Peer Review Report

July 30, 2009

Peer Review of
International Agricultural Greenhouse Gas Emissions and Factors
as provided to EPA to support its RFS2 rulemaking

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Table of Contents

A. Introduction & Background

The United States Environmental Protection Agency (EPA) has undertaken a lifecycle assessment of the greenhouse gas (GHG) emissions associated with increased renewable fuels production as part of the proposed revisions to the National Renewable Fuel Standard (RFS) program. The Energy Independence and Security Act of 2007 (EISA) set the first-ever mandatory lifecycle GHG reduction thresholds for renewable fuel categories. The Act requires EPA to conduct a broad lifecycle analysis of expanded biofuel use, including emissions associated with indirect land use changes.

EPA published the Notice of proposed rulemaking for Renewable Fuel Standards in the *Federal Register* on May 26, 2009, 74 *FR* 24903. Several new pieces of analysis were developed to support the lifecycle assessment developed as part of the Notice. One of these pieces of analysis, and the topic of this peer review, is work done by ICF International to provide information to EPA to support its estimates of international agricultural sector GHG impacts of the proposed rule. The specific work to be reviewed is a memo prepared by ICF dated 12/12/08, entitled "International Agriculture GHG Emissions and GHG Metrics (revised) V.3" (referred to hereafter as the "ICF memo"), included as Appendix 7 of this report.

EPA's use of the information supplied in the ICF memo is summarized in section VI.B. of the preamble of the Notice cited above, and in the agency's *Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program,* EPA-420-D-09-001, May 2009, §2.6.4 (excluding §2.6.4.4), pages 342-349.

Ross & Associates Environmental Consulting, Ltd., conducted this peer review process on behalf of EPA. Throughout the execution of this peer review, Ross & Associates was guided by EPA's *Peer Review Handbook*, 3rd Edition, EPA/100/B-06/002.

B. Selection of Peer Reviewers

Ross & Associates selected four individuals to serve as peer reviewers for the review of the ICF memo. This section outlines the selection process and summarizes the qualifications of the peer reviewers.

Because the ICF memo covers several topics, we worked closely with EPA to develop a description of the types of expertise desired for this peer review. The agreed-upon expertise criteria are as follows:

Expertise in:

1. **International agricultural statistics**
   Data about: Fertilizer use, pesticide use, fuel use, electricity/heat use, acreage in cultivation.
2. **N2O emissions from synthetic fertilizer and crop residues; IPCC methodologies for agricultural N2O emissions**
3. **Rice cultivation & methane emissions**
4. **On-the-ground agricultural knowledge** (international if possible), as a "reality check" on the data being used in this analysis.

Peer reviewers were not necessarily expected to have expertise in all four areas. In addition, while the data provided in the ICF memo was used by EPA as input to the FAPRI and/or FASOM models, candidates were not necessarily expected to have expertise in the details of these models.

Having first identified the four areas of expertise, we identified approximately 60 individuals who were of interest based primarily on relevant publications and referrals from other candidates contacted during the selection process. In addition, a few names came to our attention through referrals forwarded by EPA, and by expectation of expertise based on organizational affiliation.

We performed an initial screening based on information available in publications and public internet sites. Based on this information, we eliminated candidates with any of the following characteristics:

- Candidates whose expertise, on further review, was not tailored to the four areas sought
- Candidates unlikely to be perceived as impartial due to strong editorial positions taken on issues related to this rulemaking
- Candidates being used in other EPA peer reviews related to the RFS rulemaking
- Candidates whose immediate organizations are under contract to EPA or who otherwise may not be perceived as independent of EPA.

Of the names remaining, we chose those with the greatest apparent expertise in the four desired areas of expertise and sent these individuals an introductory email to gauge their interest, availability, and to explore further their qualifications in the desired areas of expertise. Several did not respond. Others were interested but not available. Several candidates who were not available provided suggestions for other candidates to consider.

Candidates who were interested, available, and who had expertise in some or all of the four desired areas of expertise were sent EPA's Conflict of Interest questionnaire, EPA Form 3110-48 (7-08)[1]. In addition, we asked them to respond to the following supplemental question: "Have you, or do you plan to, prepare or assist others in preparing comments on the RFS2 rulemaking, either in a paid or unpaid capacity?"

We carefully reviewed the responses on the COI form and to the supplemental question, together with information available on public internet sites, to identify any real or perceived conflicts of interest. In all cases, the candidate reviewers certified that they have no apparent potential or real conflicts of interest, and we found no evidence of any significant real or potential conflict of interest in our review. In one case, a peer reviewer, in response to the supplemental question, indicated his intent to provide comments on the RFS2 proposed regulations "about the need for transparency and thorough documentation of all parameters and assumptions used in regulatory LCA models." Because transparency and documentation issues have little connection to the matters for review in the ICF Memo, this was judged not to be a reason to exclude this candidate.

Selected Peer Reviewers

[1] "Confidential Financial Disclosure Form for Environmental Protection Agency Special Government Employees."

Based on the process described above, we selected four peer reviewers, as listed below together with a brief summary of their qualifications.

1. **Dr. Elizabeth W. Boyer**
   Associate Professor, Pennsylvania State University, College of Agricultural Sciences
   Assistant Director, Penn State Institutes of Energy & the Environment.

   Summary of Qualifications
   - Ph.D., University of Virginia, 1998, Environmental Sciences
   - High level of expertise in agricultural statistics, including FAO data used in the document being reviewed.
   - Example publications:
     - **Boyer EW** & RW Howarth, editors. (2002, book). *The Nitrogen Cycle at Regional to Global Scales*. Kluwer Academic Publishers, 518 pp.
     - Green PA, CJ Vörösmarty, M Meybeck, JN Galloway, BJ Peterson, and **EW Boyer** (2004). Pre-industrial and contemporary fluxes of nitrogen through rivers: a global assessment based on typology. *Biogeochemistry 68(1):71-105.*

2. **Dr. Kenneth G. Cassman**
   Professor, Department of Agronomy & Horticulture, University of Nebraska, Lincoln, NE
   Director, Nebraska Center for Energy Science Research.

   Summary of Qualifications
   - Ph.D., University of Hawaii, 1979, Agronomy and Soil Science
   - Expertise in all four areas sought
   - 125 refereed journal articles (including *Nature*, *PNAS*)
   - International agricultural experience in Brazil, Egypt, Philippines.
   - Example publications:
     - Liska A. and **Cassman KG**. 2008. Towards standardization of life-cycle assessment metrics for biofuels: Greenhouse gas emissions mitigation and net energy yield. *J. Biobased Materials and Bioenergy* 2:187-203.
     - Adam J. Liska, H. S. Yang, V. R. Bremer, T. J. Klopfenstein, D. T. Walters, G.E. Erickson, and **K.G. Cassman**. 2009. Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol. *Journal of Industrial Ecology* 13(1): 58-74, February 2009.

3. **Dr. John R. Freney**
   Honorary Research Fellow, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Canberra, Australia.

   Summary of Qualifications
   - Ph.D., Univ. of New England, 1960
   - High level of expertise in rice cultivation and related methane issues.
   - Example publications:
     - **Freney, J.R.** 2002. Emission of Nitrous Oxide from Agricultural Soils In: *Encyclopedia of Soil Science* pp. 860-863 (Ed. R. Lal) Marcel Dekker, New York.
     - James N. Galloway, Alan R. Townsend, Jan Willem Erisman, Mateete Bekunda, Zucong Cai, **John R. Freney**, Luiz A. Martinelli, Sybil P. Seitzinger, Mark A. Sutton. 2008. Transformation

of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. *Science* 320, 889-892.

4. **Dr. Arvin R. Mosier**
Consultant; formerly Visiting Professor, Department of Agricultural and Biological Engineering, University of Florida, Gainesville, Florida; and Research Chemist, USDA/Agricultural Research Service, Fort Collins, CO.

Summary of Qualifications

- Ph.D., Colorado State University, 1974, Soil Science
- Over 240 refereed publications
- Expertise in all four areas sought
- Chaired the IPCC committee that wrote the 1997 N2O guidelines referenced in the ICF Memo.
- Conducted research, mainly on nitrogen and greenhouse gas issues for almost 40 years.
- International experience in Australia, China, India, Thailand, Japan, Indonesia, Germany, Sweden, Uganda, Guyana, Jamaica, Botswana and China.
- Extensive relevant publications, including:
    - Crutzen, P.J., **A.R. Mosier**, K.A. 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.
    - Del Grosso, S.J., W.J. Parton, **A.R. Mosier**, M.K. Walsh, D.S. Ojima, and P.E. Thornton. 2006. DAYCENT National-scale simulations of nitrous oxide emissions from cropped soils in the United States. *J. Environ. Qual*. 35:1451-1460.
    - Cai, Z.C., G.D. Kang, H. Tsuruta, and **A. Mosier**. 2005. Estimate of CH_4 emissions from year-round flooded rice fields during rice growing season in China. *Pedosphere*. 15:66-71.

Curricula vitae of the four reviewers are attached as Appendix 6 of this report.

After we had reached a tentative decision to recommend Drs. Boyer, Cassman, and Mosier, we became aware that each of these individuals is a member of the EPA Science Advisory Board's Integrated Nitrogen Committee. We judged that this commonality would have no impact on our recommendations.

C. Overview of reviewer responses

Overall, the four peer reviewers found the methodologies used (for fertilizer & pesticides; N2O emissions; agricultural energy use; and CH4 emissions from rice) to be sound and a "good first approximation" of changes in GHG emissions, with "exceptions that can be easily upgraded." Such exceptions included correction of typographical errors and data tables, verifying specific emission factors used in the models, and potentially using results from other models to reduce the uncertainty range from the model used to estimate N2O emissions.

While the reviewers found the *methodologies* to be generally acceptable, all four reviewers had a variety of suggestions for ways that the *data* used in the analysis could and should be improved. In particular, numerous criticisms and suggestions were aimed at the fertilizer use data. Pesticide use data were also seen as problematic, but the results of the analysis are seen (at least by one reviewer) to have low sensitivity to the pesticide data, so attention should be focused on improving the fertilizer use data. Specific suggestions and comments related to the fertilizer data included:

- The suggestion to use data from the International Fertilizer Industry Association.
- The idea of focusing on improving data for the main countries and for specific crops that have a high impact on the results.
- Cross-checking the data with other databases, and filling data gaps related to fertilizer use for certain crops and for grassland and hay/fodder lands.

In regard to the third area of inquiry in the Charge Questions, "Building on the Data," reviewers saw the topic of how to deal with future yield increases in analytical models as a complex topic. Two reviewers saw extrapolation of recent yield trends as the best approach, while another questioned the premise that yields will continue to increase. The four reviewers provided a variety of constructive suggestions for other factors EPA should take into account when projecting future agricultural production.

D. Summary of reviewer responses to charge questions

This section summarizes the essence of all comments submitted by the four peer reviewers. The summary is organized by charge question to allow the reader to quickly grasp, for each charge question, the range of opinion among the reviewers. Each comment or combination of closely related comments is summarized in a bullet under each charge question. Although the intent of this summary is to capture the spirit of the comments without changing their meaning, as a summary, it necessarily leaves out some detail, and important nuances or subtleties may have been lost. The reader is advised to refer to the full text of the reviewer's comments (Appendices 2-5) for any topics of critical interest to them. In some cases, the reviewer's comments are copied in full, as indicated by quotation marks.

The reviewer's initials are provided at the end of each summary bullet. In cases where more than one reviewer's comments on a given topic were similar, one bullet is used, and multiple reviewers' initials are shown. The reviewers are:

EWB - Dr. Elizabeth W. Boyer
KGC - Dr. Kenneth G. Cassman
JRF - Dr. John R. Freney
ARM - Dr. Arvin R. Mosier

Because Dr. Boyer used a slightly different outline structure for her responses, the summary bullets below include a reference to the section of Dr. Boyer's response where the full text can be found.

The summary is organized using the outline structure used in the charge questions. **Charge questions are shown in bold.** The original full text of the charge questions is included as Appendix 1.

Overall Impressions Expressed by Reviewers

Reviewers were given the option of providing any comments in addition to responses to the specific charge questions. Two reviewers offered overall impressions of the work being reviewed:

- Good first approximation of changes in GHG emissions, though some refinements needed. (EWB)
- Well documented, clearly presented, methods sound (with exceptions that can be easily upgraded). Some typographical errors; track changes version of ICF memo provided. (KGC)

Charge Question Section I. Questions Related to the Data Used

A. General Questions

1. **Should EPA primarily be relying on country-level data sources, or do you recommend data sources defined by other geographic areas? What alternative data sources would you recommend?**
   - Country level data are a useful first approximation. (EWB)
   - The data sources used in ICF memo are country-based; reviewer cannot envision any other method than country level. (KGC)
   - Can get better information from each country of interest. FAO data is best available, but more up-to date fertilizer data are available from the International Fertilizer Industry Association (IFA). (JRF)
   - Country level data compiled by FAO seem appropriate, but should be cross-checked with other sources such as IFA. (ARM)

2. **For any of the data sources used in the ICF memo, what additional, or better, data sources exist?**
   - The International Fertilizer Industry Association has data for countries missing from FAO's *Fertistat*--see supplied reference at www.fertilizer.org. (JRF)
   - Use most up-to-date data: FAO is current through 2007; IFA data are current up to 2008. IFA database is interactive and easily accessed. Suggest using 5-year average data for calculations. (ARM)
   - FAO fertilizer data are appropriate for this global analysis. Reviewer suggests two additional FAO data sources: *FAOSTAT fertilizer commodity database*, and *fertilizer use by crop* publication series (see web links). Additional sources of fertilizer data include IFA, UN Comtrade, and country-specific agricultural data repositories (similar to US Census of Agriculture). (EWB, I.4.addl fert.a)

3. **What better data sources exist to represent production of materials and energy use by country or other relevant geographic area?**
   - IEA data used are probably the best available for this purpose. Three other possible sources for country-level data are suggested. (EWB)
   - See data from the US Energy Information Administration. (JRF, ARM)
   - Regarding energy required for N fertilizer production, this analysis uses values from GREET. However GREET may use an outdated value for the carbon intensity of N fertilizer production, at least for a global average. For example, the value for carbon intensity of N fertilizer production used in GREET is higher than that used by the IPCC 2006. Results are sensitive to this parameter, so reviewer suggests a review of this factor to ensure the most up-to-date value is used. (KGC)

4. **The fertilizer and pesticide data show a very wide range of application rates across countries, areas, and crops. For example, in the case of pesticides, some countries' application rates are reported as zero. Based on your knowledge, how accurate are these data? What better data sources exist for fertilizer and pesticide utilization?**

Fertilizer

Missing or out-of-date fertilizer data

- For fertilizer data, the IFA database is more up-to-date than FAO. The IFA database is free on line, and provides historical fertilizer use by product and by country. A recent publication (Heffer, full citation provided) updates IFA data to 2008. A better source would be to obtain industry data from each country and then to average consumption over a number of years rather than a single year. (JRF)
- Appendix Tables 1-3 for fertilizer are incomplete; data is missing even though such data are available from IFA. *See full text of comment for several examples.* (JRF)
- Appendix tables need to be greatly improved. Data are missing for fertilizer use on fruits and vegetables even though these crops use 15-21% of N, P, and K globally in 2007-2008 per IFA data. (JRF, ARM)

- Regarding Appendix Tables 1-3, if the application of fertilizers to grasslands and hay/fodder lands has not been taken into account, calculations should be made to show if this could be significant. (EWB, II.A.1.b)
- The data used in the Excel file "Control_2022_Foreign_Ag_NPK_Pesticide" is out of date. The IFA database, supplemented by the publication by Heffer (available at www.fertilizer.org) provide data up through 2007/2008. (JRF)
- "Fertilizer input data…should be improved and the latest possible data used and the data should be based on the same years of data across all countries. By combining IFA and FAO data it should be possible to do this. It also seems appropriate to show comparison with other projections," e.g., those from the IMPACT model. *See full text of comment for description of IMPACT model, and for citation to Wood et al, 2004.* (ARM)

Other comments about fertilizer data

- Some crops in a few countries have a large impact on overall GHG emissions, e.g., (a) N fertilizer use on sugar cane in Brazil, and (b) soybean production in Brazil. Current values used for these examples are not appropriate, e.g., the N fertilizer rates specified for Brazilian sugar cane are much too low. *See full text of comment for examples and reference to publication submitted to provide supplemental information to support reviewer's comments: Cassman, 2005.* (KGC)
- Suggest cross-checking FAO and IFA databases and using multi-year averages. (ARM)
- Reviewer found transcription errors between Appendix Table 1 and the corresponding Excel spreadsheet. (KGC)
- Reviewer checked 70 data values from Appendix tables 1-3 against the FAO database and, following conversion of units, found them to be consistent with each other. (EWB, I.4.fert.c.)
- Appendix Tables 1-3 should add a column showing the year(s) for which data were used to derive the value shown in the table. Also, specific edits to the text of the ICF memo are suggested. (EWB, I.4.fert.b)
- Reviewer suggests a method for evaluating uncertainties, or filling data gaps, in country-level fertilizer data using FAOSTAT's fertilizer commodity database (link provided). *See full text of comment.* (EWB, II.A.1.c)

Pesticides

- Pesticide use data are not very good, but the GHG emissions from pesticide use in agriculture are relatively small. In contrast, fertilizer use is of critical importance to GHG estimates. (KGC)
- Zero pesticide use probably means the country didn't respond to FAO's survey. (JRF)
- Text should be added to highlight the uncertainties associated with the FAO database; see the quotation from the FAO web site (re inter-country non-comparability of the data). (EWB, I.4.pesticide.e)
- The time period for which pesticide use rate data is reported is not consistent with the data available at the FAO web site cited in the text and the Appendix. This needs clarification. FAO has suspended pesticide consumption data collection since 2001. (EWB, I.4.pesticide.b)
- It is not clear that the reporting year(s) for pesticide consumption are the same year(s) used for agricultural area. Ideally a rate/year would be obtained using data from the same year, and then rate/year values could be averaged over a large number of years. (EWB, I.4.pesticide.c)
- Reviewer has specific suggestions for editing Appendix Table 4. Reviewer also found it difficult to recreate the data from primary data given the methodology reported; more details are needed. (EWB, I.4.pesticide.a,d, and g)

Pesticide use rate in China

- China's pesticide use rate is certainly not zero; see data in FAOSTAT. See also reference to Xinhua report of 1.2 million tons annual pesticide use in China, and see article from *Production Monthly News* reporting production and export quantities for China (links provided). (JRF)
- It is unreasonable to assume no pesticides are used in China—see reference to *Production Monthly News* article reporting 1 million tons of pesticides produced in China in 2005. (ARM)
- Appendix Table 4 incorrectly reports "zero" rather than "no data" for China's pesticide use. Estimated values should be used for countries with no data rather than assuming a value of zero. One possible source of information for estimated values is the international division of the USDA (link provided). (EWB, I.4.pesticide.f)

5. **What is the best way for EPA to deal with the limitations of the data, especially those data elements to which the results are most sensitive?**
   - EPA should highlight in the text the assumptions and associated uncertainties of the estimates, provide the methodology/data for the base calculations in the public domain, and continue to refine the estimates with each release of the ghg estimates. (EWB)
   - Reviewer recommends that EPA take a leadership role in advocating the key need for improved national and international statistics on agricultural data…. (EWB)
   - Go to each country for the information. (JRF)
   - Excel file data needs to be updated: has big gaps for which data are readily available from FAO or IFA. (ARM)
   - Suggest focusing on accurate data for China, India, Europe, Brazil, USA, and a few others to get >90% of data to be the best that can be obtained. Possibly work directly with the countries rather than relying on FAO. (ARM)

Issues with Presentation of Data

- Some data are reported using an inappropriate mix of Metric and English units (e.g., kg/acre). Data should never be reported using such mixed units; use metric units only. (KGC, JRF, ARM) The data in Appendix Tables 1-4 is already very difficult to understand and the mixed units will likely confuse most users of the data. (ARM)
- Typographical errors were found; an edited version of the ICF memo is provided. (KGC)
- Transcription errors were found between Appendix Table 1 and the corresponding Excel spreadsheet (two examples provided). (KGC)
- Appendix Tables 2 and 3 should specify P and K rates are based on P2O5 and K2O rather than on an elemental basis. (KGC, JRF)
- There is a significant problem with the reporting of zeros rather than “no-data” in Table 4. (EWB)

Charge Question Section II. Questions Related to the Methodologies Used

A. General Question

1. **For each section of the ICF memo, please describe the key strengths and weaknesses of ICF’s methods.**

Section I: Fertilizer and Pesticide Consumption Projections

Strengths

- The analysis uses the best available data to estimate fertilizer and pesticide use in agriculture. Provides a clear explanation of estimation methods. (KGC)
- The general concepts used in developing fertilizer and pesticide consumption projections are viable. (ARM)

Weaknesses

- Use of current average fertilizer rates to estimate GHG emissions from increased crop production area due to biofuel production—esp. for expanded soybean production area in Brazil. (KGC)
- Country coverage and time series are incomplete for both the fertilizer and pesticide data sets. It is unclear whether the fertilizer and pesticide data accurately covers most of the world’s agricultural area. EPA should quantify this directly for both data sets, hopefully highlighting that despite the missing information, the data sets account for the majority of global agricultural land and/or agricultural chemical use. (EWB, II.A.1.a)

Section II: N2O Emissions from Fertilizer Consumption and Crop Residues
Section III: GHG Emission Rates for Agricultural Energy Use

Section IV: CH4 emission factors for Rice Cultivation
[Other "strength/weakness" responses are incorporated into the corresponding sections (C, D, and E) below.]

2. What do you recommend for improving the methodology? What can EPA do to improve the quality of the methodology (both in the near-term and in the longer-term)?

- As part of an international effort, EPA could call for more funding allocated to measuring N fertilizer efficiency and N2O emissions from *commercial*-scale fields of major crops; small plot studies give inaccurate results. In the meantime, the IPCC methods are the best we have. (KGC)
- The IPCC 2006 methods are the best available for estimating emissions of N2O from fertilizer and methane from rice. (JRF)
- Methods for estimating GHG emissions from agricultural energy are probably adequate but it would be better to compare the data with other sources. (JRF)
- Fertilizer data could be markedly improved by using the latest IFA data. Also, compare fertilizer projections with those of IFPRI's IMPACT model (reference and link provided). (JRF)
- Pesticide data does not appear to be reliable. Better would be industry data from each country. Use latest data because pesticide use will decline with increased planting of insect resistant genetically modified crops. Also need to specify whether data reports active ingredient only or full product. (JRF)

B. For Pesticide Consumption Projections

1. Is the averaging mechanism used by ICF for the pesticide data scientifically justifiable? (See last paragraph of Section I.)

- Averaging method acceptable (EWB, ARM), subject to using the best available data (ARM).
- Suggest using 3 year average use rate rather than the entire time series. Note that increasing use of GMO crops will likely decrease use of pesticides over time. (KGC)
- Averaging mechanism not good because increased use of insect resistant genetically modified crops will cause decreased use of insecticides. (JRF)

2. What do you recommend to improve these projections?

- EPA could collaborate with FAO and IFA to obtain better estimates of pesticide use at a regional scale for use in GHG accounting. (EWB)
- Obtain up-to-date information on pesticide use from each country of interest. (JRF)

C. For N2O Emissions

Strengths

- *Strengths:* Use of IPCC (2006) Tier 1 methods, which are transparent and based on best available science. They are robust when used as average values across a large agricultural landscape. Use of the DAYCENT simulation model would not be appropriate as it has not been shown to be more accurate than IPCC estimates across a wide range of crops and environments. (KGC)

Weaknesses

- Typographical errors in the memo related to the IPCC method: Equation 3 appears to be incorrect (correction provided in track changes version of ICF memo). (KGC)

1. Are the IPCC 2006 defaults and the Tier 1 methodology appropriate for this analysis? What other methodologies are available (including those that might be applicable to specific countries or regions)?

- The IPCC 2006 defaults and Tier 1 methodology are "appropriate" (ARM)/"the best technique" (JRM) for this analysis.
- A number of people are using a modeling approach to estimate N2O emissions from agriculture, e.g., Brown and Jarvis in the UK (link provided). (JRF)

- In the future a comparison with a different approach could be used, for example, Del Grosso et al, 2008 (full reference supplied). There are likely a number of ongoing efforts in many countries to update and improve country-based N2O emission inventories and these should be followed and incorporated where appropriate. (ARM)
- Suggests a comparison of IPCC methodology results with other approaches, e.g., Del Grosso et al, 2009 (full citation provided) using the DAYCENT model. Perhaps current and future evolutions of the global DAYCENT model approach could be used to constrain highly uncertain parameters in EPA's approach. (EWB, II.C.b)
- High uncertainties are associated with the IPCC methodology for using uniform fractions for leaching and runoff across countries, despite very large variations. See review by Nevison, 2000 (full citation given). Suggests constraining these estimates using global models that consider the water balance such as DAYCENT or IFPRI's IMPACT models. *See full text of comment*. (EWB, II.C.c)
- A 2001 FAO publication (link provided) provides a comprehensive review of the literature about N emissions and regulating factors, etc. This will be a useful reference for comparison to the methods ICF applied. (EWB, II.C.a)

2. Are the direct and indirect emissions from fertilizer and crop residues identified correctly? Is it scientifically justifiable to exclude the volatilization pathway from crop residues, as described in the memo?

