: i) The calculation uses the lowest daily N_2O flux measured over all sites and years from the relevant period, as the daily flux from which the cumulative emissions for early spring (March-April) and late fall (October – November) are calculated. The use of this lowest flux to calculate cumulative emissions during these periods very likely underestimates the actual emissions over these times; and, ii) The calculation also assumes that there are no (zero) fluxes of N_2O from frozen soils, and during soil freeze–thaw cycles during the winter period (December – February). Again, this assumption almost certainly underestimates the actual fluxes that will have occurred during this time, and constitutes a very conservative approach. Please see page 1150 of			

	1^{ST} review	**Response**	**2^{nd} review**	**Response**	**Final response**
		Hoben et al. (2011) for further discussion. A less cautious but still viable approach (i.e., an extrapolation of the average daily emissions measured during the study periods to the entire year, 365 days), results in substantially higher EFs (> 1%) for all N rates within the range studied.			
2	Annex F: The IPCC 2006 GL specifies that EF1 is not only based on N additions from mineral fertilizers and organic amendments, but also crop residues, and N mineralized from mineral soil as a result of loss of soil carbon [kg N2O–N (kg N)-1]. Even though the impact on emission reductions is minimal since N input from crop residues are not affected per applicability criteria, it would be good to specifically state this in the annex so that users of the protocol do not use the 1% emission factor without taking into N input from account crop residues.	The inclusion of crop residue N and soil N mineralization is part of the IPCC rationale for rounding up the global default from ~0.9% to 1.0%. From this comment, we infer that the reviewer believes that crop residues and N mineralization are not taken into account in the methodology - this is not the case. As discussed in responses to the methodology public comments and in Annex Comment 1 (above), during the baseline period a farmer will take into account the input (N credit) from e.g., soybeans and lower his N rate to corn accordingly. Similarly, a farmer using soil N testing to estimate N rate for yield goal equations will be taking into account soil N mineralization. Therefore, the 1.0% factor is relevant and appropriate. The farmer will have taken account of these other N inputs	I was more alluding to the fact that the original IPCC equation 11.2 contains an additional term for crop residue and N mineralization (see above): $\cdot(F_{CR} + F_{SOM}) \bullet EF_1$ in addition to the rounding of 0.9% to 1%. This additional term was not found in Eq (2) or (5) of the methodology. I understand that a farmer will take into account the N credit to set his fertilizer N rate.	Thank you for the clarification. Please see response to Annex comments #1 above. The reviewer is correct – a farmer will take into account N credit from a previous crop to set N fertilizer rate for a subsequent crop.	N/a

	1^{ST} review	**Response**	**2^{nd} review**	**Response**	**Final response**
		during the baseline period, and adjusted N rate (and N_2O emissions) accordingly.			
3	Annex E: Quote: *"To date the vast majority of evidence supports nitrogen input as the most robust and reliable default proxy for calculating N_2O emissions."* I agree with this statement, but I would suggest nuancing this statement. In a lot of cases, evidence is simply lacking for other proxies. In part because they are certainly less important than the total N rate, but also because factors such as timing or placement are a lot more challenging to compare across studies than N application rate. For example, the Stehfest and Bouwman dataset codes "timing" as either single application, split application, or continuous application. Perhaps the authors can indicate that the jury is still out for timing of fertilizer, as concluded in Millar et al (2010): "Although circumstantial evidence suggests that Midwest N2O fluxes should be lower in spring—than in fall—fertilized crops, predictive quantitative evidence for the Midwest is lacking. Until evidence suggests otherwise, then, we cannot justify including it in the current	We agree. We have added the following text to Annex E: "Altering N fertilizer management practices other than N rate, such as timing, placement, and fertilizer formulation can also alter N_2O emissions. However, to date there have been far fewer studies investigating their impact on N_2O responses as compared to the impact of fertilizer rate. Nevertheless, our protocol allows credit for these practices by crediting the degree to which they allow less fertilizer to be used – i.e. the degree to which they improve system-wide fertilizer use efficiency, which is often a stated goal of their use. Their direct impact on N_2O fluxes – irrespective of fertilizer amount – awaits further validation before their use can be incorporated with confidence into the present protocol."	Response accepted	N/a	N/a

	1ST review	Response	2nd review	Response	Final response
	protocol. However, we believe this lack of information should be considered a high research priority.” I believe this point is an important nuance to the statement in the protocol.				
4	Annex G: It is not clear to me how the authors justify the extrapolation of data from five Michigan farm sites in 2007–2008 to the full NCR and for any weather scenario. I may have missed this in some of the referenced literature. I scanned Millar et al (2010). I found the following sentence in Millar et al (2010) “In the absence of evidence to the contrary we assume that these N gradient experiments are representative of the soil and corn cropping systems throughout the Midwest.” This does not seem to be an appropriate justification within the context of a carbon protocol. Perhaps the authors can elaborate further why the dataset on which the EF is based can be conservatively applied throughout the NCR.	Please see our response to comment 2.2.	See response to comment 2.2	Please see our response to comment 2.2.	N/a
5	Annex A: The procedure for determining potential leaching appears to be appropriate, although average precipitation PET relationships may not truly describe event-driven leaching events. The procedure does not address	We agree that the IPCC procedure for determining potential leaching is crude and will underestimate losses following large rain events especially following fertilization. However, on average, these events would also have been	Even if the weather patterns remain the same between baseline and project, there would be a problem if the same	Agreed. We cannot envision a scenario where leaching would be greater under	N/a

	1ST review	Response	2nd review	Response	Final response
	potential event-driven runoff events. When a large rainfall event comes soon after fertilizer application, N moves via runoff and leaching. Such movement of nitrate has been documented in sandy soils where average precipitation is far less than PET.	occurring during the baseline period and unless weather patterns differ substantially and predictably from the baseline period, there should be no under or over-reporting bias for project vs. baseline periods.	event produces more leaching under PR than under BL. However, this is unlikely given that the methodology incentivizes decreases in N additions. Please confirm.	the project period due to protocol implementation	
6	Annex E: Even after the thoughtful discussion of the issue of fall fertilization given in the public review response, I am still a bit concerned that fall N fertilization is considered in the same way as spring fertilization.	Although our approach offers no offset credit incentive to alter N fertilizer timing from fall to spring, the requirement to adhere to site relevant BMPs may require this practice change. For example, in Michigan agricultural producers would adhere to Generally Accepted Agricultural and Management Practices (GAAMPs) for N fertilizer application as published by the Michigan Commission of Agriculture and Rural Development. For corn, the GAAMPS require spring (not fall) N application. In this way, projects on fall-fertilized land where BMPs require a transition to spring fertilization, will likely further reduce their N_2O emissions, but will not be credited with offsets for doing so.	Response accepted	N/a	N/a