- Yes, except for typographical errors (see track changes version of memo). (KGC)
- The direct and indirect emissions are correctly identified. (JRF)
- The method is applied appropriately. (ARM)
- Generally it is justifiable to exclude the volatilization pathway from crop residues because the residues have a high C/N ratio (*see full text of comments*). (JRF, ARM)
- "It cannot be correct to ignore direct & indirect emissions from crop residues of cotton, palm oil, rapeseed, sugarcane, and sunflower." *[ICF memo states "IPCC default values were not available" for these crops.]* (JRF)
- "The formula and table for estimating the amount of crop residue are a mess. … I am highly suspect of the accuracy of the current approach given the lack of clarity in Appendix Table 6." *See full text of comment*. (KGC)

3. Does the report correctly apply the IPCC Tier 1 methodology? Is this the best methodology to apply?

- Yes. (KGC, JRF, ARM)…Assuming the typos are corrected. (KGC)

D. For Agricultural Energy Use

Strengths

- Best available data used. (KGC)

Weaknesses

- Consider replacing GREET upstream energy use value for production of N fertilizer with the IPCC value because the reviewer believes the former is outdated. (KGC)
- Reviewer has specific questions about the Excel file used to calculate the indirect emissions from the generation of electricity and heat. *See full text of comment*. (EWB, II.D.b)
- The method used seems reasonable, but why so many gaps in Table 8? (JRF)

1. Is the exclusion of several fuel types as "minimal" scientifically justifiable?

- The exclusion may be appropriate, however reviewer would prefer to see a quantitative estimate showing that they have very low GHG emissions in comparison to other sources. (EWB, II.D.a)
- Yes. (KGC)

- The exclusion is certainly justifiable for Australia; without other information one can only assume this would hold for other countries. (JRF)
- The exclusion is appropriate; no reason to do otherwise unless more detailed information is readily available, and even then the inclusion would make no appreciable difference. (ARM)

2. **Is it scientifically justifiable to assume that the overestimate of fuel use in the agricultural sub-sector by using data for the entire ag/forestry/fishing sector is small?**
   - Yes, if indeed they represent a small portion of energy use compared to crop and livestock agriculture. (KGC)
   - The Australian Bureau of Statistics similarly does not separate fuel use by these subsectors. Without this information for each country, it would seem justifiable in countries where forestry is not an important industry. (JRF)
   - For the major agricultural producing countries this estimate seems appropriate. In countries where forestry is important (e.g., Canada, Sweden) is the overestimate significant? Reviewer does not have the information to do this calculation. (ARM)

3. **Is the use of average CO2 emissions for the entire agricultural sector by country (from IEA, 2007) scientifically justifiable? What methods exist to break this out by crop or other geographic area?**
   - Reviewer sees no other way to do it. (KGC)
   - It seems reasonable to do this, but reviewer does not have the data to determine whether it is justifiable. Use modeling to simulate energy use and CO2 emissions, e.g., Muller et al, 1977 (citation provided) developed a simulator to evaluate alternative agricultural practiced for energy efficiency in Midwest crop production, for certain crops. (JRF)
   - Reviewer would expect considerable differences in energy use for different crops in different countries. It may be worthwhile to look at a few country-specific examples and obtain the information directly from the countries involved. (ARM)

4. **Were the factors provided by EPA (Appendix Table 7) applied appropriately? How can these factors be improved?**
   - Reviewer believes they were applied correctly; no ideas for how to improve them. (KGC)
   - It is not apparent how these factors were used. (JRF)
   - It is not clear to me what the factors in Table 7 represent and how they were used. Their derivation on the Excel spreadsheet is not transparent. (ARM)

E. For CH4 Emissions from Rice

Strengths

- Use of IPCC 2006 methodology (ARM, JRF). Use of IRRI information. (ARM, JRF) Use of specific EF values for different types of rice cultivation. (KGC)

Weaknesses

- Use of a single value for USA rice production that is nearly two-fold greater than the default, with weak justification. Recommend using the default parameter for USA rice. (KGC)

1. **Is the scaling methodology described to adjust for the four different cropping regimes scientifically justifiable?**
   - Yes, this method is appropriate. (KGC, JRF, ARM)
2. **What other methodologies are better for estimating CH4 emission factors for rice cultivation?**
   - Reviewers not aware of any better methodology. (KGC, JRF, ARM)

<u>Charge Question Section III. Building on the Data</u>

A. Future Crop Production/yield Increases

1. **EPA uses historic data to represent future crop production. How should the agency adjust for future increases in yield?**
    - "This is a complicated topic. For N, future use depends on two parameters: (i) improvements, or decreases in N fertilizer use efficiency (quantified as the yield obtained per unit of applied N), and (ii) the rate of increase in crop yields, which determines how much crop area will be required. I append a paper that describes how these two factors will govern future N fertilizer use on crops (Dobermann and Cassman, 2005). Bottom line, from my viewpoint, I believe that projecting yield increase rates of the past 40 years is the best estimate for future yield increases." (KGC)
    - Given population growth; competition for water, energy and land; climate change; land degradation, etc., there is no guarantee that yields will continue to increase. However, see yield projections from IFPRI, FAO, and fertilizer use projections from IFA to keep abreast of developments. (JRF)
    - Over the past few decades, cereal crop yields have generally increased at a relatively low but constant rate. Recommended fertilizer application rates have remained constant or declined, hence crop production per unit of fertilizer has increased. It seems these general trends should be reflected in future projections. (ARM)

2. **Specifically, if yields are increasing, how will inputs be impacted?**
    - Offsetting trends suggests that N fertilizer efficiency will remain constant as yields increase. (KGC)
    - Yield increases will increase the demand for water. (JRF)
    - If N use efficiency increases at about the same rate as yield, then the per area application of fertilizer will remain relatively constant. (ARM)

3. **What other factors should EPA take into account when projecting future agricultural production?**
    - Give special attention to obtaining more accurate estimates for N fertilizer use on sugar cane in Brazil for the sugar cane ethanol scenario, and for P, K, and Lime use on expanded soybean production in Brazil. (KGC)
    - Factors: "Population growth, GDP growth, water availability and use efficiency, fertilizer use efficiency, changing food preferences, projections for all crops not just cereals, increased cost of fertilizer and impacts on the environment." (JRF)
    - See Wood et al., 2004 (full reference supplied) for discussion of issues important to projecting crop production and fertilizer use. *See full text of comment from ARM*.   Same Wood et al, 2004 paper also recommended by EWB.
    - Rather than assuming year 2022 application rates are equal to Fertistat rates, consider using scenarios from publications FAO 2004 and FAO 2008 (links provided). (EWB)
    - In addition to the excellent FAPRI model, it may be beneficial for EPA to partner with IFPRI re: their IMPACT model (link provided). (EWB)

APPENDICES

1. Full text of Charge Questions
2. Dr. Elizabeth W. Boyer – Response to Charge Questions
3. Dr. Kenneth G. Cassman
    –Response to Charge Questions
    –Edited version of the ICF memo in track changes format
4. Dr. John R. Freney--Response to Charge Questions
5. Dr. Arvin R. Mosier--Response to Charge Questions
6. Curricula vitae of the four reviewers
7. The document being reviewed (ICF memo of 12/12/08)

Charge Questions
International Ag GHG Peer Review

Document for review: ICF memo of 12/12/08,
"International Agriculture GHG Emissions and GHG Metrics (revised) V.3"
6/12/2009

I. Questions Related to the Data Used

A. General Questions

1. Should EPA primarily be relying on country-level data sources, or do you recommend data sources defined by other geographic areas? What alternative data sources would you recommend?
2. For any of the data sources used in the ICF memo, what additional, or better, data sources exist?
3. What better data sources exist to represent production of materials and energy use by country or other relevant geographic area?
4. The fertilizer and pesticide data show a very wide range of application rates across countries, areas, and crops. For example, in the case of pesticides, some countries' application rates are reported as zero. Based on your knowledge, how accurate are these data? What better data sources exist for fertilizer and pesticide utilization?
5. What is the best way for EPA to deal with the limitations of the data, especially those data elements to which the results are most sensitive?

II. Questions Related to the Methodologies Used

A. General Question

1. For each section of the ICF memo, please describe the key strengths and weaknesses of ICF's methods.
2. What do you recommend for improving the methodology? What can EPA do to improve the quality of the methodology (both in the near-term and in the longer-term)?

B. For Pesticide Consumption Projections

1. Is the averaging mechanism used by ICF for the pesticide data scientifically justifiable? (See last paragraph of Section I.)
2. What do you recommend to improve these projections?

C. For N2O Emissions

1. Are the IPCC 2006 defaults and the Tier 1 methodology appropriate for this analysis? What other methodologies are available (including those that might be applicable to specific countries or regions)?

2. Are the direct and indirect emissions from fertilizer and crop residues identified correctly? Is it scientifically justifiable to exclude the volatilization pathway from crop residues, as described in the memo?
3. Does the report correctly apply the IPCC Tier 1 methodology? Is this the best methodology to apply?

D. For Agricultural Energy Use

1. Is the exclusion of several fuel types as "minimal" scientifically justifiable?
2. Is it scientifically justifiable to assume that the overestimate of fuel use in the agricultural sub-sector by using data for the entire ag/forestry/fishing sector is small?
3. Is the use of average CO2 emissions for the entire agricultural sector by country (from IEA, 2007) scientifically justifiable? What methods exist to break this out by crop or other geographic area?
4. Were the factors provided by EPA (Appendix Table 7) applied appropriately? How can these factors be improved?

E. For CH4 Emissions from Rice

1. Is the scaling methodology described to adjust for the four different cropping regimes scientifically justifiable?
2. What other methodologies are better for estimating CH4 emission factors for rice cultivation?

III. Building on the Data

A. Future Crop Production/yield Increases

1. EPA uses historic data to represent future crop production. How should the agency adjust for future increases in yield?
2. Specifically, if yields are increasing, how will inputs be impacted?
3. What other factors should EPA take into account when projecting future agricultural production?

To: Jerry Boese
From: Elizabeth W. Boyer
Date: July 11, 2009
Re: Review of documents

Below is a review of the document entitled "International Agriculture GHG Emissions and GHG Metrics (revised) V.3," which was prepared for the US Environmental Protection Agency by ICF Inc. in relation to the National Renewable Fuel Standard program. Associated with my area of expertise, my comments on the "ICF memo" address primarily the sections focused on fertilizer and pesticide consumption patterns, and other aspects of the international agricultural statistics, and are structured according to the charge questions that you posed. Overall, I think that the estimates prepared by ICF are a good first approximation of changes in greenhouse gas emissions, though some refinements are needed.

I. Questions Related to the Data Used

A. General Questions

1. *Should EPA primarily be relying on country-level data sources, or do you recommend data sources defined by other geographic areas? What alternative data sources would you recommend?*
   a. For a global analysis, I feel that country scale data are an appropriate and useful first approximation. It remains challenging to obtain globally-consistent and reliable agricultural statistics data that are spatially- and temporally- explicit. Though there are many countries for which such data are available at the sub-country level, there are also many countries for which reliable data at the country scale alone remain elusive. Given the fact that there are whole distributions of rates that characterize agriculture (e.g., of fertilizer application or pesticide consumption by crop type) across a country associated with the heterogeneity in environmental conditions and land management, future efforts should continue to refine the scale of the data, aiming to use any available sub-country level data to refine estimates for individual countries and to highlight variability within and among regions.
   b. Regarding potential alternative data sources, see #2, 3, 4 below.

2. *For any of the data sources used in the ICF memo, what additional, or better, data sources exist?*
   Please see responses below.

3. *What better data sources exist to represent production of materials and energy use by country or other relevant geographic area?*
   a. *Energy data.* The International Energy Agency data that are used in the ICF memo are likely the best data source for consistent information at the global scale, and provide information specific to the agricultural sector. Other sources of data that are useful for further information at the country level include the UN Energy Statistics Database

(http://unstats.un.org/unsd/energy/edbase.htm), the World Energy Council survey of energy resources, (http://www.worldenergy.org/publications/), and the BP Statistical Review of World Energy (http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622).

4. *The* <u>*fertilizer and pesticide data*</u> *show a very wide range of application rates across countries, areas, and crops. For example, in the case of pesticides, some countries' application rates are reported as zero. Based on your knowledge, how accurate are these data? What better data sources exist for fertilizer and pesticide utilization?*

With regard to fertilizer data sources that are used in the ICF memo:

a. Page 1, line 29. I suggest changing the phrase "historical fertilizer application rates" to "contemporary estimates of fertilizer application rates," which better describes the database.
b. Page 1, line 34. Delete the phrase "with the year 2000 being the most frequent year of survey data collection," since this is not the base year for many (most?) of the countries. I suggest adding a column to the appendix table showing the year(s) for which data were used. Though useful detail are provided in the associated footnote, knowing the exact years used in the calculations are important for reproducing the ICF data from, for example when additional years' data are added to the fertistat database.
c. Page 2, line 37 / Appendix Tables 1-3. I reviewed about 70 data values selected from Tables 1-3 of the appendix (from a download of the database July 10 2009), and my calculations (conversions to the units presented in the memo) were entirely consistent with the data presented.
d. Page 2, line 42. Though the Harris (1998) reference has been widely cited in the literature (in several different forms), the reference is rather elusive and is not readily available online or in libraries. Could a PDF of this reference be made available by EPA?

With regard to potential additional fertilizer data sources:

a. I feel that that the FAO fertilizer data are appropriate for use in this global analysis; despite the uncertainties in the agricultural chemical datasets, FAO data are freely available, credible, citable, and are continually updated & improved via partnerships (e.g., with countries who report data, UN Comtrade, IFA). The ICF memo makes extensive use of the FAO *fertistat* database which provides fertilizer application rates by crop type by country. Two other useful FAO data sources potentially useful for this effort are: 1) the *FAOSTAT fertilizer commodity database* providing information on total aggregate N-P-K fertilizer use (http://faostat.fao.org/site/575/default.aspx#ancor, which is described further below; and 2) the *fertilizer use by crop* publication series (online for 22 countries at: http://www.fao.org/ag/agl/fertistat/fst_pubs_en.htm, and summarized in FAO 2006; ftp://ftp.fao.org/agl/agll/docs/fpnb17.pdf, providing further information on the distribution of fertilizer application rates in sub-regions within some of the countries that may be useful toward refining the country-scale estimates.
b. Other sources of international fertilizer use data for further information include the International Fertilizer Industry Association (IFA), the United Nations Commodity Trade Statistics Division (UN Comtrade), and official agricultural statistical data repositories for individual countries (e.g., efforts similar to the US Census of Agriculture).

With regard to pesticide data sources that are used in the ICF memo:

a. Page 3, line 59 / Appendix table 4. I suggest changing the phrase “historical data” to “contemporary estimates of pesticide application rates,” which better describes the database. I also suggest changing the title of Appendix table 4 to “pesticide application rate” rather than “pesticides fertilizer rate of application.”
b. Page 3, line 69. the text in the memo says that pesticide rates were calculated from the using average pesticide consumption data reported by FAO from 1995-2003, though the supplemental spreadsheet metadata indicates a period of 1995-2004 (see the “overview” tab of the file *Control 2022 Foreign Ag NPK_Pesticide.xls*). Adding to the inconsistency in the time period, the FAO online database that is referenced only has data available up through 2001 not 2003 or 2004 (accessed July 10, 2009 using the URL provided in both the text and in the Appendix). Correspondence indicates that FAO has suspended the pesticide consumption data collection since 2001 (though the trade database has information through 2006). Please clarify the years of pesticide data that were used & averaged in these calculations (presumably 1995-2001, and if no data available during that period, then 1990-1995), and make the documentation consistent.
c. Page 3, line 62. In order to calculate the rates of pesticide application, the pesticide consumption data (averaged over X years) were divided by the agricultural area of the country. However, it is unclear from the text which year(s) of agricultural land-area data were used in the calculation of fertilizer application rate. For example, Guatamala reports pesticide consumption (mass) only for year 1996. Was the value of land area used in the calculation of the pesticide application rate (mass/area) taken from the same year (just 1996), the average ag-land area from 1995-2001 (or other period), or something else? Ideally the reported pesticide consumption should be divided by the land area in the same year, obtaining a rate/year. Then, the rate/year values could be averaged over a larger number of years to get average rates.
d. Page 3, line 64. I suggest that a column of the appropriate *agricultural area* variable for each country be added to the Appendix table 4.
e. Text should be added to highlight the uncertainties associated with the pesticide database, and the sparse number of years of data available for many countries. The FAO site says that “A strict inter-country comparison on the basis of the database is not feasible because: 1) The country coverage and time series are incomplete due to a high rate of non-response; and 2) Although countries have been requested to report data in terms of active ingredients, some countries may have reported in formulation weight (including diluents and adjuvants) without specific indication.”
f. It is a significant problem with the reporting of zeros rather than no-data in Table 4. For example, I accessed the database on July 10 and found no-data for China reported from 1990-2001 in the FAO pesticide consumption database. However, a value of 0 is reported for China by ICF in Appendix 3 table 4; and this (and others) should be changed. Other sources of data (e.g., regional or country) will need to be used to estimate values for countries with nodata rather than assuming a value of 0. I’m not knowledgeable about additional pesticide data sources, though one starting point is the international divisions of USDA, for example with some data regarding pesticide use in China: http://www.ers.usda.gov/Data/China/.
g. Page 3, line 69 & Appendix table 4. I reviewed the values in the appendix aiming to re-create the values there from the primary data, and found this process to be difficult given the methodology reported; more details are needed (see above). Using the

pesticide consumption data from 1995-2001 (presumed what was used, given data availability) and the ag-land area data provided by FAO in an accompanying spreadsheet (year uncertain?), a random check of data from 4 countries is consistent with the data values presented in table 4.

2. *What is the best way for EPA to deal with the limitations of the data, especially those data elements to which the results are most sensitive?*
    a. As EPA typically reports, they should highlight in the text the assumptions and associated uncertainties of the estimates, provide the methodology/data for the base calculations in the public domain, and continue to refine the estimates with each release of the ghg estimates.
    b. I recommend that EPA take a leadership role in advocating the key need for improved national and international statistics on agricultural data (e.g., spatially- and temporally-explicit data on agricultural land use, specific fertilizer & pesticide application rates applied to individual crops, areas fertilized, etc.) Improved data will require better assessment methods and coordination of data collection efforts. Such data are needed for accurate accounting and understanding of many aspects of the changing environment, such as biogeochemical cycles and climate variability in addition to the greenhouse gas emissions.

II. Questions Related to the Methodologies Used

A. General Question

1. For each section of the ICF memo, please describe the key strengths and weaknesses of ICF's methods.
2. What do you recommend for improving the methodology? What can EPA do to improve the quality of the methodology (both in the near-term and in the longer-term)?

    a. *Fertilizer & Pesticide consumption methods.* One concern is the lack of availability of fertilizer & pesticide application data for certain countries; it should be noted that the country coverage and uniform time series are incomplete in both data sets are incomplete due to a high rate of non-response. In looking at the data, I am wondering whether the fertilizer use data by crop/country, and the pesticide use data by country accurately covers most of the world's agricultural area, and noted that the agricultural land area accounted for in the two databases is potentially different (given the data available for countries, and the two different FAO sources of land in agriculture data). Though I suspect that most of the major agricultural land and countries are accounted for, EPA should quantify this directly for both the fertilizer and pesticide datasets, hopefully highlighting that despite the missing information, that the databases account for the majority of global agricultural land and or/ agricultural chemical use.
    b. *Fertilizer consumption methods.* In addition to the crop types accounted for in Appendix Tables 1-3, has the application of fertilizers to grasslands and hay/fodder lands been taken into account? If not, calculations should be made to show if this is could be significant.
    c. *Fertilizer consumption methods.* One method of evaluating the data on crop specific application rates of fertilizers applied per country is to reconcile them with country-level aggregate estimates of agricultural N-P-K fertilizer use from FAOSTAT's fertilizer

commodity database (http://faostat.fao.org/site/575/default.aspx#ancor; see ResourceSTAT → fertilizers → quantities in nutrients). Agricultural fertilizer use can be calculated as equal to (production + imports – exports – non-agricultural use). This comparison could be useful for highlighting uncertainties, for example in cases where the country level fertilizer applications to agricultural land are not well aligned with the estimates from the crop-specific application rate shares. This also could be useful for estimating fertilizer use in countries where no data on fertilizer application rates by crop type is available.

B. For Pesticide Consumption Projections

1. Is the averaging mechanism used by ICF for the pesticide data scientifically justifiable? (See last paragraph of Section I.)
2. What do you recommend to improve these projections?

   a. I approve of the method of averaging the pesticide application rates over a period of years, to make estimates of country-wide pesticide application rates feasible given the sparse FAO dataset.
   b. Perhaps EPA could collaborate with FAO and IFA to obtain better estimates of pesticide use at a regional scale for use in GHG accounting.

C. For N2O Emissions

1. Are the IPCC 2006 defaults and the Tier 1 methodology appropriate for this analysis? What other methodologies are available (including those that might be applicable to specific countries or regions)?
2. Are the direct and indirect emissions from fertilizer and crop residues identified correctly? Is it scientifically justifiable to exclude the volatilization pathway from crop residues, as described in the memo?
3. Does the report correctly apply the IPCC Tier 1 methodology? Is this the best methodology to apply?

   a. The FAO publication "Global estimates of gaseous emissions of NH3, NO, and N2O from agricultural land" (2001, http://www.fao.org/DOCREP/004/Y2780E/y2780e00.htm), provides a comprehensive review of the literature about N emissions and examines the regulating factors, measurement techniques and models. This will be a useful reference for comparison to the methods ICF applied.
   b. I'm not an expert in this area (and will rely on colleagues A. Moser and K. Cassman to comment in detail on this), but would suggest a comparison of results using the IPCC methodology with those using other approaches. For example, Del Grosso et al. recently applied the process based model DAYCENT to consider greenhouse gas emissions of N_2O from cropped soils globally under contemporary and future scenarios (Del Grosso et al., 2009, Global scale DAYCENT model analysis of greenhouse gas emissions and mitigation strategies for cropped soils, *Global and Planetary Change,* 67:44-50). Their approach is different from the IPCC methodology in that accounts for variability in climatic and soil conditions. Both the input datasets and the model results could be compared to EPA's analysis, highlighting the range of results and needs for future simulations. Perhaps current and future evolutions of the global DAYCENT model approach could be used to constrain highly uncertain parameters in EPA's approach.

c. Page 5, line 168. As a hydrologist, I must comment on the high uncertainties associated with the IPCC methodology for using uniform fractions for leaching and runoff across countries, despite very large variations in water budgets, watershed conditions, and agricultural systems. An excellent recent review poses that the IPCC methodology may significantly overestimate emissions from agricultural leaching and runoff, particularly from groundwater (Nevison 2000, Review of the IPCC methodology for estimating nitrous oxide emissions associated with agricultural leaching and runoff, Chemosphere – Global Change Science 2:493-500). Perhaps one way to constrain estimates of the leaching fractions and associated N2O emissions is using regional variations on these parameters achieved with global models that consider the water balance, such as the global DAYCENT model (see b above) and IFPRI's IMPACT model (see below).

D. For Agricultural Energy Use

1. Is the exclusion of several fuel types as "minimal" scientifically justifiable?
2. Is it scientifically justifiable to assume that the overestimate of fuel use in the agricultural sub-sector by using data for the entire ag/forestry/fishing sector is small?
3. Is the use of average CO2 emissions for the entire agricultural sector by country (from IEA, 2007) scientifically justifiable? What methods exist to break this out by crop or other geographic area?
4. Were the factors provided by EPA (Appendix Table 7) applied appropriately? How can these factors be improved?

    a. Page 6, line 217. I think that the assumption of exclusion of the fuel types listed here may be appropriate. However, I would prefer to see a quantitative estimate showing that they are likely to have very low GHG emissions in comparison to other sources (e..g, using regional data sources and assumptions).
    b. *Page 6, line 222.* Regarding the supplemental data table "Foreign Ag Energy Emissions.xls," on the "electricity and heat" page tab, used to calculate the indirect emissions from the generation of electricity and heat. I am wondering why some countries w/ agriculture are not listed in column A (e.g., Venezuela, Malaysia, Algeria, Ecuador, Kuwait, Indonesia, more?); are countries omitted due to lack of energy data or due to lack of importance in agricultural energy ? I also was wondering the criteria for including only a small number of countries in the computation of heat generation (a95:a118). Please expand on the written methods section to clarify, and check to make sure that the associated CO2 emissions from electricity and heat are complete.

E. For CH4 Emissions from Rice

1. Is the scaling methodology described to adjust for the four different cropping regimes scientifically justifiable?
2. What other methodologies are better for estimating CH4 emission factors for rice cultivation?
    a. I am not knowledgeable about CH_4 emissions from rice, and will rely on other reviewers to comment on this.

III. Building on the Data

A. Future Crop Production/yield Increases

1. EPA uses historic data to represent future crop production. How should the agency adjust for future increases in yield?
2. Specifically, if yields are increasing, how will inputs be impacted?
3. What other factors should EPA take into account when projecting future agricultural production?
    a. Page 2, line 36. "Application rates for the baseline 2022 scenario are assumed to be equal to rates reported by Fertistat." Perhaps scenarios from FAO would be better than this, for example, see the publication FAO 2004, Fertilizer requirements in 2015 and 2030 revisited (ftp://ftp.fao.org/agl/agll/docs/fertreqrev.pdf) and FAO 2008, Current world fertilizer trends and outlook to 2012 (ftp://ftp.fao.org/agl/agll/docs/cwfto12.pdf).
    b. In addition to relying on the excellent FAPRI model, it may be beneficial for EPA to partner with IFPRI on further scenarios as well, given current evolution of their IMPACT model (International Model for Policy Analysis of Agricultural Commodities and Trade, see http://www.ifpri.org/themes/impact/impactwater.pdf).
    c. A useful review of fertilizer data and scenarios via modelling is provided in the paper "The Role of Nitrogen in Sustaining Food Production and Estimating Future Nitrogen Fertilizer Needs to Meet Food Demand," 2004. Wood, Stanley; Henao, S. J.; Rosegrant, Mark W. In Agricultural and the Nitrogen Cycle, ed. A.R. Mosier, J.K. Syers, and J.R. Freney. Island Press, Washington.

Response to Charge Questions from K.G. Cassman, July 5, 2009

International Ag GHG Peer Review

Document for review: ICF memo of 12/12/08,
"International Agriculture GHG Emissions and GHG Metrics (revised) V.3"

General Comments

Overall I find the proposed methods to be well documented and clearly presented. While there are a number of typographical errors that need to be corrected, and I take issue with a few components that can be easily upgraded, I believe the proposed methods are sound. I append a copy of the ICF Memo with track changes showing some of the typos that need correction, and a few suggested corrections. I also append as separate documents two papers that support comments made below in my review. These include a paper on fertilizer inputs to soybean production in Brazil in areas where soybean production area is expanding, and another paper on the sensitivity of future N global N fertilizer use to the rate of increase in crop yields, which determines the amount of crop area that will be required, and the rate of change in N fertilizer efficiency.

I. Questions Related to the Data Used

A. General Questions

1. Should EPA primarily be relying on country-level data sources, or do you recommend data sources defined by other geographic areas? What alternative data sources would you recommend?

I do not believe there are more accurate data on fertilizer use by crop, or energy use in agriculture, than those used in the "International Agriculture GHG Emissions and GHG Metrics (revised) V.3". Because these sources (FAOSTAT, Fertistat, IEA, and IRRI rice production ecology) provide data on a country basis, I cannot envision how the international GHG emissions from land use change could be calculated on any other geographical basis than at a country level.

2. For any of the data sources used in the ICF memo, what additional, or better, data sources exist?

I do not know of any better data sets than those used in this analysis.

3. What better data sources exist to represent production of materials and energy use by country or other relevant geographic area?

One of the most sensitive parameter in the GHG emissions from agriculture is the energy requirement for nitrogen fertilizer production. The values for this parameter used in this analysis are taken from GREET. However, the GREET may use an outdated value for the carbon intensity of N fertilizer production, at least for a global average value. I suggest a review of this factor to ensure that the most up-to-date value is used in the analysis. For example, the value for the carbon intensity of N fertilizer production used in GREET is higher than that used by the IPCC 2006.

4. The fertilizer and pesticide data show a very wide range of application rates across countries, areas, and crops. For example, in the case of pesticides, some countries' application rates are reported as zero. Based on your knowledge, how accurate are these data? What better data sources exist for fertilizer and pesticide utilization?

Although pesticide use data are not very good for some countries, the good news is that the GHG emissions associated with pesticide use in agriculture is relatively small. Therefore, spending time and energy on obtaining better data for pesticide use by country will not have a large impact on the GHG emissions estimates from international agriculture. In contrast, fertilizer use levels by country are of critical importance to GHG estimates from agriculture. Therefore, time and effort spent on improving these data would be well spent. Here are several suggestions:

(a) Simple proofing of the data is important to ensure that there are no transcription errors in the database. For example, in the short time I spent on cross-checking the data, I found two typos as follows: Argentina corn N rate shown as 11.3 kg/acre on the "Control 2022 Foreign Ag NPK_Pesticide.xls" "Fertilizer" sheet is higher than the 9.6 kg/ac value shown in Appendix Table 1, likewise the rate of N fertilizer used on soybean in China is given as 24.3 in the xls "Fertilizer" sheet versus 23.8 in Appendix Table 1.

(b) Some crops in a few key countries have a large impact on the overall GHG emissions of the different scenarios. For example, N fertilizer use on sugar cane production in Brazil has a huge impact on the sugar cane biofuel scenario. But N fertilizer use on Brazil sugar cane shown in Appendix table 1 appears to be far too low. For example, based on FAOSTAT yield data and the N fertilizer use data from the "Fertilizer" sheet in the xls file, Brazilian sugar cane gives a yield of about 1300 kg per kg of applied N, versus 821, 499, and 398 for sugar cane in the USA, China, and Australia, respectively. But in the USA, sugar cane production largely occurs on soils of higher fertility than in Brazil, so a large yield to N fertilizer input ratio in the USA would be expected. In contrast, sugar cane in Brazil grows on soils much more similar to those in Australia and China and all three countries have relatively similar yield levels. Therefore, I believe the N fertilizer rates specified for Brazilian sugar cane are much too low, and because of the large influence this has on the sugar cane ethanol scenario, greater attention should be paid to obtaining a more appropriate value for this parameter.

Likewise, soybean production in Brazil has a huge impact on the soy biodiesel and corn ethanol scenarios—both due to expansion of soybean production area in Brazil due to indirect land use change. Soybean production in Brazil is expanding mostly into areas that have acid-infertile soils and thus require much higher rates of P and K than the average values shown in Appendix tables 1, 2, and 3. Moreover, because these soils are so highly acid, large amounts of lime are required (see Cassman, 2005—provided as a pdf file), and yet lime input is not considered in this analysis. Therefore, I urge specific attention to the fertilizer and lime use on expanded soybean production area in Brazil as a result of indirect land use change predicted by the FAPRI model in the corn ethanol and soybean biodiesel scenarios. It is not appropriate to use the current Brazil average fertilizer values for increased soybean area.

5. What is the best way for EPA to deal with the limitations of the data, especially those data elements to which the results are most sensitive?

Please see comments under #3 and #4 above.

II. Questions Related to the Methodologies Used

A. General Question

1. For each section of the ICF memo, please describe the key strengths and weaknesses of ICF's methods.

Section I: Fertilizer and Pesticide Consumption Projections

Strengths: the analysis uses the best available data to estimate average fertilizer and pesticide use in agriculture, and explanation of estimation methods is clear.

Weaknesses: the use of current average fertilizer rates to estimate GHG emissions from increased crop production area due to biofuel production—especially for expanded soybean production area in Brazil under the corn ethanol and soy biodiesel scenarios.

Section II: N2O emissions associated with fertilizer

Strengths: I strongly support the use of IPCC (2006) Tier 1 methods for estimating N2O emissions from agriculture. They are transparent and based on the best available science. While they may not capture all of the detailed effects of soil and climate variation in time and space, they are robust when used as average values across a large agricultural landscape (such as a country level) because geospatial differences offset one another. Use of a simulation model, like DAYCENT, would not be appropriate because it has not been shown to be more accurate than IPCC estimates across a wide range of crops and environments.

Weaknesses: There are typo errors in the memo related to the IPCC method, and Equation 3 appears to be incorrect. I've tried to correct these using track changes on the document, which I append along with this review.

Section III: GHG emissions from agriculture

Strengths: Here again, I believe the analysis uses the best available database for this analysis, and I do not know of any other data source.

Weaknesses: I would consider replacing the GREET upstream energy use value for production of N fertilizer with the IPCC value because I believe the former is outdated.

Section IV: Rice methane emissions

Strengths: use of specific EF values for different types of rice production (irrigated, rainfed, deepwater) in each country.

Weaknesses: use of a unique value for USA rice production that is nearly two-fold greater than the default value for irrigated rice. It seems the only justification for this approach would be because there is a publication about methane emission from a USA rice system, and the value used is based on this estimate. However, I can see not biophysical reason why methane production from USA irrigated rice is higher than that from irrigated rice in Japan, South Korea, or China. Therefore, I recommend using the default parameter for USA rice.

2. What do you recommend for improving the methodology? What can EPA do to improve the quality of the methodology (both in the near-term and in the longer-term)?

EPA can help improve the methodology by calling for more funding resources allocated to measuring both N fertilizer use efficiency and N2O emissions from commercial-scale fields of major crops that account for the vast majority of N2O emissions worldwide. This could be part *of an international effort, but with a strong component in the USA (from USDA and perhaps DOE). There are far too little data from production-scale fields, and values are affected by the scale of production. In other words, small plot studies at research stations give inaccurate estimates of both N fertilizer efficiency and N2O emissions that actually occur in farmers' fields. In the short term, IPCC methods are the best we have.*

B. For Pesticide Consumption Projections

1. Is the averaging mechanism used by ICF for the pesticide data scientifically justifiable? (See last paragraph of Section I.)

I would suggest using the most recent 3-year average use rate, rather than the average for the entire time series.

2. What do you recommend to improve these projections?

I have no good ideas how to improve these projections. It is noteworthy, however, that increasing use of GMO insect resistant crops will likely reduce the use of pesticides over time.

C. For N2O Emissions

1. Are the IPCC 2006 defaults and the Tier 1 methodology appropriate for this analysis? What other methodologies are available (including those that might be applicable to specific countries or regions)?

Yes, see response to evaluation of Section II above.

2. Are the direct and indirect emissions from fertilizer and crop residues identified correctly? Is it scientifically justifiable to exclude the volatilization pathway from crop residues, as described in the memo?

Yes, except for typos in the formulas in the memo document, which I've identified using track changes in the attached version of the memo.

3. Does the report correctly apply the IPCC Tier 1 methodology? Is this the best methodology to apply?

Yes, it appears to correctly applies the Tier 1 methodology if the correct equations are used (i.e. correct the typos).

D. For Agricultural Energy Use

1. Is the exclusion of several fuel types as "minimal" scientifically justifiable?

Yes. I don't see why these fuel types would be influenced by the biofuel scenarios.

2. Is it scientifically justifiable to assume that the overestimate of fuel use in the agricultural sub-sector by using data for the entire ag/forestry/fishing sector is small?

Yes, if indeed they represent a small portion of energy use compared to crop and livestock agriculture.

3. Is the use of average CO_2 emissions for the entire agricultural sector by country (from IEA, 2007) scientifically justifiable? What methods exist to break this out by crop or other geographic area?

I see no other way to do it. Attempts to combine country-based data into watersheds or regions would add additional errors and uncertainties to the data.

4. Were the factors provided by EPA (Appendix Table 7) applied appropriately? How can these factors be improved?

I believe they have been applied correctly. No ideas on how to improve them.

E. For CH_4 Emissions from Rice

1. Is the scaling methodology described to adjust for the four different cropping regimes scientifically justifiable?

Yes. Water regime has the greatest impact on methane emissions from rice systems. Thus, distinguishing amongst the four rice production methods, based on hydrology, is the most accurate method for estimating CH_4 emissions.

2. What other methodologies are better for estimating CH_4 emission factors for rice cultivation?

None that I know of. Here again, I am comfortable with the IPCC estimate methods.

III. Building on the Data

A. Future Crop Production/yield Increases

1. EPA uses historic data to represent future crop production. How should the agency adjust for future increases in yield?

This is a complicated topic. For N, future use depends on two parameters: (i) improvements, or decreases in N fertilizer use efficiency (quantified as the yield obtained per unit of applied N), and (ii) the rate of increase in crop yields, which determines how much crop area will be required. I append a paper that describes how these two factors will govern future N fertilizer use on crops (Dobermann and Cassman, 2005). Bottom line, from my viewpoint, I believe that projecting yield increase rates of the past 40 years is the best estimate for future yield increases.

2. Specifically, if yields are increasing, how will inputs be impacted?

In general, the same technologies that contribute to higher yields, also improve N fertilizer use efficiency. But, all else equal, N fertilizer efficiency generally decreases as yields increase due to a diminishing return response. Therefore, I believe it is justifiable to assume that these trends off set one another, which mean yields increase while N fertilizer efficiency remains constant.

3. What other factors should EPA take into account when projecting future agricultural production?

I would give special attention to obtaining more accurate estimates for N fertilizer use on sugar cane in Brazil for the sugar cane ethanol scenario, and for P, K, and Lime use on expanded soybean production in Brazil under the corn ethanol and soy biodiesel scenarios.

Final additional suggestions:

1. Please use metric units throughout. Using units of kg/acre don't make sense.
2. In appendix tables 2 and 3, specify that P and K rates are based on P2O5 and K2O rather than on an elemental basis.
3. The formula and table for estimating the amount of crop residues is a mess. The equation in Appendix Table 6 is given as:

$$\mathbf{AGDM_{(t)} = Crop_{(t)} * Slope_{(t)} + Intercept_{(t)}}$$

What does Crop (i) stand for? Is it the economic yield, adjusted for moisture content? What is the scientific basis for this equation? This generic equation suggests that the proportion of total aboveground biomass in residue changes in relation to economic yield. What peer-reviewed papers were used to justify this assumption? It seems this relationship is derived from a recent meta-analysis performed by someone at CSU. Perhaps there is more detail and justification provided elsewhere, but as given in the ICF methods document and the appendix table, the analysis does not have adequate agronomic justification. Crop residue estimates should be based on a parameter called the "harvest index" (HI), for which there is a large body of research on factors affecting it. The HI is calculated as the ratio of grain, or economic yield, to total aboveground biomass. I am highly suspect of the accuracy of the current approach given the lack of clarity in Table Appendix A6.

MEMORANDUM

To: Vincent Camobreco and Elizabeth Etchells, EPA

From: John Venezia, Erin Gray, Victoria Thompson, and Sarah Menassian, ICF

Date: December 12, 2008

Re: International Agriculture GHG Emissions and GHG Metrics (revised) V.3

The 2007 Energy Independence and Security Act significantly increases the amount of renewable fuels required to be sold in the U.S. under EPA's Renewable Fuel Standard (RFS). This mandated increase in biofuel consumption could have significant lifecycle greenhouse gas (GHG) impacts due to global shifts in land use for the production of biofuel crops due to changes in demand for energy, fertilizer and pesticides. There is significant data available on domestic energy, fertilizer, and pesticide used in agriculture. The work described here focuses on compiling information on international (non-U.S.) agricultural inputs.

This memorandum summarizes the methodology used to estimate GHG emission factors and changes in GHG emissions related to international agricultural energy use, fertilizer and pesticide consumption, and rice cultivation due to potential changes in land use to meet increased demand for biofuels. Data were obtained and analyzed from various agricultural and energy datasets. Intergovernmental Panel on Climate Change (IPCC) methodologies were used to estimate GHG emissions.

Specifically, ICF developed the following:

I. Fertilizer and Pesticide Consumption Projections
II. N_2O Emissions from Fertilizer Consumption and Crop Residues
III. GHG Emission Rates for Agricultural Energy Use
IV. CH_4 Emission Factors for Rice Cultivation

We provide a detailed explanation of the methodologies and data sources used below.

I. Fertilizer and Pesticide Consumption Projections

Fertilizer Consumption Projections

Historical fertilizer application rates (kilograms of fertilizer applied per hectare) and consumption (tonnes), as well as agricultural area, were primarily obtained from the Food and Agriculture Organization's (FAO) Fertistat Dataset.[1] Fertistat is a publicly available, international fertilizer dataset containing consumption data by crop and country. Fertistat data are available for nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) fertilizers, and are based on surveyed observations for a single year or period between planting and harvesting.[2] Survey data were collected between 1988 to 2004, with the year 2000 being the most frequent

Comment [h1]: Metric or English units?

Comment [h2]: Please specify in appendix tables that P and K data are given on a P2O5 and K2O basis, respectively.

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[1] Food and Agricultural Organization. Fertistat Database. http://www.fao.org/ag/agl/fertistat/. Last accessed October 10, 2008.

[2] Personal correspondence. Wolfgang Prante, Information Management Officer. Food and Agriculture Organization. July 15th, 2008.

year of survey data collection.[3] Application rates are calculated by Fertistat as total fertilizer consumption per country divided by agricultural area fertilized.[4] Application rates for the baseline 2022 scenario are assumed to be equal to rates reported by Fertistat. Tables 1 through 3 in the Appendix present fertilizer application rates by country and crop.

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Comment [h3]: There are Some inconsistencies between fertilizer rate values in these appendix tables and those on the "Fertilizer" sheet in the EXCEL spreadsheet "Control 2022 Foreign Ag NPK_Pesticide.xls file.

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Fertistat did not report data for several crops of interest for certain countries, including Russia wheat, China wheat, and India soybean. Fertilizer application rates for wheat cultivation in Russia and China were obtained from Harris, 1998.[5] Application rates for soybean production in India were obtained from the Fertilizer Association of India.[6]

To determine the difference in fertilizer consumption between an increased biofuels demand scenario and the 2022 baseline scenario, application rates by country and crop were multiplied by projected acreage changes for crop production from the Food and Agricultural Policy Research Institute (FAPRI) agricultural models. Change in fertilizer consumption was calculated for 33 individual countries and for 8 regions (as shown in Table 1) to match the crop production change data from the FAPRI model results. As FAPRI region definitions were largely unavailable by crop, FAO regional definitions were used.[7,8]

Table 1: Country and Region Definitions

Individual Countries			European Union		Other Africa
Algeria	India	Paraguay	Austria	Hungary	Ethiopia
Argentina	Indonesia	Philippines	Belgium	Ireland	Kenya
Australia	Iran	Russia	Czech Republic	Italy	Madagascar
Bangladesh	Japan	South Africa	Germany	Lithuania	Malawi
Brazil	South Korea	Taiwan	Denmark	Latvia	Tanzania
Canada	Malaysia	Thailand	Spain	Netherlands	Zambia
China	Mexico	Turkey	Estonia	Poland	Zimbabwe
Colombia	Morocco	Uruguay	Finland	Portugal	
Cuba	Myanmar	Uzbekistan	France	Sweden	
Egypt	Nigeria	Venezuela	United Kingdom		
Guatemala	Pakistan	Vietnam	Greece		

Other Asia	CIS	Other Eastern Europe	Other Latin America	Other Middle East	Western Africa
Cambodia	Azerbaijan, Republic of	Albania	Bolivia	Israel	Ghana
Laos	Belarus	Bulgaria	Chile	Jordan	Guinea
Sri Lanka	Moldova, Republic of	Croatia	Costa Rica	Kuwait	Mauritania
Korea, Dem People's Rep		Slovakia	Dominican Republic	Lebanon	Togo
			Ecuador	Saudi Arabia	
			Honduras	Sudan	
			Nicaragua	Syrian Arab Republic	
			El Salvador		

[3] For several countries, Fertistat reported two or three years of data collection to represent growing periods for crops or yearly averages for a range of years. Data does not refer to fertilizer consumption over a two or three year timespan. For crop data with two years mentioned, the data refer to the period between planting and harvesting, and the latter year is used in the analysis. For crop data with three years mentioned, values reported are yearly averages, and the middle year was used in the analysis.

[4] Where the percentage of total agricultural area fertilized is not available, application rates are calculated by Fertistat as consumption divided by agricultural area planted (i.e. this assumes all area is fertilized). Personal correspondence. Jan Poulisse, Senior Manager. Food and Agriculture Organization.

[5] Harris, Gene. 1998. An Analysis of Global Fertilizer Application Rates for Major Crops. Agro-Economics Committee. Fertilizer Demand Meeting. Toronto, Canada.

[6] Fertilizer Association of India. "Usage of Fertilisers by Various Crops: 1996-97."

[7] Region definitions: Switzerland and Norway are included in the "Rest of World" category for land use change. Sudan is included in "Other Middle East." "Russia and Ukraine" category applies only to Russia. The United States is excluded from the dataset.

[8] FAPRI regions vary by crop type, so "Other" categories (e.g. Other Latin America") could potentially differ in the countries they include.

Pesticide Consumption Projections

Pesticide consumption projections are calculated using the same methodology as fertilizer projections. Historical data were taken from FAO's FAOSTAT database for pesticide consumption, including fungicides and bactericides, herbicides, and insecticides. Data were available by country, but not by crop. Data refers to the quantity of pesticides used in or sold to the agricultural sector for crops and seeds.[9] Rates of pesticide application were determined by dividing FAOSTAT's pesticide data by "agricultural area," a variable found in FAO's ResourceStat - Land dataset[10] (see Appendix, Table 4). Agricultural area is defined as arable land (land under temporary crops), land cultivated with permanent crops (e.g. coffee), and permanent pastures (land used for five or more years for herbaceous forage crops).[11] Change in pesticide consumption by country was calculated by multiplying pesticide application rates by the change in crop production acreage due to increased U.S. demand for biofuels.

To ensure that pesticide application rates were representative of a typical year, an average of pesticide consumption was calculated from 1995 through 2003. If data were not available during this period, data were averaged from 1990 through 1995.

II. N_2O Emissions from Fertilizer Consumption and Crop Residues

Change in fertilizer consumption and associated nitrous oxide (N_2O) emissions due to increased U.S. biofuel demand are projected based on crop production acreage for priority crops and countries. GHG emissions are calculated based on nitrogen (N) inputs from synthetic N fertilizer consumption and crop residues, both of which cause direct and indirect N_2O emissions from agricultural soils. Emission estimates are based on the IPCC 2006 default emissions factors and emissions equations for Tier 1 methodology.[12]

Projections of Changes in GHG Emissions from Fertilizer Consumption

Changes in fertilizer consumption cause changes in the amount of N added to soils, which change the amount of N_2O eventually emitted to the atmosphere. For this analysis, we estimate changes in N_2O emissions due to changes in synthetic fertilizer consumption and changes in crop residue application for certain crops. As Fertistat reports only mineral (or synthetic) fertilizer consumption data, we did not estimate changes in GHG emissions from organic fertilizer consumption. Emissions from organic fertilizer were handled separately by EPA through analysis of manure management changes from livestock operations. Calculations are based on Tier 1 methodologies for managed soils from the IPCC 2006 Guidelines. Tier 1 methodologies do not consider different land cover, soil type, climatic conditions, or management practices, and also do not consider any lag time for direct emissions from crop residues.[13]

The pathways of N in the soil are complex, but can be summarized as follows: N_2O emissions from soils occur either directly or indirectly. Direct emissions occur when N is applied to soil (from fertilizer, crop residues, or other sources), and eventually N_2O is emitted through the processes of nitrification and denitrification. Indirect emissions occur in two ways: (1) N applied to soils can be volatilized in a non- N_2O form, and redeposited in another location, where N_2O emissions will occur and (2) applied N can be leached by water in a non- N_2O form, and the N transported in the runoff will emit N_2O in a different location from

[9] FAO. FAOSTAT: Pesticide Consumption. http://faostat.fao.org/site/424/default.aspx#ancor. Last accessed: October 9, 2008.
[10] FAO. ResourceStat-Land. http://faostat.fao.org/site/377/default.aspx#ancor. Last accessed: October 15, 2008.
[11] FAO. FAOSTAT: Glossary. http://faostat.fao.org/site/379/DesktopDefault.aspx?PageID=379. Last accessed: October 10, 2008.
[12] Intergovernmental Panel on Climate Change. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry, and Other Land Use.
[13] IPCC. op. cit., pg. 11.6

that where the N was applied. This analysis looks at direct and indirect emissions from synthetic N fertilizer application and crop residues. GHG emissions from fertilizer consumption are determined based on the annual amount of synthetic fertilizer applied. Crop residue emissions are based on the N content of above- and below-ground crop residues (including N-fixing crops) that are returned to soils. Indirect crop residue emissions only include leaching/runoff emissions, as crop residue N is not thought to volatilize. In summary, GHG emission pathways include:

1. Direct emissions from N additions to soils from synthetic fertilizers
2. Indirect emissions from N additions to soils from synthetic fertilizers from volatilization and leaching/runoff.
3. Direct emissions from N in crop residues
4. Indirect emissions from N in crop residues due to leaching and runoff.

Emissions were estimated using IPCC default emission factors and default crop residue parameters (see Appendix, Tables 5 and 6). Emissions were calculated using the following Tier 1 equations:

Direct Emissions:

1. Direct N_2O emissions from synthetic fertilizers:

$$\text{(1)} \quad \text{Emissions} = F_{SN} \times EF_1 \times 44/28$$

Where:

F_{SN} = the annual amount of synthetic fertilizer N applied to soils (kg N)
EF_1 = emission factor,(equal to 0.1 kg N_2O-N/kg N input)
44/28 = conversion of N_2O -N to N_2O

Comment [h4]: Typo error: IPCC Tier 1 value is 0.01 kg N2O-N/kg N input.
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2. Direct N_2O emissions from crop residues:

$$\text{(2)} \quad \text{Emissions} = F_{CR} \times EF_1 \times 44/28$$

Where

F_{CR} = the annual amount of N in crop residues and forage/pasture renewal, kg N_2O-N.
EF_1 = emission factor,(equal to 0.1 kg N_2O-N/kg N input)
44/28 = conversion of N_2O -N to N_2O

Comment [h5]: Typo: should be kg N, not kg N2O
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Comment [h6]: Typo: should be 0.01
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N additions to soils from crop residues depend on the crop type and yield, since different crop types have different N contents and different amounts of residue typically left in the soil. The equation for F_{CR} is:

(3) $F_{CR} = \sum (\text{Yield Fresh}_T \times DRY_T \times S_T + I_T) \times Area_T \times N_{ag(T)}) + (N_{ag(T)}$ x ~~+~~ $R_{bg(T)} \times N_{bg(T)})$

Comment [h7]: This equation appears to be wrong. I've tried to revise it to give the correct value for the N input from residues, both above and below ground.
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Where:

T = crop or forage type
Yield Fresh = fresh weight yield of crop (kg fresh weight/ha)
DRY = dry matter fraction of harvested crop (kg dry matter/kg fresh weight)
S = Slope for above-ground residue dry matter
I = Intercept for above-ground residue dry matter
Area = total annual area harvested (ha)
N_{ag} = N content of above-ground residues (kg N/kg dry matter)
R_{bg} = ratio of below-ground residues to harvested yield
N_{bg} = N content of below-ground residues (kg N/kg dry matter)

Table 6 in the Appendix presents crop residue factors by crop type. If default factors were not available for a particular crop, then proxies were used based on “major crop type” categories. Rice and sorghum estimates are based on default factors for grains; and peanut and sugarbeet estimates are based on root crops default factors. IPCC default factors were not available for cotton, palm oil, rapeseed, sugarcane and sunflower. As a result, direct and indirect emissions from crop residues for these crops are not included in total N_2O emissions estimates.

To determine the fresh weight yield for priority crops and countries, the change in crop production provided from the FAPRI model results in the year 2022 was divided by the change in crop production acreage. Area in the F_{CR} equation refers to the change in crop production acreage. Changes in crop acreage were obtained from the FAPRI model forecasts for key crops, countries, and regions.

Indirect emissions:

The two pathways for indirect emissions from managed soils are: (1) volatilization of N as NH_3 and oxides of N (NO_x), and the deposition of these gases and their products NH_4 and NO_3 onto soils and the surface of lakes and other waters; and (2) the leaching and runoff from land of N from synthetic fertilizer and crop residues. Leaching and runoff refers to the inorganic N in or on soils which bypasses biological retention mechanisms by transport in runoff, or overland water flow, and through flow through soil macropores or pipe drains.[14]

3. Indirect emissions from synthetic fertilizer consumption:

$$\text{(4)} \quad \text{Emissions} = [(F_{SN} \times Frac_{GASF} \times EF_2) + (F_{SN} \times Frac_{leach} \times EF_3)] \times 44/28$$

Where:

F_{SN} = annual amount of synthetic fertilizer N applied to soils (kg N)

$Frac_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x (equal to 0.10 kg N volatilized/kg N applied)

EF_2 = emission factor for N_2O emissions from N volatilization (equal to 0.01 kg N_2O-N/(kg NH3-N + NOx-N volatilized))

$Frac_{leach}$ = N lost from leaching and runoff (equal to 0.30 kg N/kg N applied)

EF_3 = emission factor for N_2O emissions from N leaching and runoff (equal to 0.0075 kg N_2O-N/kg N leached or runoff)

44/28 = conversion of N_2O -N to N_2O

4. Indirect emissions from crop residues:

$$\text{(5)} \quad \text{Emissions} = F_{CR} \times Frac_{leach} \times EF_3 \times 44/28$$

Where:

$Frac_{leach}$ = N lost from leaching and runoff (equal to 0.30 kg N/kg N applied)

EF_3 = emission factor for N_2O emissions from N leaching and runoff (equal to 0.0075 kg N_2O-N/kg N leached or runoff)

44/28 = conversion of N_2O -N to N_2O

Total Emissions

To derive total N_2O emissions from changes in fertilizer consumption due to changes in crop acreage, emissions were summed across these four pathways.

[14] IPCC, op. cit., pg. 11.19

III. GHG Emission Rates for Agricultural Energy Use

We estimated GHG emissions per area of agricultural land by country, due to agricultural energy inputs in the form of direct emissions from fuel consumption and indirect emissions from electricity and heat.

Total CO_2 emissions from fuel combustion in the agriculture/forestry/fishing sector of each country for 2005 and 2006 were taken from the International Energy Agency's (IEA) CO_2 Emissions from Fuel Combustion 2007.[15] As these estimates also include forestry and fishing activities, using these estimates for agriculture results in an overestimate of emissions. However, we believe this overestimate to be small, as agriculture is by far the largest consumer of energy use of these sectors. Furthermore, emissions were determined per acre of cropland, no distinction was made between different types of crops. Emissions from the use of the following fuel types are minimal and were therefore not included in each country's total CO_2 emissions: Biogas, Charcoal, Gas Works Gas, Geothermal, Other liquid biofuels, Primary Solid Biomass, Solar thermal.

To estimate indirect emissions from the generation of electricity and heat, 2005/2006 data on electricity and heat consumption in the agriculture/forestry/fishing sector were obtained from IEA's Energy Statistics of Non-OECD Countries, 2008 and Energy Statistics of OECD Countries, 2008.[16, 17] CO_2 emissions were estimated by multiplying consumption by the average rate of CO_2 produced per kWh of electricity or heat generated (provided by IEA's CO2 Emissions from Fuel Combustion, 2007).

Lifecycle GHG emission factors[18] were applied to all calculated emissions to estimate GHG emissions from fuel exploration, production, transportation, and distribution (see Appendix, Table 7). To estimate CO_2 emissions per agricultural area, emissions estimates were divided by total agricultural area for each country (see Appendix, Table 8).[19]

IV. CH_4 Emission Factors for Rice Cultivation

For this analysis, we developed country- and region specific emission factors for rice cultivation. We also provided rice growing season lengths.

Calculating emissions from rice cultivation, per the IPCC 2006 guidelines, requires the following data: area of rice harvested, an emissions factor, and planting to harvesting season length. Changes in area of rice harvested were provided from the FAPRI model results. Emissions from rice cultivation can be affected by a number of factors, namely water regimes during the cultivation period, water regimes before the cultivation period, and organic amendments. If country-specific data are available on these, the data can be used to scale the IPCC default emission factor.

For countries in this analysis, country-specific data on organic amendments and the water regime before the cultivation period were not available. Data were available, however, for the water regimes used during the cultivation period. Therefore, the default IPCC emission factor was scaled for each cropping regime: irrigated, rainfed lowland, upland and deepwater. Default factors are presented in the Appendix, Table 9.

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Comment [h8]: Based on Appendix table 9, it appears that the USA EF value is double the default value for irrigated rice. From a biophysical perspective, I cannot understand why this would be so/ More justification needed for this.

[15] International Energy Agency. 2007. CO_2 Emissions from Fuel Combustion: 1971-2005. IEA Statistics. IEA reports 2006 data for OECD countries and 2005 data for OECD countries.
[16] International Energy Agency. 2008. Energy Statistics of Non-OECD Countries. IEA Statistics.
[17] International Energy Agency. 2008. Energy Statistics of OECD Countries. IEA Statistics.
[18] Factors provided by Vincent Camobreco, EPA, based on "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" (GREET) model results for different fuels and scaling combustion vs. upstream GHG emissions.
[19] FAO: ResourceStat-Land. Dec. 2007. http://faostat.fao.org/site/377/default.aspx#ancor. Last accessed: October 17, 2008.

Rice cultivation season lengths were available from the International Rice Research Institute (IRRI) for priority countries.[20]

To be able to apply the cropping practice-specific emission factor, the area harvested under each cropping regime must be known. Data were collected from IRRI regarding the cropping practices in the major rice growing countries of the world. Data covers the percentage of area cultivated under each cropping regime (irrigated, rainfed lowland, upland and deepwater) in each country (see Appendix, Table 10). To calculate emissions from rice cultivation, the IRRI cropping regime percentages for each country can be applied to area harvested to determine the area grown under each regime in the country. Then, using the season length for the country and the scaled emission factors for each cropping regime, emissions can be calculated for each cropping regime, and then summed to produce the total emission estimate for each country. These country totals were multiplied by the changes in rice production acres from the FAPRI model results to determine overall rice methane emission changes.

[20] International Rice Research Institute. www.iri.org. Last accessed: October 15, 2008.

Responses to Charge Questions

I. Questions Related to the Data Used

A. General Questions

1. Should EPA primarily be relying on country-level data sources, or do you recommend data sources defined by other geographic areas? What alternative data sources would you recommend?

You will get better information if you can get data from each of the countries of interest. Data averaged over regions is unlikely to give you good results. In general the data from the FAO data base is the best available, but better up to date fertilizer data is available from the International Fertilizer Industry Association. They report fertilizer consumption by regions as well as fertilizer use by individual countries.

2. For any of the data sources used in the ICF memo, what additional, or better, data sources exist?

Fertilizer consumption data for nitrogen, phosphorus and potassium is available from the International Fertilizer Industry Association (www.fertilizer.org). You state that Fertistat did not report data for several crops of interest for certain countries, including Russia wheat, China wheat and India soybean. This data is available from International Fertilizer Industry Association; it is given in their publication "Assessment of Fertilizer Use by Crop at the Global Level 2006/07 – 2007/08" by Patrick Heffer in www.fertilizer.org

3. What better data sources exist to represent production of materials and energy use by country or other relevant geographic area?

The Energy Information Administration of the United States Government provides energy statistics for various countries. http:/tonto.eia.doc.gov

4. The fertilizer and pesticide data show a very wide range of application rates across countries, areas, and crops. For example, in the case of pesticides, some countries' application rates are reported as zero. Based on your knowledge, how accurate are these data? What better data sources exist for fertilizer and pesticide utilization?

FAO originally collected data for individual pesticides 30 years ago through administering the Pesticide Annual Questionnaire to participating governments. Following poor response from the questionnaire FAO in cooperation with the Commission of the European Union simplified the survey to include only major groupings of pesticides. The current database contains the results of these more recent surveys. If the pesticide application rate is given as zero it probably means that the government of that country didn't respond to the questionnaire or they don't have data for pesticides.

For fertilizer data the International Fertilizer Industry Association (IFA) data base is more up to date than the FAO database. The IFA database allows free online access to historical fertilizer consumption statistics by product and by country from 1973/74 to 2006 (IFADATA). In addition IFA have recently produced a publication entitled "Assessment of Fertilizer Use by Crop at the Global Level 2006/07 – 2007/08" by Patrick Heffer (See www.fertilizer.org) containing more recent data.

Other sources for pesticide use are Nation Master and World Resources Institute. However, investigation reveals that the source of Nation Master's data is the World Resources Institute, and their source is the FAO database. This tends to reinforce the selection of the FAO data base as being the best available source. A better source would be to obtain Industry data from each country, and to average consumption for a number of years rather than use information for a single year.

5. What is the best way for EPA to deal with the limitations of the data, especially those data elements to which the results are most sensitive?

Go to each country for the information.

II. Questions Related to the Methodologies Used

A. General Question

1. For each section of the ICF memo, please describe the key strengths and weaknesses of ICF's methods.

Section I. Fertilizer and Pesticide Consumption Projections

In a document such as this the data should be reported in metric units, e.g. kg/hectare. Data should never, under any circumstances, be reported using a mixture of imperial and metric units as is used in the ICF memo - Appendices, viz. kg/acre.

Should have used the latest data available. In the excel file "Control_2022_Foreign_Ag_NPK_Pesticide" the most recent data is for India and South Africa in 2004. Data for the other countries is older than that and goes as far back as 1994. The IFA data base and publication by Heffer has data for fertilizer use up to 2007/2008.

Appendix Tables 1, 2, and 3 for fertilizer use are incomplete: Some examples of the deficiencies are given below:

Algeria, Ivory Coast, Iraq, Peru, Tunisia and Ukraine are listed but no data for fertilizer use is given. **Chile** is not even mentioned. Data for total N, P and K consumption for all of these countries except Ivory Coast is available on the IFA database.

Australia; information is given for nitrogen use on cotton and sugarcane only. No information is given for wheat or other cereals even though most of the nitrogen used in

Australia is applied to cereals (See IFA 2009). Considerable nitrogen is also applied to oilseeds, fruits and vegetables.

China; no information is given for nitrogen use on cotton even though 1,376,000 tonnes of N was applied to this crop in 2007-2007/2008.

Russia; information is given for nitrogen use on wheat only. IFA provides information for nitrogen use on wheat, rice, maize, other grains, soybeans, other oil crops, sugar, fruits and vegetables and other crops

Fruits and Vegetables; No data are given for fertilizer use on fruits and vegetables even though 15.6%, 17.9% and 21.5% of the world consumption of N, P and K, respectively, was used on these crops in 2007-2007/2008 (IFA 2009)

It is very difficult to interpret the pesticide data (Table 4) because of the mixed units, and it is not known whether the data given is for total amount of pesticide applied or the amount of active ingredient. The caption for Table 4 is incorrect. Pesticides are not "fertilizers" Delete "fertilizer" from the caption.

In Table 4 pesticide use in China is given as zero even though information is given for pesticide use in China in FAOSTAT. It certainly is not zero, as according to Xinhua (China's main state news agency), the annual pesticide use in China is about 1.2 million tons (Li Zijun 2006. "Soil Quality Deteriorating in China, Threatening Public Health and Ecosystems." http://www.worldwatch.org/node/4419). Also in 2005 China produced 1,039,000 tons of pesticides and exported 428,000 tons (Production Monthly News. July 7, 2006. Shanxi Petroleum and Chemistry Industry Office. http://www.sxsh.gov.cn/news/news/view.asp?id=224)

Section II. N_2O Emissions from Fertilizer Consumption and Crop Residues

In general there is no problem with the methodology in this section as it is exactly the same as that prescribed by IPCC 2006. However, it cannot be correct to ignore direct and indirect emissions from crop residues of cotton, palm oil, rapeseed, sugarcane and sunflower because IPCC default factors were not available.

Section III. GHG Emission Rates for Agricultural Energy Use

The method used for the estimation of greenhouse gas emission rates for energy use is reasonable, but one wonders why there are so many gaps in Table 8? Does this mean those countries used no fuel for agricultural purposes or that no data are available? It is reasonable to use the International Energy Agency's data, but the user would have more confidence in the results if comparisons were made with other sources; e.g. The Energy Information Administration of the United States Government (http:/tonto.eia.doc.gov).

Section IV. CH_4 Emission Factors for Rice Cultivation

The methodology used in this section is suitable as it follows that prescribed by IPCC 2006 and is well supported by published material. In my experience all material derived from The International Rice Research Institute is up-to-date and reliable.

2. What do you recommend for improving the methodology? What can EPA do to improve the quality of the methodology (both in the near-term and in the longer-term)?

The methodology used for the calculations of nitrous oxide emission from fertilizer and methane from rice production is the best available as it is based on the IPCC 2006 work. The greenhouse gas emission estimations from agricultural energy use are probably OK, but it would be better if they were compared with data from another source, e.g. The EIA data (http:/tonto.eia.doc.gov). The fertilizer use data could be markedly improved by using the latest data available from the International Fertilizer Industry Association (www.fertilizer.org). The pesticide data does not appear to be reliable and better information need to be obtained. You also need specify whether you are reporting the amount of active ingredient or pesticide product. A better source would be Industry data from each country. Use the latest data available because the amount used will decrease with the increased planting of insect resistant genetically modified crops, e.g. Bt cotton.

As far as projections of fertilizer use are concerned it would be profitable to compare your results with those obtained with the International Food Policy Research Institute's IMPACT model (International Model for Policy Analysis of Agricultural Commodities and Trade; (Rosegrant, M.W., Meijer, S. and Cline, S.A. 2002. International model for policy analysis of agricultural commodities and trade (IMPACT): Model description. Washington, D.C.: International Food Policy Research Institute.
http://www.ifpri.org/themes/impact/impactmodel.pdf.

B. For Pesticide Consumption Projections

1. Is the averaging mechanism used by ICF for the pesticide data scientifically justifiable? (See last paragraph of Section I.)

Probably not because of the increased use of insect resistant genetically modified crops and decreased use of insecticides

2. What do you recommend to improve these projections?

Obtain up-to-date information on pesticide use from each country of interest

C. For N2O Emissions

1. Are the IPCC 2006 defaults and the Tier 1 methodology appropriate for this analysis? What other methodologies are available (including those that might be applicable to specific countries or regions)?

The IPCC 2006 defaults and the Tier 1 methodology is the best technique to use for this analysis. A number of people are using a modelling approach to estimate nitrous oxide emission from agriculture. One such approach was reported by Lorna Brown and Steve Jarvis in ‘Estimation of nitrous oxide emissions from UK agriculture’ (http://www.aber.ac.uk/en/media/chapter_10.pdf)

2. Are the direct and indirect emissions from fertilizer and crop residues identified correctly? Is it scientifically justifiable to exclude the volatilization pathway from crop residues, as described in the memo?

The direct and indirect emissions from fertilizer and crop residues are correctly identified.

With dried cereal crop residue of high C/N ratio little ammonia should be lost. Exclusion of ammonia volatilization from crop residues depends on the carbon/nitrogen ratio and type of residue. Mannheim T., Braschkat J. and Marschner H. Zeitschrift für Pflanzenernährung und Bodenkunde 160. 125-132 (1997) showed that ammonia emissions from decomposing crop residues ranged from 0.9 to 3.7% of the N content. The emissions from sugarbeet leaves and potato shoots with high water content ranged from 2.8 to 3.7%, whereas the emission from field bean straw with high dry matter was relatively low (0.9%). Janzen, H.H., and McGinn S.M. (Soil Biology and Biochemistry 1991, 23, 291-297) showed that ammonia volatilization from the residue of a legume left on the soil surface was 5% of N content.

3. Does the report correctly apply the IPCC Tier 1 methodology? Is this the best methodology to apply?

The IPCC 2006 Tier 1 methodology has been correctly used and it is the best technique to use for this analysis.

D. For Agricultural Energy Use

1. Is the exclusion of several fuel types as “minimal” scientifically justifiable?

The exclusion of the other fuel types for agriculture is certainly justifiable for Australia. According to the Australian Bureau of Statistics the bulk of the energy for agriculture, forestry and fisheries comes from electricity and diesel oil. Without information from other countries one can only assume that this would hold for the other countries.

2. Is it scientifically justifiable to assume that the overestimate of fuel use in the agricultural sub-sector by using data for the entire ag/forestry/fishing sector is small?

The Australian Bureau of Statistics did not separate fuel use for each of agriculture, forestry and fisheries in Australia. Without this information for each country one could only say that it is justifiable in countries where forestry is not an important industry.

3. Is the use of average CO2 emissions for the entire agricultural sector by country (from IEA, 2007) scientifically justifiable? What methods exist to break this out by crop or other geographic area?

It seems reasonable to do this, but I do not have the data to determine whether it is justifiable.

Use modelling to simulate energy use and CO_2 emission. e.g. Muller et al (Energy input-output simulation of midwest crop production, in Proceedings of the 9th conference on Winter simulation-1977) developed a simulator to evaluate alternative agricultural practices for energy efficiency in Midwest crop production. Information is provided for corn, winter wheat, soybeans, alfalfa hay, and hairy vetch.

4. Were the factors provided by EPA (Appendix Table 7) applied appropriately? How can these factors be improved?

It is not apparent how these factors were used?

E. For CH4 Emissions from Rice

1. Is the scaling methodology described to adjust for the four different cropping regimes scientifically justifiable?

As the methods were developed by the IPCC the methodology is scientifically justifiable.

2. What other methodologies are better for estimating CH4 emission factors for rice cultivation?

None that I know.

III. Building on the Data

A. Future Crop Production/yield Increases

1. EPA uses historic data to represent future crop production. How should the agency adjust for future increases in yield?

Because of the rapidly increasing population there is going to be strong competition for water, energy and land use. Already water is scarce in some important agricultural areas in the world and numerous rivers around the world e.g. Yellow River, China and the Murray-

Darling River in Australia do not discharge to the sea for long periods. With climate change the problem will increase. Land available for agriculture is also decreasing in many countries because of land degradation, acidification and salinization, and expansion of cities and roads etc. Thus there is no guarantee that yields will continue to increase. However, the International Food Policy Research Institute and the Food and Agriculture Organization develop yield projections and IFA develops regular fertilizer use projections so EPA can keep abreast of developments.

2. Specifically, if yields are increasing, how will inputs be impacted?

Research is continuing on ways to increase the efficiency of use of fertilizer nitrogen. If this research is successful then yields will increase at a faster rate than fertilizer inputs. However, yield increases will increase the demand for water.

3. What other factors should EPA take into account when projecting future agricultural production?

Population growth, GDP growth, water availability and use efficiency, fertilizer use efficiency, changing food preferences, projections for all crops not just cereals, increased cost of fertilizer and impacts on the environment.

Charge Questions
International Ag GHG Peer Review

Document for review: ICF memo of 12/12/08,
"International Agriculture GHG Emissions and GHG Metrics (revised) V.3"
6/12/2009

I. Questions Related to the Data Used

A. General Questions

1. Should EPA primarily be relying on country-level data sources, or do you recommend data sources defined by other geographic areas? What alternative data sources would you recommend?

Yes, country level data, as compiled by FAO, seems appropriate. Where possible, however, these data should be cross-checked with other data sources. For example, the International Fertilizer Industry Association (IFA)(www.fertilizer.org) develops fertilizer use data by country and by crop. There may be other such independent data sets prepared, but I am not aware of them.

2. For any of the data sources used in the ICF memo, what additional, or better, data sources exist?

I think that the most up to date data available should be used. Currently the FAO fertilizer data base is compiled through 2007. Although the FAO data base is not user friendly, the current data can be located with considerable effort. The IFA fertilizer data is more readily accessible and is current up to 2008. Current data should be used rather than the older data that is shown in the Excel spread sheets. Using these current data, I suggest then computing an average of the last 5-years and using those data to make all calculations. The FAO data for fertilizer use needs to be cross checked with the IFA data. IFA has an interactive data base that contains country/crop fertilizer consumption which is easily accessed.

3. What better data sources exist to represent production of materials and energy use by country or other relevant geographic area?

For all international information on energy the IEA material is certainly the common reference. Whether or not the data presented are different or needs some scrutiny but the DOE data base (http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm) may provide useful information.
Rather than relying upon data compilation by some other organization, is it reasonable to go directly to the data base of each country and tie into their information release system?

4. The fertilizer and pesticide data show a very wide range of application rates across countries, areas, and crops. For example, in the case of pesticides, some countries' application rates are reported as zero. Based on your knowledge, how accurate are these data? What better data sources exist for fertilizer and pesticide utilization?

The data for some countries are likely not reliable. Either they don't keep track of all fertilizer and pesticide use or don't wish to provide the data externally. I expect that some countries do not keep track of pesticide use thus report use to FAO as zero. I am not aware of pesticide use data bases other than FAO. Please check the Table 4 title. Also, it is quite unreasonable to assume that no pesticides are used in China. According to Production Monthly News. July 7, 2006. Shanxi Petroleum and Chemistry Industry Office. (http://www.sxsh.gov.cn/news/news/view.asp?id=224) 1,030,000 tons of pesticides was produced in China in 2005.

As noted above, for fertilizer use checking the IFA reports for fertilizer application by crop is a potential cross check of the FAO data. This is also why it seems reasonable to use multi-year averages for data input rather than focusing on a single year.

For N and other fertilizer application rates to various crops I think that the FAO data bases and the IFA data need to be cross checked. These data may not all be independent sources but careful cross checking at least permits one to evaluate random error problems.

5. What is the best way for EPA to deal with the limitations of the data, especially those data elements to which the results are most sensitive?

If the appendix tables are the data to be used in the exercise, I think that they need to be greatly improved. The Excel file "Control_2022_Foreign_Ag_...." data file needs to be updated. There are big gaps in the data for countries that use significant amounts of N fertilizer for major crop production. There is no need for these gaps as data provided by FAO and IFA are readily available. Also missing from the data is fertilizer that is applied to fruit and vegetables. According to the IFA data, approximately 15% of all N fertilizer used globally is applied to fruit and vegetable crops.

Note that in the appendix tables 1,2,3, & 4 fertilizer application rates are listed as kg/acre. Please, do not mix metric and English measurement units. Please express all calculations in metric units only!!! The data presented in those tables is very difficult to understand and will likely confuse most users of the data.

Depending upon the goal of the project, but generally, I would say get the big numbers, i.e. fertilizer input for China, India, Europe, Brazil, USA and a few others as correct as possible and worry much less about the very small agricultural production countries. If >90% of the data are the best that can be obtained, then the errors in the remaining few % aren't so important. Working more directly with the sources of the statistics in these countries may prove less problem than relying upon FAO to provide the data bases.

II. Questions Related to the Methodologies Used

A. General Question

1. For each section of the ICF memo, please describe the key strengths and weaknesses of ICF's methods.
2. What do you recommend for improving the methodology? What can EPA do to improve the quality of the methodology (both in the near-term and in the longer-term)?

I. Fertilizer and Pesticide Consumption Projections

I think that the general concepts used in developing fertilizer and pesticide consumption projections are viable. As noted previously I do think that the fertilizer input data used in projections should be improved and the latest possible data used and the data used be based on the same years of data across all countries. By combining the IFA and FAO data it should be possible to do this. It also seems appropriate to show comparison with other projections of fertilizer use in particular. For example the IMPACT model has been used to predict food production and fertilizer use. There are probably more recent analyses which reflect changes in biofuel production than the following reference:

Wood, S., J. Henao and M. Rosegrant. 2004. The role of nitrogen in sustaining food production and estimating future nitrogen fertilizer needs to meet food demand. In. Mosier, Arvin R., J. Keith Syers and John R. Freney (eds.). 2004. Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment. SCOPE Volume 65, Island Press, Washington, pp 245-260.

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) represents the global agricultural market for 32 crop and livestock commodities, including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, oilcakes and meals, sugar and sweeteners, fruits and vegetables, and fish. IMPACT comprises 43 different countries or regions, each with its conditions for supply, demand, and prices for agricultural commodities that are linked through trade, highlighting the interdependence of countries and commodities through global agricultural markets. World agricultural commodity prices are determined annually at levels that clear international markets. Demand is a function of prices, income, and population growth, and growth in crop production in each country is determined by crop prices and the rate of productivity growth. The IMPACT model seeks to minimize the sum of net international trade for each commodity at a world market price that satisfies market-clearing conditions. IMPACT projections were made for both 2020 and 2050. A regional summary of the production of selected crops for the 1997 base period as well as those projected for 2020 and 2050 are shown in Table 18.2 of the SCOPE 65 publication.

II. N_2O Emissions from Fertilizer Consumption and Crop Residues

This calculation is based upon the IPCC (2006) methodology which is appropriate for this exercise. The IPCC methodology was based upon the best information that was available at that time and has undergone intense scrutiny by many scientists. The key to using the IPCC methodology is in the data used for N fertilizer input and crop production. As noted above, it appears that the N input and crop production data used to drive the calculations could be improved. It is not correct to ignore direct and indirect emissions from crop residues of cotton, palm oil, rapeseed, sugarcane and sunflower because IPCC default factors were not available.

In the future I think that a comparison with a different approach to the question could be used. For example the methodology used by Del Grosso et al. (2008) [Del Grosso, S.J., T. Wirth, .S.M. Ogle and W.J. Parton. 2008. Estimating agricultural nitrous oxide emissions. *Eos (Transactions of the American Geophysical Union)* 89:529-540.] could be used as a cross check of the calculations. These authors use a combined modeling and IPCC methodology method to estimate N2O emissions from agricultural soils.

III. GHG Emission Rates for Agricultural Energy Use

Using the IEA data to estimate GHG emissions from agricultural energy use seems appropriate. It is not clear how the information in Table 7 of the appendix is used. One statement in the background information Excel file on Foreign Agriculture Energy Emissions is that “energy calculator assumes that the same mixture of fuels is used to generate electricity and heat in each country”. Does this mean that the same fuel mixture is used for all countries or that the fuel mixture to generate electricity and heat is the same?

It seems appropriate that comparison with other estimates be made. For example the energy use in ethanol production from wheat in the UK can be seen in: Smith, T.C., D R Kindred, J. M. Brosnan, R. M. Weightman, M. Shepherd, and R. Sylvester-Bradley. 2006. Wheat as a feedstock for alcohol production (HGCA) *The Home-Grown Cereals Authority, Research Review No. 61***,** London, UK. 89 p; and viewed at www.hgca.com/bioFuelCal/.

IV. CH_4 Emission Factors for Rice Cultivation

This calculation is based upon the IPCC 2006 methodology for estimating CH4 emissions from rice cultivation. This is the appropriate methodology for this estimate. The IRRI-based information should be current and the best information available.

B. For Pesticide Consumption Projections

1. Is the averaging mechanism used by ICF for the pesticide data scientifically justifiable? (See last paragraph of Section I.)
2. What do you recommend to improve these projections?

The averaging mechanism should be appropriate. As noted for fertilizer use, effort should be made to ensure that the most current and comprehensive data are being used. I do not have a suggestion as to data other than FAO, unless direct link to the countries is made.

C. For N2O Emissions

1. Are the IPCC 2006 defaults and the Tier 1 methodology appropriate for this analysis? What other methodologies are available (including those that might be applicable to specific countries or regions)?

I think that the IPCC 2006 defaults and Tier 1 methodology is appropriate for this analysis. In the future I think that a comparison with a different approach to the question could be used. For example the methodology used by Del Grosso et al. (2008) [Del Grosso, S.J., T. Wirth, .S.M. Ogle and W.J. Parton. 2008. Estimating agricultural nitrous oxide emissions. *Eos (Transactions of the American Geophysical Union)* 89:529-540.] could be used as a cross check of the calculations. There are likely a number of ongoing efforts within many countries to update and improve country-based N2O emissions inventories and these efforts should be followed and incorporated where appropriate.

2. Are the direct and indirect emissions from fertilizer and crop residues identified correctly? Is it scientifically justifiable to exclude the volatilization pathway from crop residues, as described in the memo?

The methodology is applied appropriately. Generally, it is justifiable to exclude volatilization pathway from crop residues because the residues have a high C/N ratio and little ammonia volatilization should occur. This assumption is applicable to cereal crops e.g. corn, wheat, sorghum, barley, and rice. Roughly 70% of all N use is in cereal crops. If freshly cut grass is included in the residue mix, then ammonia volatilization would likely occur from freshly cut forage.

3. Does the report correctly apply the IPCC Tier 1 methodology? Is this the best methodology to apply?

The methodology is appropriate and used as designed.

D. For Agricultural Energy Use

1. Is the exclusion of several fuel types as “minimal” scientifically justifiable?

I think that this is appropriate. These seems no reason to do otherwise unless the more detailed information is readily available, and even then inclusion of the excluded sources would make no appreciable difference

2. Is it scientifically justifiable to assume that the overestimate of fuel use in the agricultural sub-sector by using data for the entire ag/forestry/fishing sector is small?

For the major agricultural producing countries this estimate seems appropriate. In countries, Canada and Sweden as examples, where forestry product production is large, is the overestimate significant? I do not have the information readily available to do this calculation.

3. Is the use of average CO2 emissions for the entire agricultural sector by country (from IEA, 2007) scientifically justifiable? What methods exist to break this out by crop or other geographic area?

I have not made an estimate of CO2 emissions by crop, but would expect considerable differences in energy use in the production of crops like corn and sugar cane in Brazil, wheat, corn and rice in China, wheat and sugar cane in Australia, just to name a few examples that come to mind. The expected differences in energy requirement come from differences in crop production within each of these countries. It may be worthwhile to look at a few country-specific examples and obtain the information directly from the countries of selected test cases.

4. Were the factors provided by EPA (Appendix Table 7) applied appropriately? How can these factors be improved?

It is not clear to me what the emission factors shown in Table 7 represent and how they are used. The derivation of these factors in the Excel spread sheet is not transparent, to me at least.

E. For CH4 Emissions from Rice

1. Is the scaling methodology described to adjust for the four different cropping regimes scientifically justifiable?

   I think that the IPCC 2006 methodology is appropriate.

2. What other methodologies are better for estimating CH4 emission factors for rice cultivation?

   I am not aware of a more appropriate methodology.

III. Building on the Data

A. Future Crop Production/yield Increases

1. EPA uses historic data to represent future crop production. How should the agency adjust for future increases in yield?

   During the past few decades cereal crop yields have continued to increase in many parts of the world, generally at a relatively low but constant rate. Recommended fertilizer application rates have generally remained relatively constant or declined. As a result, crop production as a unit of fertilizer application has increased. It seems that the general trends of crop production and fertilizer use should be reflected in future projections.

2. Specifically, if yields are increasing, how will inputs be impacted?

   If N use efficiency increases at approximately the same rate as yield then the per area application of fertilizer would remain relatively constant.

3. What other factors should EPA take into account when projecting future agricultural production?

Wood et al. (2004---see reference above) note that the following are important issues in projecting crop production and fertilizer use:

1. Improvements in fertilizer use efficiency-----N loss rates for most crops continue to be near 50%
2. Having appropriate and adequate data on which to base projections
3. Projected market prices of fertilizer (According to The fertilizer-to-crop price ratio is a key factor taken into account by farmers when they purchase fertilizers. Heffer, P. and M. Prud’homme. 2009. Fertilizer Outlook 2009-

2013. International Fertilizer Industry Association (IFA). International Fertilizer Industry Association (IFA) – 28, rue Marbeuf – 75008 Paris – France (ifa@fertilizer.org – www.fertilizer.org)

Wood et al. (2004) suggest that earlier food- projection modeling may have been overly optimistic in our ability to maintain growth in crop productivity. Concerns such as underinvestment in publicly funded agricultural research; diminishing exploitable yield gaps in major cereals; overconfidence in the likelihood of biotechnology-based productivity breakthroughs in the short to medium term; soil degradation, salinization, water-logging of irrigated areas are among factors which may limit projected increases in crop production.

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EDUCATION

- **Pennsylvania State University**, University Park, PA. B.S. 1990, Department of Geography, College of Earth & Mineral Sciences. Minor certificate 1990, Program in Science, Technology and Society.
- **University of Virginia**, Charlottesville, VA. M.S. 1994 and Ph.D. 1998, Department of Environmental Sciences, College of Arts & Sciences.
- **Cornell University**, Ithaca, NY. Department of Ecology & Evolutionary Biology: Postdoctoral Research Associate, Program in Biogeochemistry and Environmental Change (1997-1999).

POSITIONS

- **Pennsylvania State University**, University Park, PA. (2008-present):
  - Associate Professor of Water Resources (tenured), School of Forest Resources, College of Agricultural Sciences.
  - Assistant Director, Penn State Institutes of Energy & the Environment.
  - Director, Pennsylvania Water Resources Research Institute.
  - Faculty Participant, Pennsylvania Agricultural Experiment Station.
- **Swedish University of Agricultural Sciences** (SLU), Guest Professor, Department of Aquatic Sciences and Assessment, Uppsala, Sweden, 2008-2010.
- **University of California**, Berkeley, CA.
  - Associate Professor of Watershed Sciences (tenured, 2007-present; currently on leave), and Assistant professor (untenured, 2005-2007), Dept. of Environmental Science, Policy, and Management, College of Natural Resources.
  - Affiliate faculty member, Energy & Resources Group (2006-2008).
  - Faculty Participant, California Agricultural Experiment Station (2005-2008).
- **State University of New York**, College of Environmental Science & Forestry, Syracuse, NY. Dept. of Forest & Natural Resources Management: Assistant Professor (1999-2004).
- **Syracuse University**, Syracuse, NY. Department of Geography: Adjunct Asst. Prof. (2000-2004).
- **Cornell University**, Ithaca, NY. Center for the Environment, Adjunct Asst. Prof. (1999-2001).
- **University of Virginia**, Charlottesville, VA. Dept. of Environmental Sciences: Graduate research assistant (1993-1997); Graduate teaching assistant (1991-1993).
- **United States Geological Survey**, Menlo Park, CA. Water Resources Division, National Research Program. Graduate student appointment as physical scientist (1991-1997).
- **United States Department of Energy**, Richland, WA. Battelle/Pacific Northwest Labs; Surface water hydrology group; Science and Engineering Research Internship (1989).

HONORS

- Berkeley Presidential Chair Fellows Program, 2006-2007.
- Elected as Chair for Gordon Research Conferences on *Catchment Science: Interactions of Hydrology, Biology, & Geochemistry* 2005-2007, and Vice-Chair 2003-2005.
- New York Academy of Sciences, inducted 1999.
- Maury Environmental Sciences Prize, University of Virginia (departmental honor for outstanding graduate student), 1997.
- Outstanding student paper, American Geophysical Union hydrology section, 1996.
- Du Pont Fellowship, Department of Environmental Sciences, University of Virginia, 1996.
- Society of Sigma Xi - scientific research honor society, inducted 1992.
- Sigma Gamma Epsilon - geosciences honor society, Beta Kappa chapter, inducted 1992.
- Valedictorian, Penns Valley Area High School, Spring Mills, PA, 1986.

PUBLICATIONS

Peer-reviewed papers

1. Hoover KA, MG Foley, PG Heasler, and **EW Boyer** (1991). Sub-grid scale characterization of channel lengths for use in catchment modeling. *Water Resources Research,* 27(11), 2865-2873.
2. **Boyer EW,** GM Hornberger, KE Bencala, & DM McKnight (1995). Variation of dissolved organic carbon during snowmelt in soil and streamwaters of two headwater catchments. In: Biogeochemistry of Seasonally Snow Covered Catchments, IAHS Publication No. 228: 303- 312.
3. Hornberger GM & **EW Boyer** (1995). Recent advances in watershed modeling. *Reviews of Geophysics* 33: 949-958.
4. **Boyer EW**, GM Hornberger, KE Bencala, & DM McKnight (1996). Overview of a simple model describing variation of dissolved organic carbon in an upland catchment. *Ecological Modelling,* 86: 183-188.
5. **Boyer EW**, GM Hornberger, KE Bencala, & DM McKnight (1997). Response characteristics of DOC flushing in an alpine catchment. *Hydrological Processes*, 11, 1635-1647.
6. **Boyer EW**, GM Hornberger, KE Bencala, & DM McKnight (2000). Effects of asynchronous snowmelt on flushing of dissolved organic carbon: a mixing model approach. *Hydrological Processes,* 14, 3291-3308.
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8. Alexander RB, PJ Johnes, **EW Boyer** & RA Smith (2002). A comparison of methods for estimating the riverine export of nitrogen from large watersheds. *Biogeochemistry,* 57: 295-339.
9. **Boyer EW**, CL Goodale, NA Jaworski, & RW Howarth (2002). Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA. *Biogeochemistry,* 57:137-169.
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11. Howarth RW, **EW Boyer**, W Pabich, & JN Galloway (2002). Nitrogen use in the United States from 1961 – 2000 and potential future trends. *Ambio,* 31(2):88-96.
12. Mayer B, **EW Boyer**, CA Goodale, NA Jaworski, N Van Breemen, RW Howarth, S Seitzinger, G Billen, K Lajtha, K Nadelhoffer, D Van Dam, LJ Hetling, M Nosall, K Paustian (2002). Sources of nitrate in rivers draining sixteen watersheds in the northeastern US: Isotopic Constraints. *Biogeochemistry,* 57:171-197.
13. McKnight DM, GM Hornberger, KE Bencala, & **EW Boyer** (2002). In-stream influences on dissolved organic carbon concentration and composition in an acidic and metal-enriched stream: a reach-scale reactive solute transport experiment. *Water Resources Research, 381-412.*
14. Seitzinger S, RV Styles, **EW Boyer**, RB Alexander, G Billen, RW Howarth, B Mayer, & N Van Breemen (2002). Nitrogen retention in rivers: Model development and application to watersheds in the eastern U.S. *Biogeochemistry,* 57:199-237.
15. Van Breemen N, **EW Boyer**, CL Goodale, NA Jaworski, K Paustian, SP Seitzinger, K Lajtha, B Mayer, D VanDam, RW Howarth, KJ Nadelhoffer, M Eve, & G Billen (2002). Where did all the nitrogen go? Fate of nitrogen inputs to large watersheds in the northeastern USA. *Biogeochemistry,* 57:267-293.
16. Driscoll C, D Whitall, J Aber, **E Boyer**, M Castro, C Cronan, C Goodale, P Groffman C Hopkinson, K Lambert, G Lawrence, S Ollinger (2003). Nitrogen pollution in the northeastern United States: Sources, effects and management options. *Bioscience* 53(4):357-374.
17. Driscoll C, D Whitall, J Aber, **E Boyer**, M Castro, C Cronan, C Goodale, P Groffman C Hopkinson, K Lambert, G Lawrence, S Ollinger (2003). Nitrogen pollution: sources and consequences in the U.S. northeast. *Environment* 45(7):8-22.

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19. McClain ME, **EW Boyer**, CL Dent, SE Gergel NB Grimm, PM Groffman, SC Hart, JW Harvey, CA Johnston, E Mayorga, WH McDowell, G Pinay (2003). Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. *Ecosystems* 6(4): 301-312.
20. **Boyer EW**, RW Howarth, JN Galloway, FJ Dentener, P Green, C Vörösmarty, C Cleveland, & GP Asner (2004). Current nitrogen inputs to world regions. In AR Mosier, K Syers & JR Freney (eds), Agriculture and the nitrogen cycle: assessing the impact of fertilizer use on food production and the environment, pp. 221-230. Washington, D.C. Island Press.
21. Galloway JN, FJ Dentener, DG Capone, **EW Boyer**, RW Howarth, SP Seitzinger, GP Asner, C Cleveland, P Green, E Holland, DM Karl, AF Michaels, JH Porter, A Townsend & C Vörösmarty (2004). Nitrogen Cycles: Past, Present and Future. *Biogeochemistry* 70: 153-226.
22. Green PA, CJ Vörösmarty, M Meybeck, JN Galloway, BJ Peterson, and **EW Boyer** (2004). Pre-industrial and contemporary fluxes of nitrogen through rivers: a global assessment based on typology. *Biogeochemistry 68(1):71-105.*
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25. Van Drecht G, AF Bouwman, **EW Boyer**, P Green, & S Seibert (2005). A comparison of global spatial distributions of nitrogen inputs for nonpoint sources and effects on river nitrogen export. Global Biogeochemical Cycles, 19, GB4S06, DOI: 10.1029/2005GB002454.
26. Borbor MJ, **EW Boyer**, CA Hall, & WH McDowell (2006). Nitrogen and phosphorus budgets for a tropical agricultural watershed impacted by extensive export crops: Guayas, Ecuador. Biogeochemistry, 79:135-161, DOI: 10.1007/s10533-006-9009-7.
27. **Boyer EW**, RW Howarth, JN Galloway, FJ Dentener, PA Green, and CJ Vörösmarty (2006). Riverine nitrogen export from the continents to the coasts. *Global Biogeochemical Cycles*, 20, GB1S91, DOI:10.1029/2005GB002537.
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29. Filoso S, LA Martinelli, RW Howarth, **EW Boyer**, & FJ Dentener (2006). Human activities changing the nitrogen cycle in Brazil. *Biogeochemistry*, 79:61-89, DOI: 10.1007/s10533-006-9003-0.
30. Howarth RW, R Marino, DP Swaney, & **EW Boyer** (2006). Wastewater and watershed influences on primary productivity and oxygen dynamics in the lower Hudson River estuary. Pp. 121-139 in: J. Levinton & J.R. Waldman (eds.), The Hudson River Estuary, Cambridge University Press.
31. Howarth RW, DP Swaney, **EW Boyer,** R Marino, N Jaworski, & C Goodale (2006). The influence of climate on average nitrogen export from large watersheds in the Northeastern United States. *Biogeochemistry*, 79:163-186, DOI: 10.1007/s10533-006-9010-1.
32. Alexander RB, **EW Boyer,** RA Smith, GE Schwarz, & RB Moore (2007). The role of headwater streams in downstream water quality. *Journal of the American Water Resources Association*, 43(1):41-59. Recipient of AWRA's 2007 *Boggess Award* for best paper.
33. Elliott EM, C Kendall, SD Wankel, DA Burns, **EW Boyer**, K Harlin, DJ Bain, & TJ Butler (2007). Nitrogen isotopes as indicators of NO_x source contributions to atmospheric nitrate deposition across

the Midwestern and Northeastern United States. *Environmental Science & Technology,* 41 (22), 7661 -7667, DOI: 10.1021/es070898t.

34. Alexander RB, RA Smith, GE Schwarz, **EW Boyer**, JV Nolan, & JW Brakebill (2008). Differences in sources and recent trends in phosphorous and nitrogen delivery to the Gulf of Mexico from the Mississippi and Atchafalaya River Basins. *Environmental Science & Technology,* 42(3), 822–830, DOI: 10.1021/es0716103.
35. **Boyer EW** & RW Howarth (2008). Nitrogen fluxes from rivers to the coastal oceans. Chapter 36, pp. 1565-1584, in: Capone DG, DA Bronk, MR Mulholland, and EJ Carpenter (eds.), Nitrogen in the Marine Environment, 2nd edition, Academic Press, San Diego, 1668 pp.
36. Christopher SF, MJ Mitchell, MR McHale, **EW Boyer**, DA Burns, & C Kendall (2008). Factors controlling nitrogen release from two forested catchments with contrasting hydrochemical responses. *Hydrological Processes,* 22:46-62, DOI: 10.1002/hyp.6632.
37. Doctor D, C Kendall, S Sebestyen, J Shanley, N Ohte, **E Boyer** (2008). Carbon isotope fractionation of dissolved inorganic carbon due to outgassing of carbon dioxide from a headwater stream. *Hydrological Processes*, 22(14):2410-2412, DOI 10.1002/hyp.6833.
38. Golden HE and **EW Boyer** (2008). Contemporary estimates of atmospheric nitrogen deposition to the watersheds of New York state, USA. *Environmental Monitoring and Assessment,* DOI 10.1007/s10661-008-0438-8.
39. Golden HE, **EW Boyer,** MG Brown, EM Elliott, and DK Lee (2008). Simple approaches for measuring dry atmospheric nitrogen deposition inputs to watersheds. *Water Resources Research,* 44, DOI:10.1029/2008WR006952.
40. Sebestyen SD, **EW Boyer**, JB Shanley, C Kendall, DH Doctor, GR Aiken, and N Ohte (2008). Sources, transformations, and hydrological processes that control stream nitrate and dissolved organic matter concentrations during snowmelt in an upland forest. *Water Resources Research,* 44, W12410, doi:101029/2008WR006983.
41. Alexander RB, JF Böhlke, **EW Boyer**, M David, JW Harvey, PJ Mulholland, SP Seitzinger, CR Tobias, C Tonitto, W Wollheim (2009). Simulating temporal variations of nitrogen losses in river networks with a dynamic transport model unravels the coupled effects of hydrological and biogeochemical processes. *Biogeochemistry,* DOI 10.1007/s10533-008-9274-8.
42. Sebestyen, SD, **EW Boyer,** and JB Shanley (2009). Responses of stream nitrate and DOC loadings to hydrological forcing and climate change in an upland forest of the northeastern United States, J. Geophys. Res., 114, G02002, doi:10.1029/2008JG000778.
43. Campbell, JL, LE Rustad, **EW Boyer,** SF Christopher, CT Driscoll, IJ Fernandez, PM Groffman, D Houle, J Kiekbusch, AJ Magill, MJ Mitchell, and SV Ollinger (2009). Consequences of climate change for biogeochemical cycling in forests of northeastern North America. *Canadian Journal of Forest Research* 39: 264-284.
44. Burns DA, **EW Boyer**, EM Elliott, and C Kendall (2009). Sources of nitrate and processes that affect its transformation and transport in stream watersheds draining varying land uses: evidence from dual isotope analysis. *Journal of Environmental Quality,* 38:1149–1159, doi:10.2134/jeq2008.0371.
45. Golden HE, **EW Boyer,** MG Brown, ST Purucker, and RH Germain. Spatial variability of nitrate concentrations under varying seasonal conditions in tributaries to Cayuga Lake Watershed, New York, USA. In press, *Journal of the American Water Resources Association.*
46. Elliott EM, **EW Boyer**, DA Burns, K Harlin, C Kendall, G Lear, and H Golden. Dual nitrate isotopes in actively and passively collected dry deposition: Utility for partitioning NOx sources, understanding reaction pathways, and comparison with isotopes in wet nitrate deposition. In press, *Journal of Geophysical Research - Biogeosciences.*

Other published works

1. **Boyer EW**, GM Hornberger, & KE Bencala (1993, conference proceedings). Hydrological controls

on the temporal variation of dissolved organic carbon in Deer Creek near Montezuma, Colorado. In: Proceedings of the International Congress on Modelling and Simulation, MODSIM 1993. McAleer, M.J. & A.J. Jakeman, eds. University of Western Australia, Perth.

2. **Boyer EW** (1994, thesis). Hydrology and the variation of dissolved organic carbon in soil and stream waters of two headwater catchments; Summit County, Colorado. M.S. Thesis, University of Virginia, Department of Environmental Sciences.
3. **Boyer EW** (1998, dissertation). Landscape scale controls on the hydrological and hydrochemical responses of mountainous catchments. Ph.D. Dissertation, University of Virginia, Department of Environmental Sciences.
4. **Boyer EW**, DM McKnight, KE Bencala, PD Brooks, MA Anthony, GW Zellweger, & RE Harnish (1999, data report). Streamflow and Water Quality Characteristics for the Upper Snake River and Deer Creek catchments in Summit County, Colorado: Water Years 1980 to 1990. Institute of Arctic and Alpine Research, Paper No. 53, University of Colorado.
5. Driscoll CT, DR Whitall, J Aber, **EW Boyer**, M Castro, C Cronan, CL Goodale, P Groffman, C Hopkinson, KF Lambert, G Lawrence, S Ollinger (2002, fact sheet for the policy makers & the public). Nitrogen pollution: From the sources to the sea. Hubbard Brook Research Foundation, Science Links Publication.
6. **Boyer EW** & CL Dent (2000, invited review & commentary). Towards an integration of hydrology and ecosystem ecology at regional scales. *Hydrological Processes*, 14, 2613-2615.
7. Boyer EW & RW Howarth, editors. (2002, book). The Nitrogen Cycle at Regional to Global Scales. Kluwer Academic Publishers, 518 pp.
8. **Boyer, EW** & RW Howarth (2002, foreword to special issue of journal). The Nitrogen Cycle at Regional to Global Scales: Foreword. *Biogeochemistry*, 57 (1): vii-ix.
9. Driscoll CT, J Aber, **EW Boyer**, M Castro, C Cronan, CL Goodale, C Hopkinson, KF Lambert, G Lawrence, S Ollinger, & DR Whitall (2003, scientific report for policy makers & the public). Nitrogen pollution: From the sources to the sea. Hubbard Brook Research Foundation, Science Links Publication Vol. 1, No. 2.
10. Grigg N, **E Boyer**, J Dozier, N Grimm, V Lakshmi, U Lall, D McLaughlin, Y Reinfelder, D Tarboton, C Vörösmarty (2003, scientific community report). A national center for hydrologic synthesis: scientific objectives, structure, and implementation. Consortium of Universities for the Advancement of Hydrologic Science, Inc. Technical report #5.
11. Driscoll CT, **EW Boyer**, M Castro, C Goodale, KG Harrison, S Ollinger, R Stahl, T Cameron, & L Chestnut (2005, scientific community report). Advisory on Plans for Ecological Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis – Benefits and Cost of the Clean Air Act, 1990 – 2020. U.S. Environmental Protection Agency, Ecological Effects Subcommittee, EPA Advisory Council on Clean Air Compliance Analysis, EPA-SAB-COUNCIL-ADV-05-010.
12. C Kendall, **EW Boyer**, DA Burns, & EM Elliott (2005, fact sheet for policy makers & the public). Quantifying Atmospheric Nitrogen Sources with New Stable Isotope Techniques. New York State Research & Development Authority, Environmental Monitoring, Evaluation, & Protection Program.
13. **Boyer EW** (2007, citation). John Martin Award for a High Impact Paper in the Aquatic Sciences to Vannote et al. 1980, for the River Continuum Concept. American Society of Limnology and Oceanography, *Limnology & Oceanography Bulletin*, Volume 15(4):77.
14. JA Lynch, KS Horner, JW Grimm, HC Carrick, & **EW Boyer** (2007, scientific report for state government). Mercury deposition in Pennsylvania: 2006 status report. Report prepared for Pennsylvania Department of Environmental Protection.
15. JA Lynch, HC Carrick, KS Horner, JW Grimm, & **EW Boyer** (2007, scientific report for state government). Reductions in acidic wet deposition in Pennsylvania following implementation of the Clean Air Act Amendments of 1990: 1995-2006. Report prepared for Pennsylvania Department of Environmental Protection.
16. JA Lynch, KS Horner, JW Grimm, **EW Boyer**, and HC Carrick (2007, scientific report for state

government). Atmospheric deposition: spatial and temporal variations in Pennsylvania 2006. Report prepared for Pennsylvania Department of Environmental Protection.

17. Sebestyen SD, JB Shanley, and **EW Boyer**. Documenting effects of atmospheric pollutants on stream chemistry using high-frequency sampling. In press, *Proceedings of the Third Interagency Conference on Research in the Watersheds.*

SPONSORED RESEARCH PROJECTS

Current awards

- Principal Investigator EW Boyer with DR DeWalle. Long-term responses of stream chemistry to changes in atmospheric deposition in mid-Appalachian forests of Pennsylvania. US Environmental Protection Agency, $693,420.
- Principal Investigator EW Boyer. The Pennsylvania Atmospheric Deposition Research Program. Pennsylvania Department of Environmental Protection, Bureau of Air Quality Control, 7/2008–6/2011, $1,598,643.
- Principal Investigator EW Boyer with DR DeWalle. Mercury in Pennsylvania forest streams: Do hotspots exist? US Geological Survey, Pennsylvania Water Resources Research Center, 3/2008-3/2009, $20,000.

Past awards

- Co-Investigator EW Boyer with R Bales (PI), MH Conklin, JW Kirchner, and C Tague. Critical Zone Observatory: Snowline processes in the southern Sierra Nevada, National Science Foundation, Award # 0725097, GEO/EAR Critical Zone Observatories, $4,250,000 total, 11/2007-10/2011. (terminated – left UC Berkeley).
- Principal investigator EW Boyer. Coupled hydrological & ecological processes in watersheds controlling water quality. University of California, California Agricultural Experiment Station, $100,000, 10/2005-9/2010. (terminated – left UC-AES).
- Co-investigator EW Boyer with C Kendall (PI), D Burns and R Carlton. Quantifying atmospheric nitrogen sources with new stable isotope techniques. New York State Energy Research and Development Authority, $430,000, 10/2003-10/2008.
- Co-investigator EW Boyer with PG Stålnacke (PI). Norwegian Institute for Water Research (NIVA), Oslo, Norway. Advances in nutrient source apportionment in river basins using two state-of-the-art statistical models. Norwegian Research Council, grant designed to foster bilateral research cooperation between Norway and USA. $25,000 (to PGS) for workshops to be held at USGS in Reston, VA and at UC Berkeley, 2005-2006.
- Principal investigator EW Boyer. Quantifying freshwater carbon fluxes in the nation’s surface waters and implications for water quality. University of California, Committee on Research, $6000 to ewb/ Berkeley, 2006-2007.
- Principal investigator EW Boyer. Regional-scale models of nutrient fluxes for the Central Valley of California. US Geological Survey, National Water Quality Assessment Program, $31,000 to ewb/ Berkeley, 2005-2007.
- Co-Investigator EW Boyer with R Bales (PI), J Dozier, G Fogg, J Kirchner, N Miller, T Harmon, N Molotch, K Redmond, R Rice. Observatory design in the mountain west: scaling measurements and modeling in the San Joaquin Valley and Sierra Nevada. National Science Foundation, Hydrologic Sciences Program, $307,678 total; $20,000 to ewb/Berkeley, 2006-2007.
- Co-investigator EW Boyer with RW Howarth, RM Marino, DP Swaney, M Alber, D Scavia. Developing regional-scale stressor models for managing eutrophication in coastal marine ecosystems, including interactions of nutrients, sediments, land-use change, and climate variability and change. US Environmental Protection Agency: EPA-STAR, $749,644 total; $30,000 to ewb/ State University

of New York, 2003-2006.

- Co-investigator EW Boyer with CT Driscoll, TA Endreny, KE Limburg, MJ Mitchell, DI Siegel, and PJ Wilcoxen. Development of interdisciplinary graduate training program on watershed analyses: an integration of science, engineering, and policy. ($25,000 to State University of New York, 2004)
- Co-investigator EW Boyer with C Kroll and MJ Mitchell. Hydrochemical responses in diverse forested ecosystems. (US Department of Agriculture: USDA/CSREES McIntire-Stennis Program, $72,000 to ewb/ State University of New York, 2001-2004).
- Principal Investigator EW Boyer with MJ Mitchell. Terrestrial/Aquatic linkages controlling nutrient dynamics in a forested catchment of the Adirondack Mountains. (United States Department of Agriculture: USDA/CSREES McIntire-Stennis Program, $73,261 to ewb/ State University of New York, 2000-2004).
- Co-investigator EW Boyer with RW Howarth, D Swaney, R Alexander, and P Phillips. A Watershed-scale biogeochemical loading model for nitrogen and phosphorus. USGS Water Resources Institute ($216,999 to Cornell University, $64,200 to ewb/ State University of New York, 2000-2003).
- Co-investigator EW Boyer with M Borbor, C Hall, and W McDowell. Modeling how land use change affects the nutrient budget in the Guayas Watershed, Ecuador: Ecological & economic implications. (Instituto Inter-Americano para Pesquisa em Mudancas Globais, $40,000 to State University of New York, 2002-2003).
- Co-investigator EW Boyer with GM Hornberger and KE Bencala. Landscape- scale determinants of the hydrological and hydrochemical responses of mountainous catchments. (National Science Foundation, Hydrologic Sciences Program, $358,000 to University of Virginia, 1993-1996).

SERVICE ACTIVITIES

University

Penn State University (current):

University-wide

- Director, *Pennsylvania Water Resources Research Center*, 2008-present.
- Assistant Director (Water), *Penn State Institutes of Energy & the Environment,* 2008-present.
- Lead faculty adviser, student chapter of the *American Water Resources Association,* 2008-present.
- Lead representative to *Universities Council on Water Resources*, 2008-present.
- Member, campus task force on *Water and Energy,* 2008.
- Member, campus committee on *Network Science and Research,* 2008.

College of Agricultural Sciences

- Faculty participant, *Pennsylvania Agricultural Experiment Station*, 2008-present.
- Member, advisory committee for *Environment & Natural Resources Institute,* 2008-present.
- Co-Chair, *Water Quality & Quantity Initiative* strategic planning team, 2008-present.

School of Forest Resources

- Member, *forest lands committee,* 2008-present.
- Member, *undergraduate recruitment committee,* 2008-present.
- Member, *strategic planning - water committee,* 2008-present.

Penn State University (past):

- Member, campus coordinating committee for *EarthTalks* seminar series on water resources, 2008.
- Member, College of Agricultural Sci. strategic planning team on *Sustainable Environments*, 2008.

University of California, Berkeley:

- Oversight Committee, UC Berkeley *Geospatial Imaging & Informatics Facility,* 2005-2007.
- Research Advisory Committee, *Hopland Research & Extension Center*, 2005-2007.
- Steering Committee, UC Berkeley *Center for Fire Research and Outreach,* 2005-2007.

- Faculty Advisory Board, Inner-College undergraduate major in *Environmental Sciences*, 2005-2007.
- Coordinator, *Environmental Science, Policy, and Management Colloquium series*, 2007.
- Search Committee, for faculty position in Ecosystem Management, 2006.
- Faculty participant, California Agricultural Experiment Station, 2005-2007.

State University of New York, Syracuse:

- Representative to *Universities Council on Water Resources*, 2000-2004.
- Lead representative to *Consortium of Universities for the Advancement of Hydrologic Sciences, Inc.*, 2001-2004.
- Faculty adviser, student chapter of the *American Water Resources Association*, 2002-2004.

Cornell University:

- Faculty participant, Integrative Graduate Education and Research Traineeship (IGERT) *Program in Biogeochemistry & Environmental Biocomplexity*, Cornell University, 2000-2004.

Professional societies and organizations

- Memberships: American Geophysical Union (AGU), American Water Resources Association (AWRA), American Society of Limnology & Oceanography (ASLO), Ecological Society of America (ESA), Northeastern Ecosystem Regional Cooperative (NERC).
- American Geophysical Union: 1) Member, Hydrology section *water quality* technical committee, 2000-present; Chair 2008-present. 2) Member, *Biogeosciences section* executive committee, 2001-2002.
- American Society of Limnology & Oceanography: Martin Award committee, recognizing manuscript that has had a high impact on the aquatic sciences, 2005-2008.
- Session Co-Chair at international meetings:
  - AGU, Sources, transport and cycling of nutrients in aquatic system. San Francisco, CA 2008.
  - N2007 4th International Nitrogen Conference, Nitrogen balances in different regions of the world. Costa do Sauipe, Brazil, October 2007.
  - AGU, Water quality of hydrologic systems. San Francisco, CA, Dec. 2005.
  - AGU, Hypoxia in the Mississippi Basin, Gulf of Mexico, and other major ecosystems. New Orleans, LA, May 2005.
  - AGU, Water quality of hydrologic systems. San Francisco, CA, Dec. 2004.
  - AGU, Water quality of hydrologic systems. San Francisco, CA, Dec. 2003.
  - AGU, Nitrogen cycling in aquatic systems. San Francisco, CA, Dec. 2003.
  - Estuarine Research Federation, Nitrogen inputs to the coastal zone at regional scales. Seattle, WA; Sept. 2003.
  - AGU, Water quality of natural systems. Washington, DC, May 2002.
  - AGU, Human impacts on nitrogen cycling: science and policy. Boston, MA, May 2001.
  - AGU, Dissolved organic matter in surface & ground waters. San Fran., CA, Dec. 2000.
  - ESA, Nitrogen transport & transformations: a global analysis. Spokane, WA; Aug. 1999.
  - AGU, Organic matter in aquatic systems. San Francisco, CA, Dec. 1996.

Advising or planning activities for the scientific community

- NADP National Atmospheric Deposition Program (2008-present). 1) Technical Committee member, providing guidance and decision making for scientific and technical aspects of a nationwide network of >250 precipitation chemistry monitoring sites. 2) Budget Advisory Committee member, assisting with financial planning, recommendations, and budget allocations for the NADP network.
- EPA Integrated Nitrogen Research Committee (2006-present). Member of an ad hoc advisory committee of the US Environmental Protection Agency, Science Advisory Board, that is considering integration among various federal programs regarding nitrogen research and management.
- NSF Denitrification Research Coordination Network Advisory Committee (2005-present). Member of a steering committee that is planning activities & workshops of the NSF sponsored Research

Coordination Network on Denitrification: integration across landscapes and waterscapes.

- CALFED Determination of Sources of Organic Matter and Nutrients in the San Joaquin River (2006-2008). Member of advisory committee for this California Bay-Delta Authority Project.
- Gordon Research Conferences (2003-2007). Leader of international conferences on *Catchment Science: Interactions of Hydrology, Biology and Geochemistry*. North American Co-Chair 2005-2007 (for meeting 07/07 in New London, NH). Vice Chair 2003-2005 (for meeting 07/05 in Waterville, ME).
- EPA Ecological Effects Advisory Committee (2004-2006). Member of a sub-committee of the US Environmental Protection Agency, Science Advisory Board, Advisory Council on Clean Air Compliance Analysis, to consider ecological effects of atmospheric emissions.
- AGU Biogeosciences at the threshold. Participating member in workshop of the American Geophysical Union to plan activities of the Union's (then) new biogeosciences section. Elkridge, MD, March 21-22 2001.

Invited participant in workshops to identify interdisciplinary scientific research agendas

- Terrestrial and coastal carbon fluxes and exchanges in the Gulf of Mexico, Workshop of the National Science Foundation, Ocean Carbon and Biogeochemistry Program, to develop ideas for integrated research regarding carbon cycling in coastal ecosystems. St. Petersburg, FL, May 6-8 2008.
- CUAHSI Committee on river basin science: an integrated research area (2005). A working group of the (now named) Berkeley Water Center to develop ideas for this thrust area of research.
- Water: challenges at the intersection of human and natural systems. Workshop of the National Science Foundation & Department of Energy to shape research programs on water as a complex environmental system. Richland, WA, September 16-17 2004.
- CUAHSI Committee on hydrologic synthesis (2003). A working group of the Consortium of Universities for Advancement of Hydrologic Sciences, Inc. to develop a vision (and white paper) for a national hydrology synthesis center.
- Integrated studies of coupled biosphere-atmosphere carbon and nitrogen cycles. Workshop of the National Center for Atmospheric Research to develop a nitrogen cycle science plan & research agenda. Boulder, CO, November 14-17 2003.
- Emerging research issues for limnology, the study of inland waters. Workshop of the American Society of Limnology & Oceanography, sponsored by the National Science Foundation. Boulder, CO, December 1-4 2002.

Peer reviews

- Journals: *Water Resources Research; Hydrological Processes; Biogeochemistry; Ecosystems; Applied Geochemistry; Global Biogeochemical Cycles; Water, Air, & Soil Pollution; Environmental Science & Technology; Nature.*
- Proposals & Technical Documents: 1) National Science Foundation (including programs in Hydrologic Sciences, Methods and Models for Integrated Assessment, Ecosystems, Education and Human Resources). 2) U.S. Department of Agriculture (including Water Resources Assessment Program, Soils and Soil Biology Program, Watershed Processes & Water Resources Program). 3) Environmental Protection Agency (Office of Water).
- Review panels: 1) Environmental Protection Agency, Adirondack Effects Assessment Program. Lake George, NY June 18-20, 2002. 4) National Science Foundation, Integrative Graduate Education and Research Traineeship Program, Arlington, VA, July13-16 2004. 5) National Science Foundation, Integrative Graduate Education and Research Traineeship Program, Arlington, VA, June 18-19 2007. 4) Northeastern States Regional Cooperative, Ecosystem Research and Assessment Program. Durham, NH June 24-25 2003, April 12-13 2004, May 19-20 2005, April 2008. 6) National Science Foundation, Geochemistry & Geobiology Program, Arlington, VA, May 2009.

Invited participant in regional working groups to integrate & synthesize research

- Northeast consortium for hydrologic synthesis. Working group associated with NSF project entitled *Humans Transforming the Water Cycle: Community-Based Activities in Hydrologic Synthesis*, Consortium of Universities for the Advancement of Hydrologic Sciences, Inc., December 2007-present.
- Integrated modeling of nitrogen fluxes in regional watersheds: Linking atmospheric, terrestrial, aquatic and coastal interactions. Working group sponsored by Nitrogen in Europe (NinE): Assessment of current problems and future solutions. Structure et fonctionnement des systèmes hydriques continentaux, Université Pierre et Marie Curie Paris VI, Paris, France, January 14-17 2007.
- Denitrification modeling across terrestrial, freshwater and marine systems. Workshop of NSF Research Coordination Network on Denitrification: integration across landscapes and waterscapes, Institute of Ecosystem Studies, Millbrook, New York, November 28-30 2006.
- Hydrologic modeling to support riverine ecosystem needs for fresh water. Workshop of the Global River Sustainability Project, sponsored by the National Science Foundation. Estes Park, CO, June 9-11 2005.
- Large scale modeling of nutrient fluxes in watersheds – implications for management. Working group of the Swedish research program MaRE: Marine Research on Eutrophication - A scientific basis for cost-effective measures for the Baltic Sea. Sigtuna, Sweden, January 17-19 2005.
- Fertilizer nitrogen rapid assessment project. Workshop of the International Nitrogen Initiative, sponsored by the Scientific Committee on Problems of the Environment. Kampala, Uganda; January 13-16 2004.
- Nitrogen fluxes and process in tropical and temperate systems. Working group of the International Nitrogen Initiative to compare and contrast nitrogen cycling processes among regions. Ubatuba, Brazil, March 13-17 2003.
- Nitrogen pollution in the northeastern USA. Working group of the Hubbard Brook Research Foundation "Science Links" project, to synthesize information on nitrogen pollution and develop media for the public and policy makers. Albany, NY, November 9 2001 & March 21-22 2002.
- Assessment of the uncertainties of estimates of atmospheric nitrogen inputs to U.S. estuaries. Workshop at the University of Maryland, Appalachian Lab Center for Environmental Science, December 11-12 2001.
- Merging terrestrial and aquatic perspectives of biogeochemistry. Working group sponsored by the National Center for Ecological Analysis and Synthesis. Santa Barbara, CA, July 6-10 1999, February 8-11 2000, September 24-28 2000, June 18-22 2001, March 7-17 2002.

PRESENTATIONS

Invited presentations

1. Boyer EW, GM Hornberger, KE Bencala, and DM McKnight. Combining hydrometric and geochemical techniques to interpret DOC flux in an upland catchment. American Geophysical Union, Baltimore, MD, May 1996.
2. Boyer EW, GM Hornberger, DM McKnight, and KE Bencala. Coupling of a hydrological model with a simple model of DOC in an upland catchment. North American Benthological Society, Annual Meeting, Kalispell, MT, June 1996.
3. Boyer EW, GM Hornberger, KE Bencala, and DM McKnight. DOC patterns at the catchment scale. American Society of Limnology and Oceanography, Aquatic Sciences Meeting, Sante Fe, NM, February 1997.
4. Boyer EW, R Alexander, V Bashkin, F Dentener, R Howarth, A Townsend, C Vörösmarty, and G Xing. Regional and landscape-scale nitrogen budgets. Plenary Session on Nitrogen Transport & Transformations. Ecological Society of America, Annual Meeting, Spokane, WA, August 1999.

5. Boyer EW. Hydrological controls on organic matter export. Workshop: integrating approaches to microbial-DOC tropic linkages. Institute of Ecosystem Studies, Milbrook, NY May 2000.
6. Boyer EW. Catchment-scale nitrogen budgets -- new insights and questions regarding N sources, storage, and losses. Gordon Research Conference on Forested Catchments: Hydrological, Geochemical, and Biological Processes. Andover, NH, July 2001.
7. Boyer EW, CA Goodale, and RW Howarth. Relationships of anthropogenic nitrogen loading to riverine nitrogen export. 2nd International Nitrogen Conference, Potomac, MD, Oct. 2001.
8. Boyer EW, CA Goodale RW Howarth, and N Van Breemen. Where did all the nitrogen go? Use of watershed-scale budgets to quantify nitrogen inputs, storages, and losses. American Geophysical Union, San Francisco, CA, December 2001.
9. Boyer EW. Challenges and opportunities in estimating atmospheric deposition. Special session on tracking nutrient enrichment of water resources in the 21st century: challenges and opportunities for information management at the national level. Universities Council on Water Resources, Washington, DC, July 2003.
10. Boyer EW, RW Howarth, and JN Galloway. Riverine nitrogen export from the world's watersheds. Estuarine Research Federation, Annual Meeting, Seattle, WA, September 2003.
11. Boyer EW, RW Howarth, and RB Alexander. Case study: Nitrogen sources and impacts to rivers and estuaries of New York Sate. Multi-agency Conference on Environmental monitoring, evaluation, and protection in New York: linking science and policy. Albany, NY, October 2003.
12. Boyer EW and RB Alexander. Modeling nitrogen movement and loss in soils and streams: A biogeochemical perspective. Workshop on Advanced Approaches to Quantify Denitrification, Sponsored by the International Nitrogen Initiative, Woods Hole, MA, May 2004.
13. Boyer EW, RW Howarth, JN Galloway, FJ Dentener, C Cleveland, GP Asner, P Green, C Vörösmarty. Riverine nitrogen export from the world's watersheds. 3rd International Nitrogen Conference, Nanjing, China, October 2004.
14. Boyer EW, RB Alexander, RW Howarth, and RA Smith. Nitrogen inputs and delivery to coastal waters in the northeastern USA. Northeastern Ecosystem Research Cooperative, Durham, NH, November 2004.
15. Boyer EW, RA Smith, RB Alexander, and GE Schwarz. Quantifying sources and fluxes of aquatic carbon in U.S. streams and reservoirs using spatially referenced regression models. American Geophysical Union, San Francisco, CA, December 2004.
16. Boyer EW, SB Bricker, RA Smith, RB Alexander, and GB Schwarz. Nutrient enrichment of coastal receiving waters from catchments across the USA. American Geophysical Union, Joint Assembly, New Orleans, LA, May 2005.
17. Boyer EW, RB Alexander, SD Sebestyen. Apportioning sources of riverine nitrogen at multiple watershed scales. American Geophysical Union/North American Benthological Society, Joint Assembly, New Orleans, LA, May 2005.
18. Boyer EW. It's all about connections: coupled hydrological and biogeochemical cycles in watersheds. Ecological Society of America, 90th Annual Meeting, Montréal, Canada, August 2005.
19. Boyer EW, RB Alexander, SD Sebestyen, RA Smith, and JB Shanley. Coupled hydrological and biogeochemical cycles affecting delivery of nitrogen to surface waters. American Geophysical Union, San Francisco, CA, December 2005.
20. Boyer EW and RB Alexander. Modeling approaches to quantify denitrification across terrestrial, freshwater and marine systems. NSF Research Coordination Network workshop on Denitrification Modeling, Millbrook, NY, November 2006.
21. Boyer EW, S Filoso, and R Howarth. Nitrogen inputs to landscapes around the world, with implications for water quality. N2007 4th International Nitrogen Conference, Costa do Sauipe, Brazil, October 2007.
22. Boyer EW. Modeling watershed nutrient fluxes and delivery to coastal waters. Terrestrial and Coastal Carbon Fluxes in the Gulf of Mexico, National Science Foundation, Workshop of the Ocean

Carbon and Biogeochemistry Program, St. Petersburg, FL, May 2008.

23. Boyer EW. Agriculture and water resources. Pennsylvania State Agricultural Council, University Park, PA, September 25, 2008.
24. Boyer EW. Nutrient pollution in waters of Pennsylvania and the nation. Penn State University EarthTalks series, University Park, PA, October 27, 2008.

Contributed presentations or invited as co-author (since 2006)

1. (invited) Shanley JB, SD Sebestyen, **EW Boyer**, and D Ross. Solute flushing: a hydro-biogeochemical phenomenon. American Geophysical Union, San Francisco, CA, December 2005.
2. **Boyer EW**, Golden HE, Alexander RB, Burns DA, Elliott EM, Kendall C, and Butler TJ. Elucidating sources and factors affecting delivery of nitrogen to surface waters of New York State. New York State Energy Research & Development Authority, Conference on Environmental Monitoring, Evaluation, and Protection in New York: Linking Science and Policy. Albany, NY, October 2005.
3. Elliott EM, C Kendall, DA Burns, **EW Boyer**, K Harlin, SD Wankel, TJ Butler, & R Carlton. Nitrate isotopes in precipitation to distinguish NO_x sources, atmospheric processes, and source areas in the United States. Eos Trans. AGU, 87(36), Jt. Assem. Suppl., Abstract H52B-01. American Geophysical Union, Baltimore, MD, May 2006.
4. Golden HE & **EW Boyer.** Atmospheric nitrogen deposition and links to water quality in large watersheds of New York state. American Fisheries Society, 136th Annual Meeting, Lake Placid, NY, September 2006.
5. (invited) Alexander RB, RA Smith, and GE Schwarz, and **EW Boyer**. Insights about denitrification in aquatic ecosystems from the SPARROW model, Spatially Referenced Regressions on Watershed attributes. NSF Research Coordination Network workshop on Denitrification Modeling, Millbrook, NY, November 2006.
6. (invited) Alexander RB, RA Smith, GE Schwarz, and **EW Boyer.** Advances in estimating nutrient sources, transport, and fate in the Mississippi/Atchafalaya River basins using the SPARROW model. Symposium on Sources, Transport, and Fate of Nutrients in the Mississippi and Atchafalaya River Basins, Sponsored by the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, Minneapolis, MN, November 2006.
7. Elliott EM, DA Burns, **EW Boyer**, and C Kendall. Sources of nitrogen to streams of varying land use as determined through dual isotope analysis of nitrate. EOS Trans. AGU, 87(52), Fall Meet. Suppl., Abstract H12C-07. American Geophysical Union, San Francisco, CA, December 2006.
8. Conklin M, R Bales, **E Boyer**, D Cayan, J Dozier, G Fogg, T Harmon, J Kirchner, N Miller, N Molotch, and K Redmond. Observatory design in the mountain west: scaling measurements and modeling in the San Joaquin Valley and Sierra Nevada. American Geophysical Union, San Francisco, CA, December 2006.
9. Sebestyen SD, **EW Boyer**, JB Shanley, DH Doctor, C Kendall, and GR Aiken. Quantifying nutrient sources in an upland catchment using multiple chemical and isotopic tracers. American Geophysical Union, San Francisco, CA, December 2006.
10. Doctor DH, Sebestyen SD, GR Aiken, JB Shanley, C Kendall, and **EW Boyer**. Carbon isotope composition as an indicator of DOC sources to a stream during events in a temperate forested catchment. American Geophysical Union, San Francisco, CA, December 2006.
11. Short A, **EW Boyer,** and R Harris. Interrelationships among rural development, regulation, and watershed health. 2nd Conference on Emerging Issues at the Urban/Rural Interface. Atlanta, GA, April 2007.
12. Sebestyen SD, **EW Boyer,** JB Shanley, & C Kendall. Tracing Water and Nitrogen Sources to Identify Controls on Stream Nitrogen Variation. American Geophysical Union, Joint Assembly, Acupulco, Mexico, May 2007.
13. DA Burns, EM Elliott, C Kendall, & **EW Boyer**. Nitrate Isotopes as Tracers of Nitrogen Cycling

Processes in Watershed of Varying Land Use in New York. New York State Energy Research & Development Authority, Conference on Environmental Monitoring, Evaluation, and Protection in New York: Linking Science and Policy. Albany, NY, November 2007.

14. EM Elliott, C Kendall, SD Wankel, DA Burns, **EW Boyer**, DJ Bain, & TJ Butler. An isotopic tracer of stationary source NOx emissions across the Midwestern and northeastern United States. New York State Energy Research & Development Authority, Conference on Environmental Monitoring, Evaluation, and Protection in New York: Linking Science and Policy. Albany, NY, November 2007.
15. C Kendall, EM Elliott, DA Burns, & **EW Boyer**. Quantifying atmospheric nitrogen sources with new stable isotope techniques: what have we learned? New York State Energy Research & Development Authority, Conference on Environmental Monitoring, Evaluation, and Protection in New York: Linking Science and Policy. Albany, NY, November 2007.
16. C Kendall, EM Elliott, SD Wankel, **EW Boyer**, & DA Burns. Why do different anthropogenic sources of atmospheric nitrate have distinctive isotopic signatures? New York State Energy Research & Development Authority, Conference on Environmental Monitoring, Evaluation, and Protection in New York: Linking Science and Policy. Albany, NY, November 2007.
17. Sebestyen SD, JB Shanley, **EW Boyer**, and C Kendall. A role for high frequency hydrochemical sampling in long term ecosystem studies. American Geophysical Union, Fall Meeting, San Francisco, CA, December 2007.
18. Bales R, **B Boyer**, M Conklin, M Goulden, J Hopmans, C Hunsaker, D Johnson, J Kirchner, and C Tague. Southern Sierra Critical Zone Observatory: integrating water cycle and biogeochemical processes across the rain-snow transition. American Geophysical Union, Fall Meeting, San Francisco, CA, December 2007.
19. (invited) EM Elliott, C Kendall, **EW Boyer**, DA Burns, K Harlin, G Lear, and SD Wankel. Distinguishing NO_x source contributions to wet and dry nitrate deposition in the United States using stable isotopes. EOS Trans. AGU, 88(52), Fall Meet. Suppl., Abstract B24A-03. American Geophysical Union, San Francisco, CA, December 2007.
20. Kendall C, EM Elliott, SW Wankel, **EW Boyer**, and DA Burns. Why do different anthropogenic sources of atmospheric nitrate have distinctive isotopic signatures? EOS Trans. AGU, 88(52), Fall Meet. Suppl., Abstract B31A-0059. American Geophysical Union, San Francisco, CA, December 2007.
21. Sebestyen SD, JB Shanley, and **EW Boyer** (2008). The role for high frequency sampling in documenting the effects of atmospheric pollutants on stream chemistry. In, Third Interagency Conference on Research in the Watersheds, 9-11 September 2008, Estes Park, CO. US Geological Survey, Estes Park, CO.
22. Burns DA, **EW Boyer**, EM Elliott, and C Kendall (2008). Sources and Transformations of Nitrate from Streams Draining Varying Land Uses: Evidence from Dual Isotope Analysis, Northeast Ecosystem Research Cooperative Bi-Annual Conference, November, Durham, NH.
23. (invited) Alexander RB, RA Smith, GE Schwarz, **EW Boyer**, and JV Nolan. Recent Advances in Modeling Phosphorus and Nitrogen Delivery to the Gulf of Mexico and Implications for Managing Nutrients n the Mississippi River Basin. Eos Trans. AGU, 89*(53)*, Fall Meet. Suppl., Abstract H23J-01. American Geophysical Union, San Francisco, CA, December 2008.
24. Alexander RB, JK Bohlke, **EW Boyer**, MB David, JW Harvey, PJ Mulholland, SP Seitzinger, CR Tobias, C Tonitto, WM Wollheim. Modeling the Effects of Hydrological and Biogeochemical Processes on Denitrification and Stream Nitrogen Losses in River Networks. *Eos Trans. AGU, 89*(53), Fall Meet. Suppl., Abstract H13I-06. San Francisco, CA, December 2008.
25. Burns DA, **EW Boyer**, EM Elliott, and C Kendal (2008). Sources and Transformations of Nitrate from Streams Draining Varying Land Uses: Evidence from Dual Isotope Analysis, Eos Transactions American Geophysical Union, 89(53), Fall Meeting Supplement, Abstract No. H23J-07. San Francisco, CA, December 2008.

Invited discussion leader or panelist

1. Panelist, session on future needs for watershed science and management. Cornell University, Cayuga Lake Research Symposium. Ithaca, NY, October 12, 1999.
2. Panelist, Session on nutrient pollution in coastal waters, sponsored by NOAA National Ocean Service. Coastal Zone 2001, Cleveland, OH, July 17, 2001.
3. Discussion Leader, session on watershed hydrology. Lake Ontario Interdisciplinary Science and Management Conference. Syracuse, NY, March 13, 2003.
4. Discussion Leader, Session on water pollution. Gordon Research Conference on Forested Catchments: Hydrological, Geological, and . New London, NH, July 24, 2003.
5. Discussion Leader, Gordon Research Conference on Forested Catchments: Hydrological, Geological, and Biological Processes. Waterville, ME, July 17-22, 2005.
6. Panelist, symposium on ecosystem ecology at the watershed scale: cycles across the terrestrial aquatic divide. Ecological Society of America, Montréal, Canada, August 9, 2005.
7. Panelist, New Directions in Rangelands, Forests, Watersheds, and Communities Conference, Watershed Panel. University of California, Berkeley, March 14, 2006.
8. Discussion Leader, meeting on Coupled Biogeochemical Cycles, Gordon Research Conference on Catchment Science: Interactions of Hydrology, Biology, & Geochemistry, New London, NH, July 2007.
9. Panelist, Mid-Atlantic Regional Water Resources Research Conference: The Water-Energy Nexus: A Necessary Synergy for the 21st Century. Shepherdstown, WV, November 18, 2008.

TEACHING

Penn State University, University Park, PA (2008-present), *Watershed Management.* Introduces basic watershed hydrology and management of landscapes to protect water quality and quantity.

University of California, Berkeley, CA (2005-2007), Courses in the Department of Environmental Science, Policy & Management: *1) Watershed Hydrology:* Introduces physical hydrological processes operating in watersheds and connections of hydrology to other disciplines. *2) Forests and Water:* Reviews hydrological processes important in forested settings; emphasizes impacts of forest management on the water cycle and water quality. *3) Research Concepts and Approaches in Environmental Science, Policy & Management:* Introduces research questions, encourages critical thinking, and develops grant writing skills. *4) Environmental Science, Policy, and Management Colloquium:* provides seminars on contemporary issues and associated discussion.

State University of New York, College of Environmental Science & Forestry, Syracuse, NY (2000-2004): Courses in: *Watershed Hydrology; Forest Hydrology; Hydrological Techniques; Watershed Ecology; Current Topics in Hydrology; Current Topics in Biogeochemistry.*

University of Virginia, Charlottesville, VA (1991-1994), Department of Environmental Sciences - Taught lab sections as graduate teaching assistant for: *Physical Hydrology; Catchment Hydrology; Hydrological Transport Processes;* and *Applied Statistics for Environmental Sciences.* (1996-1997), Department of Information Technology and Communication - Taught short courses introducing *HTML Programming* and *Microsoft Excel.*

ADVISING

At: Penn State University, University Park, PA (PSU); State University of New York, Syracuse, NY (SUNY); Syracuse University, Syracuse, NY (SYR); and University of California, Berkeley, CA (UCB).

Current graduate students as major professor:

1. Christopher Grant, PhD student (co-advisor with Dave DeWalle), PSU

2. Kristin Brubaker, PhD student (co-advisor with Wayne Myers), PSU
3. Lida Iavorivska, MS student (Fulbright scholar, Ukraine), PSU
4. Justin Kozak, MS student, (co-adviser with Sandy Smith), PSU

Current graduate students as advisory committee member:

1. Kate Blansett, PhD student, Dept. of Agricultural and Bio. Engineering, PSU
2. Mike Costello, PhD student, Dept. of Crop & Soil Sciences, PSU
3. Kate Gordon, MS student, School of Forest Resources, PSU
4. George Holmes, MS student, Dept. of Civil & Environmental Engr., PSU
5. Ken Takagi, PhD candidate, Dept. of Crop & Soil Sciences, PSU
6. Misha Williams-Tober, MS candidate, Dept. of Geography, PSU
7. Neihl Williamson, MS student, School of Forest Resources, PSU

Current post-doctoral students as supervisor:

1. Neil Brown, PSU, 2008-present (tri-adviser with AESEDA, Rachel Brennan, PSU)
2. Matt Miller, PSU, 2009-present

Current supervision of staff:

1. Jeffrey Grimm, research specialist, PSU, 2008-present
2. Kevin Horner, research specialist, PSU, 2008-present
3. Matt Borden, research assistant, PSU, 2008-present
4. Scott Atkinson, PSIEE lab manager, PSU, 2008-present
5. Karol Confer, PSIEE lab assistant, PSU, 2008-present

Past graduate students (doctoral) as major professor:

1. Heather E. Golden, PhD 2007, SUNY. Dissertation: *Role of multiple stressors on watershed nitrogen response across New York. Awards:* Environmental Protection Agency GRO dissertation fellowship award, 2004-2007; SUNY *Farnsworth Memorial Fellowship* for outstanding student in forestry; National Science Foundation, East Asia & Pacific Summer Institutes (Korea), 2005.
2. Stephen D. Sebestyen, PhD 2007, SUNY. Dissertation: *Coupled hydrological and biogeochemical processes control nutrients in streams of forested watersheds. Awards:* Environmental Protection Agency STAR dissertation fellowship award, 2003-2007; National Science Foundation, East Asia & Pacific Summer Institutes (Japan), 2005; SUNY *Leaf Award* for student excellence in research; American Geophysical Union, *hydrology section research award*, 2004.

Past graduate students (masters) as major professor:

1. Todd McDonnell, MPS 2005, SUNY (co-advisor with Ted Endreny).
2. Ruthanna Hawkins, MPS 2003, SUNY.
3. Eric McNeill, MPS 2005, SUNY.
4. Lynn Washlaski, MS 2003, SUNY. Thesis: *Nutrient Dynamics of Salmon Creek, NY.*
5. Chia-Lun Lee, MS, SUNY. Thesis: *Longitudinal Profiles of Stream Chemistry in Urbanizing Watersheds.*

Past post-doctoral students as supervisor on research projects:

1. Emily Elliott, US Geological Survey, 2004-2007 (co-adviser with Carol Kendall, USGS); now an Assistant Professor at the University of Pittsburgh.

Past undergraduate students as supervisor on research projects:

1. Matt Conlon, BS 2004 SUNY, *Watershed management plan for Long Island Sound, NY.*
2. Jennifer Fleuret, BS 2004 SUNY, *Forest nitrogen fixation rates.*

3. Lisa Forma, BS 2007 UCB. Honors thesis: *Decision making for road closures and restoration projects in California watersheds.* Citationist as head of the class, Conservation and Resource Studies Major; and nominee for University Medal, UC Berkeley.
4. Chris Hone, BS student, PSU, *Water use in Pennsylvania.*
5. Scott Means, BS 2004 SUNY, *Analytical & field methods in hydrology.*
6. Mike Prokolkin, BS 2004 SUNY, *Water use in New York.*
7. Rebecca Sauter, BS 2004 SUNY, *Analytical & field methods in biogeochemistry.*
8. Jason Siemion, BS 2002 SUNY, *Karst hydrology of Benson's Cave, Schoharie County, NY.*

Past graduate students as advisory committee member:

1. Eric Bernsten, MS, Dept. Environmental & Forest Biology, SUNY
2. Mercy Borbor, PhD, Dept. Environmental & Forest Biology, SUNY
3. Emera Bridger, MPS, Dept. Forest & Natural Resources Mgmt., SUNY
4. Donna Busby, MS, Dept. Environmental Resources & Forest Engineering, SUNY
5. John Campbell, PhD, Environmental & Forest Biology, SUNY
6. Sheila Christopher, Dept. Environmental & Forest Biology, SUNY
7. Carol Franco, MS, Dept. Forest & Natural Resources Mgmt., SUNY
8. Maria Goodrich, PhD candidate, Dept. of Integrative Biology, UCB
9. Sarah Godsey, PhD candidate, Dept. of Earth & Planetary Sciences, UCB
10. Jon Hallock, MS, Dept. Environmental & Forest Biology, SUNY
11. Mary Hegarty, MPS, Dept. Forest & Natural Resources Mgmt., SUNY
12. Nick Hjerdt, PhD, Dept. Forest & Natural Resources Mgmt., SUNY
13. Scott Ingmire, MS, Graduate Program in Environmental Sciences, SUNY
14. Justin Lawrence, PhD student, Dept. of Environmental Science, Policy & Mgmt., UCB
15. Joana Luz, PhD, Dept. Environmental Resources & Forest Engineering, SUNY
16. Trina Mackie, PhD candidate, School of Public Health, UCB
17. Bryan McGlynn, PhD, Dept. Forest & Natural Resources Mgmt., SUNY
18. Nancy Nowicki, MPS, Dept. Forest & Natural Resources Mgmt., SUNY
19. Sheila Palmer, PhD, Dept. Civil & Environmental Engineering, SYR
20. Alison Purcell, PhD 2007, Dept. of Environmental Science, Policy & Management, UCB
21. Wilnelia Rivera, MS 2008, Program in Environmental Pollution Control, PSU
22. Jon Sanderman, PhD 2007, Dept. of Environmental Science, Policy & Management, UCB
23. Seth Shonkoff, PhD student, Dept. of Environmental Science, Policy & Management, UCB
24. Anne Short, PhD candidate, Energy & Resources Group, UCB
25. Madeline Solomon, PhD candidate, Dept. of Geography, UCB
26. Julie Tasillo, MS, Dept. Environmental & Forest Biology, SUNY
27. Brian Wellington, PhD, Dept. Civil & Environmental Engineering, SYR

Past supervision of staff:

1. Jacqueline Erbe, water quality lab manager, UC Berkeley, 2005-2007

Curriculum Vitae - Kenneth G. Cassman

Current Position:	Director, Nebraska Center for Energy Sciences Research, and Heuermann Professor of Agronomy	2006-present

Address Department of Agronomy and Horticulture
University of Nebraska
377 Plant Science Building
Lincoln, Nebraska 68583-0724

Phone/email: Phone: (402) 472-5554, Email: kcassman1@unl.edu

Areas of expertise: Plant ecophysiology, nutrient cycling, and crop yield potential; energy efficiency and environmental impact of biofuels; global food security; scientific administration, strategic planning, and research prioritization.

Education:	Postdoctoral Fellow, University of California Davis	1979-1980
	Ph.D. (Agronomy and Soil Science) University of Hawaii	1979
	B. Sc. (Biology) University of California San Diego	1975
Previous Positions:	Professor of Agronomy, Dept. of Agron. and Horticulture, UNL	2004-2005
	Dept. Head and Professor, Dept of Agron. and Horticulture, UNL	1996-2004
	Head, Division of Agronomy, Plant Physiology, and Agroecology, International Rice Research Inst., Los Baños, Laguna, Philippines	1991-1995
	Affiliate faculty member, Dept. of Agronomy and Soil Science, University of the Philippines, Los Banos, Philippines	1991-1995
	Assist./Assoc. Professor, Dept. Agronomy and Range Sci., University of California Davis	1984-1991
	Agronomist, Egyptian Major Cereals Improvement Project, Egypt	1982-1984
	Project Leader, Amazon Rice Res. Station, San Raimundo, Brasil	1980-1982
Honors & Awards:	Agronomic Research Award, American Soc. of Agronomy	2006
	Fellow, American Assoc. for the Advancement of Science (AAAS)	2005
	Weston Distinguished Lecture, Univ. of Wisconsin SAGE Program	2005
	International Crop Nutrition Award, International Fertilizer Assoc.	2004
	Outstanding Alumnus, College of Tropical Agric., Univ. of Hawaii	2003
	Robert E. Wagner Award, Potash and Phosphate Institute	2000
	Fellow, Crop Science Society of America	1999
	Research and Education Award, Nebraska Agric. Business Assn.	1998
	Fellow, Soil Science Society of America	1997
	M.S. Swaminathan Outstanding Research Award from the Philippine Council for Agriculture & Natural Resources Res. & Development	1996
	Fellow, Agronomy Society of America	1996
	Researcher of the Year, Fluid Fertilizer Foundation	1989
Professional Societies:	Soil Science Society of America	since 1977
	American Society of Agronomy	since 1977
	Crop Science Society of America	since 1977
	American Association for the Advancement of Science	since 2001
Editorial Boards:	Editorial Advisory Board: *Field Crops Research*	1992-2000
	Editorial Board: *Soil Science and Plant Nutrition* (Japan)	2000-present
	Editorial Advisory Board: *Biofuels, Bioproducts and Biorefining*	2007-present
	Editorial Board, *Biobased Materials and Bioenergy*	2007-present

Selected Professional Activities and Service:

Chair, ICRISAT (South Asia & Africa) External Program and Mgt Review	2008-2009
US-EPA Science Advisory Comm., Integrated Nitrogen Management	2007-2009
Chair, IRRI-CIMMYT Alliance Working Group, Rockefeller Found.	2004-2005
Coordinating Lead Author, Cultivated Systems Chapter, Millennium Ecosystem Assessment	2003-2005
Science and Policy Committee, 3rd International Nitrogen Conference	2002-2004

North Central State Research Advisory Committee, USDA—CSREES	1996-2004
Nebraska Crop Improvement Association, Board of Directors	1997-2004
American Soc. Agronomy Board of Directors (elected) representing Division A-6, International Agriculture	1999-2002
Chair, IITA (Africa) External Program and Management Review Team	2001
Chair, Nebraska Livestock Environmental Quality Task Force	1998-2001
External Review Panel, Dept. of Soil Science, Univ. of Wisconsin	1999
Chair, External Review of Agricultural Sciences, Wageningen Agricultural University, the Netherlands	1998
Nebraska Certified Crop Advisors Executive Board, A092 ARCPACS Committee	1996-2002
Task Force on "Animal Agriculture and Global Food Security", Council for Agriculture, Science and Technology	1996-1999
Chair, Committee for Long-Term Research on Agricultural Systems, University of California Davis	1989-1990
California Task Force on Sustainable Agriculture	1985-1986

Major Research Grants (since 2000):

2006-2011	Nebraska Public Power: UNL Energy Center grant program	$5,000,000
2009-2010	WEAI--Enhancing water productivity of maize and soybean	$ 450,000
2008-2011	Gates Foundation: Biofuels, Food Security & Poverty	$ 210,000
2008-2010	NSF, Pre-Contact Hawaiian Agriculture	$ 150,000
2007-2010	U.S. DOE—BER: Carbon sequestration in agroecosystems	$1,000,116
2007-2010	USDA-NRCS: Limited Irrigation Systems for Corn	$231,500
2006-2007	Western Governors Assn: Environmental impact of biofuels	$ 75,000
2006-2008	Simulation of optimal irrigation for soybean, NE Soy Board	$168,000
2005-2006	Real-time water-limited irrigation scheduling, NE Corn Board	$144,000
2004-2006	U.S. DOE—BER: Carbon sequestration in agroecosystems	$900,000
2004-2006	U.S. DOE—EPSCoR: Carbon sequestration program	$1,000,066
2001-2003	U.S. DOE—BER: Carbon sequestration in agroecosystems	$977,000
2000-2003	U.S. DOE—EPSCoR: Carbon sequestration program	$840,000
2000-2008	FAR, FFF, IPNI—Ecological intensification of agriculture	$450,000

Publication Summary (full publication list available upon request):

125 refereed journal articles (including *Nature*. *PNAS,* other high-impact journals)
15 book chapters: co-editor/co-author of two books & two journal spec. volumes
29 papers published in proceedings of major conferences/symposia

Selected publications:

1. Liska A. and Cassman KG. 2008. Towards standardization of life-cycle assessment metrics for biofuels: Greenhouse gas emissions mitigation and net energy yield. J. Biobased Materials and Bioenergy 2:187-203.
2. Cassman K.G. and Liska A. J. 2007. Food and fuel for all: Realistic or foolish? Biofuels Bioprod. Biorefin. 1:18-23.
3. Olk, D.C, Cassman, K.G., Schmidt-Rohr, K., Anders, M.M., Mao, J.D., Deenik, J.L. 2006. Chemical stabilization of soil organic nitrogen by phenolic lignin residues in anaerobic agroecosystems. Soil Biol. Biochem. 38:3303-3312
4. Peng S, Huang J, Sheehy JE, Laza R, Visperas RM, Zhong X, Khush G, Cassman KG. 2004. Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci. *(USA)* 101: 9971-9975.
5. Yang HS, Dobermann A, Lindquist JL, Walters DT, Arkebauer T, and Cassman KG. 2004. Hybrid Maize—A maize simulation model that combines two crop modeling approaches. Field Crops Res. 87: 131-154.
6. Cassman KG, Dobermann A, Walters DT, and Yang H. 2003. Annu. Rev. Environ. Resour. Meeting cereal demand while protecting natural resources and improving environmental quality. 28:315-358.
7. Tillman D, Cassman KG, Matson PA, Naylor R, and Polasky S. 2002. Agricultural sustainability and intensive production practices. Nature 418: 671-677.
8. Cassman, K.G. 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proc. National Acad. Sci. (USA) 96: 5952-5959.

Teaching:

- Supervised 13MSc and 9 PhD students at UC Davis, IRRI/UPLB, UNL
- Courses taught: *Analysis and Determinants of Cropping Systems*, UC Davis, a required course in the International Agric. Development MSc program — 1984-1990

Kenneth G. Cassman: List of Publications

176. Grassini P, Yang HS, Cassman KG. 2009. Limits to maize productivity in the Western Corn-Belt: A simulation analysis for fully irrigated and rainfed conditions. Agric. Forest Meteorol. *In Press,* http://dx.doi.org/10.1016/j.agrformet.2009.02.012
175. Liska AJ, Yang HS, Bremer VR, Klopfenstein TJ, Walters DT, Erickson GE, Cassman KG. Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol. 2009. J. Industrial Ecol. 13:58-74. http://www3.interscience.wiley.com/cgi-bin/fulltext/121647166/PDFSTART.
174. Cassman, K.G. 2008. Biofuels or Food? Scientific American Earth3.0 18(4): 28. http://www.sciam.com/article.cfm?id=biofuels-or-food
173. Liska A. and Cassman KG. 2008. Towards standardization of life-cycle assessment metrics for biofuels: Greenhouse gas emissions mitigation and net energy yield. J. Biobased Materials and Bioenergy 2:187-203.
172. Salvagioti F, Cassman KG, Specht JE, Walters DT, Weiss A, Dobermann A. 2008. Nitrogen uptake, fixation and response to N fertilizer in soybeans: A review. Field Crops Res. 108:1-13.
171. Bastidas AM, Setiyono TD, Dobermann A, Cassman KG, Elmore RW, Graef GL, and Specht JE. 2008. Soybean Sowing Date: The Vegetative, Reproductive, and Agronomic Impacts. Crop Sci. 48:727-740.
170. Powlson D.S, Addiscott T.M., Benjamin N., Cassman K.G., de Kok T.M., van Grinsven H., L'hirondel J.L., Avery A.A., van Kessel C. 2008. When Does Nitrate Become a Risk for Humans? J. Environ. Qual. 37:291–295.
169. Naylor RL, Liska AJ, Burke MB, Falcon WP, Gaskell J, Rozelle SD, and Cassman KG. 2007. The Ripple Effect: Biofuels, Food Security, and the Environment. *Environment*. 49: 30-43.
168. Cassman K.G. and Liska A. J. 2007. Food and fuel for all: Realistic or foolish? Biofuels Bioprod. Biorefin. 1:18-23. http://www3.interscience.wiley.com/cgi-bin/fulltext/114283521/PDFSTART
167. Cassman K.G. 2007. Can organic agriculture feed the world—science to the rescue? Renewable Agric. Food Sys. 22:83-83.
166. Cassman K.G. 2007. Climate change, biofuels, and global food security. Environ. Res. Lett. 2: 011002. http://stacks.iop.org/1748-9326/2/011002
165. Cassman KG, Eidman V, Simpson, E. 2006. Convergence of energy and agriculture: Implications for Research and Policy. CAST Commentary QTA 2006-3. CAST, Ames, Iowa. http://www.cast-science.org/cast/src/cast_top.htm.
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15. Cassman, K. G., D. N. Munns, and D. P. Beck. 1981. Growth of *Rhizobium* strains at low concentrations of phosphate. Soil Sci. Soc. Am. J. 45:520-523.

14. Cassman, K. G., D. N. Munns, and D. P. Beck. 1981. Phosphorus nutrition of *Rhizobium japonicum*: strain differences in phosphate storage and utilization. Soil Sci. Soc. Am. J. 45:517-520.

13. Cassman, K. G., A. S. Whitney, and R. L. Fox. 1981. Phosphorus requirements of soybean and cowpea as affected by mode of N nutrition. Agron. J. 73:17-22.

12. Cassman, K. G., and D. N. Munns. 1980. Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci. Soc. Am. J. 44:1233-1237.

11. Cassman, K. G., A. S. Whitney, and R. L. Fox. 1980. Symbiotic nitrogen fixation by legumes requires extra phosphorus. Illustrated Concepts in Tropical Agriculture, No. 17. College of Tropical Agric., Univ. of Hawaii.

10. Cassman, K. G., A. S. Whitney, and K. R. Stockinger. 1980. Root growth and dry matter distribution of soybean as affected by phosphorus stress, nodulation, and N source. Crop Sci. 20:239-244.

9. Guevarra, A. B., Y. Kitamura, A. S. Whitney, and K. G. Cassman. 1980. A low-cost system for circulating nutrient solutions in pot studies. Crop Sci. 20:110-112.

8. Cassman, K. G., M. O. Mapes, and R.M. Bullock. 1978. Synergistic effects of guava (*Psidium guajava* L.) stem exudate with auxin. Plant Propagator 24:13-15.

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6. Doolittle, R. F., K. G. Cassman, B. A. Cottrell, and S. J. Friezner. 1977. Amino acid sequence studies on the A-chain of human fibrinogen: Isolation and characterization of the two linked A-chain cyanogen bromide fragments from fully cross-linked fibrin. Biochem. 16:1715-1719.

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3. Cassman, K. G., and R. F. Doolittle. 1975. Heterogeneity of human fibrinogen fragment D. In: Proceedings of Pacific Slopes Biochemical Conference.

2. Doolittle, R. F., K. G. Cassman, R. Chen, J. J. Sharp, and G. L. Wooding. 1972. Correlation of the mode of fibrin polymerization with the pattern of cross-linking. Annals of New York Academy of Sciences. 202:114-126.

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CURRICULUM VITAE

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2. Work - CSIRO, Plant Industry, G.P.O. Box 1600, Canberra, A.C.T. 2601, Australia.

I. **ACADEMIC RECORD**

Degrees received:

1949	Bachelor of Science	University of Queensland.
1956	Master of Science	University of Queensland.
1960	Doctor of Philosophy	University of New England.

II. **PROFESSIONAL POSITIONS HELD:**

1950-1951	Assistant to Analysts, Queensland Department of Agriculture and Stock, Brisbane.
1951-1993	CSIRO, Division of Plant Industry
1951-1957	Technical Officer
1957	Senior Technical Officer
1957-1965	Research Scientist
1965-1970	Senior Research Scientist
1970-1976	Principal Research Scientist
1976-1986	Senior Principal Research Scientist
1986-1993	Chief Research Scientist
1983-1986	Head, Plant Nutrition Section
1986-1989	Leader, Program C (Nutrition of Crops & Pastures)
1989-1993	Leader, Sub-program ZC (Nitrogen Cycling)
1993-present	Honorary Research Fellow

III. **AWARDS AND HONORARY POSITIONS:**

(a) Awards

1957-1958	CSIRO Overseas Studentship.
1974	Awarded Travelling Fellowship Japan Society for the Promotion of Science.
1982	Exchange Fellow, Australian Academy of Science - Academia Sinica, China.
1984	Elected Fellow of the Soil Science Society of America.
1985	Awarded J.A. Prescott Medal, for excellence and achievement in the field of soil science by the Australian Society of Soil Science.
1986	Lincoln College Foundation (New Zealand) Award.
1986	Elected Fellow of the Australian Academy of Technological Sciences & Engineering.
1987	Semi-finalist for Environmental Studies in B.H.P. Awards for the Pursuit of Excellence.
1990	Exchange Fellow, CSIRO-Academia Sinica, China.
1991	Elected Fellow of the American Society of Agronomy
1995	Lincoln University Foundation (New Zealand) Award.
1999	Awarded Honorary Membership for Life by the Australian Society of Soil Science in recognition of the outstanding contribution to soil science.
2003	Awarded the Centenary Medal for service to Australian society in plant production and processing.

(b) Honorary Positions

1957-1958	Junior Specialist, Kearney Foundation of Soil Science, University of California Berkeley, California.
1965-1966	Visiting Professor, University of Illinois, Urbana, Illinois.
1974	Visiting Professor, Tohoku University, Sendai, Japan.
1978	Visiting Scientist, International Rice Research Institute, Philippines.
1992	Appointed Professor of Environmental Sciences, Griffith University, Nathan, Queensland.
1993.	Appointed to Editorial Board of Fertilizer Research (now Nutrient Cycling in Agroecosystems).
2006	Appointed Adjunct Professor, Shanxi Academy of Agricultural Sciences, China.
2006	Appointed Senior Fellow, School of Resource Management, The University of Melbourne.
2006.	Appointed Member of International Selection Committee for the 2006 International Fertilizer Industry Association Crop Nutrition Award.
2008	Appointed Member of International Selection Committee for the 2008 International Fertilizer Industry Association Crop Nutrition Award.
2008	Appointed Adjunct Professor in the Centre for Forestry and Horticultural Research, Griffith University, Nathan, Queensland.

IV. **RESEARCH CONTRIBUTIONS:**

New techniques were devised for measuring emissions of nitrogen gases in the field. The results showed that up to 92% of the fertilizer nitrogen applied by farmers was lost to the atmosphere as ammonia, nitrous oxide and molecular nitrogen. The emissions not only affect the productivity of farmers, but the ammonia emitted affects climate, visibility and health, and the nitrous oxide emitted affects the ozone layer and is a greenhouse gas. This work established the environmental importance and economic significance of emissions of these gases from pastures, and from fertilizers applied to bananas, cotton, dairy pastures, maize, sunflowers, flooded rice, sugar cane and wheat. After studying the chemical, biological and physical factors involved, practices were devised to improve the efficiency of fertilizer use and to reduce the emissions of these gases and the impact of fertilizer use on climate change and the environment. Examples of this work are:

(1) Made the first measurements of nitrous oxide emission from flooded rice fields and showed that little nitrous oxide was emitted as long as the soils were flooded before fertilizer application.

(2) Discovered a new pathway for the emission of nitrous oxide from soils. Showed in field studies that the amounts of nitrous oxide emitted from aerated soils during nitrification could be greater than that emitted during denitrification.

(3) Showed that as much as 100 kg N ha^{-1} as ammonia is emitted to the atmosphere from unfertilized grazed pastures each year. These results established directly what was only guessed at in previous studies.

(4) Discovered a closed ammonia cycle in a pasture canopy, whereby ammonia liberated at the ground surfaces is reabsorbed by green leaves higher in the canopy. This work confirms the ability of field grown plants to absorb ammonia from the air.

(5) Devised micrometeorological methods for the direct measurement of ammonia emission from fertilized fields. These methods are now regarded as the accepted international standards for quantifying ammonia volatilization from agricultural fields following fertilization.

(6) Developed a unique micrometeorological method for assessing ammonia loss during the injection of anhydrous ammonia fertilizer. This was a big improvement in practice when compared with the older soil sampling approaches; the aerial measurements were completed in two hours instead of two days, and the error in estimating the loss was reduced by a factor of 100.

(7) Constructed a passive sampler for measuring atmospheric ammonia fluxes, leading to an enormous improvement in technique. One sampler costing $100 can now be used for a complete experiment, replacing the need for complete arrays of anemometers and sampling arms, plus pumps, power and personnel, typically costing $7000 per experiment. This enables ammonia loss measurements to be made in remote locations

(8) Developed models of ammonia volatilization from flooded rice fields leading to simplified measurement techniques whereby ammonia loss can be calculated from measurements of wind speed, and floodwater ammoniacal N concentration, pH and temperature.

(9) Demonstrated that applications of fertilizer nitrogen to wheat at heading were more efficiently used than those applied at sowing (16% loss compared with 25-50% loss). In addition, the application at heading increased grain protein and improved the baking quality of the dough.

(10) Examination of ammonia loss following the application of ammonia in irrigation water to maize revolutionized farmers' fertilizer practices. Discovery that up to 30% of the nitrogen applied could be lost each hour led to farmers switching to dissolving urea rather than ammonia in the irrigation water. As a consequence ammonia loss to the atmosphere was reduced to zero. An independent evaluation of the research put the costs of the research at $1,665,000 while the benefits to the farming community in the Murrumbidgee area alone total in excess of $2,000,000 per year.

(11) Showed that sugar cane farmers who practiced green cane harvesting and trash retention lost >40% of their fertilizer nitrogen to the atmosphere by ammonia volatilization when they broadcast urea fertilizer (costing >$105 per hectare). This work showed that the residues have high urease activity and low ammonia retention capacity and thus lose considerable ammonia when the residues are wetted by overnight dew.

(12) Developed management practices to reduce ammonia loss from sugar cane fields. Using a coulter cutter to cut through the trash, cane stool and soil, and drilling the urea into the slot reduced ammonia loss from 37% to 5% of the applied nitrogen. Other measures which were shown to be very effective, and are now widely used in the industry, are delaying fertilization until a substantial canopy has developed, and using ammonium sulfate instead of urea.

(13) Successfully devised techniques to reduce the very large losses of ammonia which occur when urea fertilizer is broadcast into the floodwater of flooded rice fields. One technique which is now widely practiced in China, the Philippines and Indonesia is removal of the floodwater before application of the urea and incorporation by harrowing. At one site in the Philippines use of this technique reduced ammonia loss from 56% to 7% of the applied nitrogen. More than 50% reduction was achieved at other sites.

(14) Devised a protocol for the successful use of the commercially available urease inhibitor N-(n-butyl)thiophosphorictriamide (NBPT) to reduce ammonia loss following application of fertilizer urea to flooded rice fields. The research showed that addition of NBPT failed to reduce ammonia loss because it had to be converted its oxygen analogue before it was an effective inhibitor, and the conversion rate in flooded rice fields was slower than the rate of hydrolysis of urea. Addition of phenylphosphorodiamidate (PPD), and an algicide to limit pH increase and decomposition of PPD, with NBPT inhibited urea hydrolysis and ammonia loss until the conversion of NBPT took place. The combination of inhibitors reduced ammonia loss at one site in Thailand from 15% to 3% of the applied nitrogen and increased rice yield by 14%.

(15) Demonstrated convincingly that ammonia volatilization and denitrification must be controlled simultaneously to reduce total nitrogen loss from flooded rice. If ammonia loss only is prevented, then the conserved nitrogen is oxidized to nitrate and lost by denitrification. Denitrification was controlled by using a new nitrification inhibitor, wax coated calcium carbide, which provided a slow release of acetylene to inhibit the oxidation of ammonium to nitrate, thus removing the substrate for denitrification. This treatment markedly reduced the emission of nitrous oxide and methane from flooded rice.

(16) Assessed the fate of fertilizer nitrogen applied to cotton in north western New South Wales and showed that, depending on the time of application, up to 92% of the nitrogen applied was lost in gaseous form by denitrification. Use of the new nitrification inhibitor, wax coated calcium carbide, reduced nitrogen loss by 52% and increased lint yield by 14%.

(17) Formulated isotope dilution methods for assessing the amount of nitrogen fixed by pasture legumes and transferred to associated grasses. This allows farmers to choose the species or variety which fixes the most nitrogen under their growing conditions.

(18) Developed and patented a new nitrification inhibitor.

(19) Developed techniques to improve efficiency of fertilizer sulfur. Showed that soil analysis did not always provide a reliable indication of sulfur supply, but that analysis of the whole plant for sulfate and total sulfur would allow the accurate diagnosis of the sulfur status of crops and pastures.

(20) Methane emissions from animals represent a significant contribution to anthropogenically produced greenhouse gases. A new mass balance technique was devised for measuring emissions of methane from grazing animals under pasture and feedlot conditions. The results showed that cattle fed low quality, high fibre diets produced more methane (about four times) then cattle fed high grain diets. The method provides a useful tool for developing management practices to reduce methane emission from agriculture.

V. **RESEARCH GRANTS:**

1965-1966	The Sulphur Institute	US$10,000
1974	Japan Society for the Promotion of Science	Y1,100,000
1974	Nomura Gakugei Zaiden Foundation	Y 100,000
1981	Australia - China Council	A$ 3,567
1982	Australian Development Assistance Bureau	A$ 4,700
1983-1985	Australian Centre for International Agricultural Research	A$477,620
1985	Australian Centre for International Agricultural Research	A$ 50,000
1984	University of Melbourne-CSIRO Collaborative Research Fund	A$ 5,000
1985	University of Melbourne-CSIRO Collaborative Research Fund	A$ 5,500
1986-1989	Wheat Research Council	A$230,788
1987-1990	Cotton Research Council	A$528,552
1988-1991	Wheat Research Council	A$185,408
1988	University of Melbourne-CSIRO Collaborative Research Fund	A$ 7,000
1989-1991	Sugar Research Council	A$165,983
1989-1993	Wool Research and Development Fund	A$199,466
1990-1993	Australian Centre for International Agricultural Research	A$567,106
1991-1993	Cotton Research and Development Corporation	A$420,208
Total		A$2,882,739

VI. **RESEARCH TRAINING AND VISITING SCIENTISTS:**

(a) Supervision for Students

University	Degree	Candidate	Status
A.N.U.	Ph.D.	G.E. Melville	Graduated 1974
A.N.U.	Ph.D.	S.F. Ledgard	Graduated 1984
Queensland	Ph.D.	Cai Gui-xin	Graduated 1988
Tasmania	M.Sc.	A. Jayatilake	Graduated 1988
Griffith	Ph.D.	P. Prammanee	Graduated 1992
Griffith	Ph.D.	W.N. Obcemea	Graduated 1996
Melbourne	Ph.D.	Chen De-li	Graduated 1996
Griffith	Ph.D.	P. Prasertsak	Graduated 2000
Melbourne	Ph.D.	D. Turner	Current

(b) Visiting Scientists

1974	Professor M.B. Jones, University of California, Hopland, California.
1981	Professor Zhu Zhao-liang, Institute of Soil Science, Nanjing, China.
1982	Ms Cai Gui-xin, Institute of Soil Science, Nanjing, China.
1984	Ms Wilma Obcemea, International Rice Research Institute, Los Baños, Philippines.
1985	Dr Zulkifli Malik, MARDI, Serdang, Malaysia.
1985	Professor D.J. McKenney, Dept. of Chemistry, Windsor University, Ontario, Canada.
1985	Ms Cai Gui-xin, Institute of Soil Science, Academia Sinica, Nanjing, China.
1985	Chen De-li, Institute of Soil Science, Academia Sinica, Nanjing, China.
1986	Ren Zhu-jian, Fujian Academy of Agricultural Sciences, Fuzhou, China.
1986	Ms Marianne Samson, International Rice Research Institute, Los Baños, Philippines.
1987	Dr A.R. Mosier, United States Department of Agriculture, Fort Collins, Colorado.
1988	Dr R.R. Sherlock, Department of Soil Science, Lincoln College, New Zealand.
1990	Professor Li Chen Bao, Institute of Soil Science, Nanjing, China.
1991	Dr. A.R. Mosier, United States Department of Agriculture, Fort Collins, Colorado.
1991	Professor Luo Qi-xiang, Soil and Fertilizer Institute, Nanchang, China.
1991	Dr. S. Phongpan, Department of Agriculture, Bangkhen, Bangkok, Thailand.
1991	Lin Xin-jian, Fujian Academy of Agricultural Science, Fuzhou, China.
1992	Ms Jariya Prasatsrisupab, Department of Agriculture, Bangkhen, Bangkok, Thailand.

1992	Professor K.M. Goh, Department of Soil Science, Lincoln University, New Zealand.
1993	Dr. S. Phongpan, Department of Agriculture, Bangkhen, Bangkok, Thailand.
1993	Dr. P. Chaiwanakupt, Department of Agriculture, Bangkhen, Bangkok, Thailand.
1993	Wang Xian-zhong, Institute of Soil Science, Nanjing, China.

VII. **ADVISORY COMMITTEES FOR INTERNATIONAL PROJECTS ON THE ENVIRONMENT**

1. Member of Advisory Committee for SCOPE[1] project on "The Global Biogeochemical Sulfur Cycle", 1978-1987.
2. Member of Advisory Committee for SCOPE project on "The Interactions of the Biogeochemical Cycles of Carbon, Nitrogen, Phosphorus and Sulfur", 1979-1983.
3. Member of Advisory Committee for SCOPE project on "The Biogeochemical Phosphorus Cycle" 1986-1994.
4. Co-chairman for SCOPE project on "Nitrogen Transport and Transformations - A Regional and Global Analysis" 1992-2002
5. Member of International Geosphere-Biosphere Programme (IGBP) Co-ordinating Panel on "Terrestrial Biosphere-Atmosphere Chemistry Interactions", 1989-1990.
6. Member IGBP-IGAC Co-ordinating Committee for project on "Exchange of Methane, Nitrous Oxide and Carbon Monoxide in Mid- Latitudes".
7. Member of Advisory Committee for SCOPE project on "Nitrogen Fertilizer Rapid Assessment Project" 2003-2004.
8. Member of Advisory Committee for SCOPE and IGBP project on "International Nitrogen Initiative" 2003-2010.

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[1]Scientific Committee on Problems of the Environment

VIII. **SERVICE TO THE PROFESSION**

1. Secretary, A.C.T. Branch, Australian Society of Soil Science, Incorporated 1961-1962.
2. President, A.C.T. Branch, Australian Society of Soil Science, Incorporated 1972-1973.
3. Presented lectures for course in Soil Science at Canberra College of Advanced Education, 1973.
4. Vice Chairman, Soil Biology Section, International Soil Science Society 1978-1982.
5. Member of Curriculum Committee for Faculty of Science, Canberra College of Advanced Education 1980-1987.
6. President, Australian Society of Soil Science, Incorporated 1986-1988.
7. Selection Committee, Australian Society of Soil Science, Publication Medal 1984-1986.
8. Member of National Committee for the Environment, Australian Academy of Science, 1985-1991.
9. Convenor, International Workshop on Soil Fertility and Fertilizer Evaluation for Rice, Griffith, N.S.W. 1985.
10. Member of Advisory Committee for planning International Symposium on "Advances in Nitrogen Cycling in Agricultural Ecosystems", Brisbane 1987.
11. Member Research Advisory Committee for Department of Conservation, Forests and Lands, Victoria, 1987-1988.
12. Chairman, Organizing Committee for Australian Soil Science Conference, May 1988.
13. Academic Adviser Institute of Soil Science, Chinese Academy of Sciences, Nanjing, 1991-2002.
14. Elected to Editorial Board of Fertilizer Research, 1993
15. Lead author for preparation of report for Intergovernmental Panel on Climate Change on Agricultural Options for Mitigation of Greenhouse Gas Emissions for the publication "Climate Change 1995; Impacts, Adaptations and Mitigation of Climate Change.
16. Convener Selection Committee, Australian Society of Soil Science, Publication Medal 2001-3.
17. Member Selection Committee, Australian Society of Soil Science, J.K. Taylor Gold Medal 2002.
18. Member of the Science and Policy Committee for the 3rd International Nitrogen Conference, Nanjing, China, 12-16 October 2004

IX. **INVITED TO ATTEND INTERNATIONAL SYMPOSIA**

1966 Sulphur Symposium, Wilson Dam, Alabama.
1966 Conference on Soil Organic Matter, Des Plains, Illinois.
1970 International Symposium on Hydrogeochemistry and Biogeochemistry, Tokyo, Japan.
1970 Future of Soil Microbiology, Sendai, Japan.
1973 Environmental Biogeochemistry, Logan, Utah.
1974 Sulphur in Australasian Agriculture, Canberra.
1975 Climatic Change and Variability: A Southern Perspective, Melbourne, Victoria.
1975 Environmental Biogeochemistry, Burlington, Ontario, Canada.
1978 Nitrogen and Rice, Los Baños, Philippines.
1979 The Global Biogeochemical Sulphur Cycle, Pushchino, Russia.
1979 Terrestrial Nitrogen Cycles - Processes, Ecosystem Strategies and Management Impacts, Gysinge, Sweden.
1979 Nitrogen Cycling in South East Asian Wet Monsoonal Ecosystems, Chiang Mai, Thailand.
1979 Biogeochemistry of Ancient and Modern Environments, Canberra, A.C.T.
1980 Interactions of Biogeochemical Cycles of Carbon, Nitrogen, Sulfur and Phosphorus, Fort Collins, Colorado.
1981 Nitrogen Mobility in Ecosystems, Sydney, N.S.W.
1981 Interactions of Biogeochemical Cycles of Carbon, Nitrogen, Phosphorus and Sulphur, Orsundsbro, Sweden.
1982 Lecture Tour of China, Australia / China Council
1982 Sulphur 82, London, U.K.
1982 Denitrification, Atlanta, Georgia.
1983 Soil Fertility and Fertilizer Evaluation for Rice, Jakarta, Indonesia.
1983 Sulphur in South East Asian and South Pacific Agriculture, Ciawi, Indonesia.
1983 Stable Isotopes in the Assessment of Natural and Anthropogenic Sulphur in the Environment, Pushchino, Russia.
1984 Sulphur-84. Calgary, Alberta.
1984 Characterization, Classification and Utilization of Wetland Soils, Los Baños, Philippines.
1984 Evolution of the Global Sulphur Cycle. Tallinn, Estonia.
1985 Establishment of an Asia-Pacific Association on Agricultural Research, Bangkok, Thailand.
1986 Yield Maximization of Feed Grains through Soil and Fertilizer Management, Kuala Lumpur, Malaysia.
1986 International Synthesis Workshop on C, N, P and S Interactions in Ecosystems, Sapelo Island, Georgia.
1986 Sulfur in Agriculture, Dhaka, Bangladesh.
1986 Soil Fertility and Fertilizer Evaluation for Rice, Hangzhou, China.
1987 Advances in Nitrogen Cycling in Agricultural Ecosystems, Brisbane, Queensland.
1987 Fertilizer Use Efficiency in Major Rice-Based Cropping Systems, New Delhi, India.
1988 First OIES Global Change Institute on Trace Gases and the Biosphere, Snowmass, Colorado.
1989 IGBP Coordinating Panel on Terrestrial Biosphere-Atmospheric Chemistry Interactions, Mainz, F.R.G.
1989 Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania, Los Baños, Philippines.
1989 Denitrification in Soil, Rhizosphere and Aquifer, Giessen, Germany.
1989 Sulphur Cycling in Wetland and Terrestrial Ecosystems, Peterborough, Ontario, Canada.
1989 To work with Dr. A.R. Mosier at U.S.D.A. Agricultural Research Service, Fort Collins, Colorado.
1989 IGBP Coordinating Panel on Terrestrial Biosphere Atmospheric Chemistry Interactions. Woods Hole, Mass. U.S.A.
1989 Phosphorus Cycling in Terrestrial and Aquatic Ecosystems in Latin America, Caracas, Venezuela.
1989 The Contribution of Greenhouse Gas Emissions from Agricultural Systems to Climatic Change, Washington D.C.
1990 Trace Gas Exchange in a Global Perspective, Sigtuna, Sweden.
1990 International Congress on Soil Science, Kyoto, Japan, 12-18 August..
1990 Material Cycling in Pedosphere and Human Survival. Nanjing, China, 20-23 August.
1990 Direct Seeding Practices and Productivity for Rice Penang, Malaysia.

1991 Asian Workshop on the International Geosphere-Biosphere Programme - A Study of Global Change, New Delhi, India.
1991 Phosphorus Cycling in Semi Arid Regions, Nairobi, Kenya.
1991 Trace-Gas Fluxes in Mid-Latitude Ecosystems: An International Geosphere-Biosphere Activity, Boulder, Colorado.
1991 International Conference on an Agenda of Science for Environment and Development into the 21st Century (ASCEND21). Vienna, Austria. (Chairman of Working Group 6 on Global Cycles).
1992 VIII SCOPE General Assembly, Seville, Spain
1992 Climate Change, Agriculture and Forestry, Canberra, ACT.
1992 Nutrient Management for Sustained Productivity. Ludhiana, India.
1992 International Workshop on CH_4 and N_2O Emission from Natural and Anthropogenic Sources and their Reduction Research Plan, Tsukuba, Japan.
1992 Fertilizer Usage in Tropics (Fertrop), Kuala Lumpur, Malaysia.
1992 International Symposium on Paddy Soils, Nanjing, China.
1992 Trace-Gas Fluxes in Mid-Latitude Ecosystems, Fort Collins, Colorado, U.S.A.
1992 Workshop to set up Trace-Gas Network, Pingree Park, Colorado, U.S.A.
1993 International Conference on Flooded Soils, Baton Rouge, Louisiana, U.S.A.
1993 Global Biogeochemical Phosphorus Cycling, Budapest, Hungary
1993 Second International Conference on Material Cycling in the Pedosphere, Nanjing, China.
1993 Rice Conference 93, Penang, Malaysia.
1994 Nitrogen in Tropical Soils, St. Augustine, Trinidad.
1994 Intergovernmental Panel on Climate Change, Workshop on Mitigation of Methane and Nitrous Oxide Emission from Agriculture, Fort Collins, Colorado, U.S.A.
1994 Symposium on Sustainable Agriculture and Conservation of Agro-Ecosystems, Tsukuba, Japan.
1994 Nitrogen Dynamics of the North Atlantic Basin, Block Island, U.S.A.
1995 Soil - Source and Sink of Greenhouse Gases, Nanjing, Peoples Republic of China.
1995 IXth SCOPE General Assembly, Tokyo, Japan
1995 Appropriate Use of Fertilizers, Taipei, Taiwan.
1996 NO_x Emission from Soils and its Influence on Atmospheric Chemistry, Tsukuba, Japan.
1996 Sustainable Agriculture and Control of Greenhouse Gas Emissions, Tsukuba, Japan
1996 The Effect of Human Disturbance on the Nitrogen Cycle in Asia, Taipei, Taiwan.
1996 Maximizing Sustainable Rice Yields through Improved Soil and Environmental Management, Kohn Kaen, Thailand.
1996 A Comparative Analysis of Nitrogen Cycling in the Temperate and Tropical Americas, Termas de Chillan, Chile.
1997 The Effect of Human Disturbance on the Nitrogen Cycle in Asia, Nanjing, China.
1998 Transfer Processes in the Natural Environment: State of the Science, Canberra, Australia.
2003 Abatement of Agricultural Non-Carbon Dioxide Greenhouse Gas Emissions in New Zealand.
2004 Nitrogen Fertilizer Rapid Assessment Project, Kampala, Uganda.
2004 Advanced Approaches to Quantify Denitrification, Woods Hole, Massachusetts, USA.
2004 The 3rd International Nitrogen Conference, Nanjing, China.
2004 Climate Change Workshop in Monsoonal East China, Hangzhou, China.
2005 Special Symposium to honour the retirement of Dr A. R. Mosier, Salt Lake City, USA
2006 Nitrogen Policy Workshop, Paris, France
2008 Anthropogenic Changes of the Asian Monsoon, Nanjing, China.
2008 History of Nitrogen Research: The Bremner Factor, Houston, Texas, USA

X. **INVITED SPEAKER AT NATIONAL SYMPOSIA**

1968 Australian Sheep and Wool Conference, Leura.
1969 Symposium on the Biology of Atriplex, Deniliquin.
1969 Workshop on Phosphorus and Sulphur, Perth.
1971 Specialist Conference in Soil Biology, Adelaide.
1974 Fertilizers and the Environment, Sydney.
1975 Specialist Conference in Soil Biology, Adelaide.
1976 Air Pollution Diffusion Modelling, Canberra.
1977 Hannaford Workshop on Nutrient Release and Turnover of Organic Matter, Adelaide.
1977 Australian Workshop on Nitrogen Cycling, Canberra.

1978 Sulfur Cycling in Australian Ecosystems, Canberra.
1978 Dynamic Aspects of Nitrogen Cycling in Australian Ecosystems, Aspendale.
1980 CSIRO, Executive Seminar on Soil Fertility, Melbourne.
1980 Field Cropping: Nutritional/Structural Interaction in Heavy Textured Soils Under Irrigation, Griffith
1980 Managing Nitrogen Economies of Natural and Man Made Forest Ecosystems, Mandurah, W.A.
1982 Stable Isotopes in the Environment, Canberra.
1985 Production and Utilization of Pasture in South Australia, Leura.
1986 Nitrogen Cycling in Agricultural Systems of Temperate Australia, Yanco.
1988 Cadmium Accumulations in Australian Agriculture, Canberra.
1990 The Fifth Australian Cotton Conference, Broadbeach, Qld.
1990 Utilization of Renewable Biological Resources and Global Change, Canberra.
1991 Sustainable Rice Production, Griffith, N.S.W..
1992 The Sixth Australian Cotton Conference, Broadbeach, Qld.
1992 Trace Gas Exchange in South-East Australia, Aspendale, Vic.
1994 Nitrogen Management of Sugar Cane, Townsville, Qld.

XI. **REVIEWS**

1978 International Fertilizer Development Center, Muscle Shoals, Alabama, to review research programs on nitrogen and sulfur.
1995 International Council of Scientific Unions to review project on Global Change in Terrestrial Ecosystems, Buenos Aires, Argentina.
2002-2003 Review work on Abatement of Agricultural Non-Carbon Dioxide Greenhouse Gas Emissions in New Zealand, and prepare a report on Research Requirements for the Ministry of Agriculture and Forestry.

XII. **CONSULTANCIES**

1994 CSIRO, Centre for Environmental Mechanics, Canberra, A.C.T. to conduct field investigations on methane emission from agriculture on regional basis at Wagga Wagga, N.S.W.
1994 CSIRO, Division of Soils, Canberra, A.C.T. to determine ammonia loss from effluent applied to forest plantations at Flushing Meadows, N.S.W.
1995 CSIRO, Division of Soils, Canberra, A.C.T. to determine ammonia loss from effluent applied to pasture at Flushing Meadows, N.S.W.
1995 Department of Soil Science, Lincoln University, Canterbury, New Zealand, to determine ammonia, nitrous oxide and methane loss following application of pig slurry to pastures.
1995 CSIRO, Division of Plant Industry, Canberra, A.C.T. to establish and interpret field trials on new nitrification inhibitors in corn at Coleambally, N.S.W..
1995 International Atomic Energy Agency, Vienna, Austria, to train scientists at University of Khon Kaen, Thailand in use of labelled materials to improve efficiency of fertilizer nitrogen for sugar cane.
1995 International Fertilizer Development Center, Muscle Shoals, Alabama, to interpret results of field experiments with urease inhibitors on flooded rice, Los Banos, Philippines.
1996 International Atomic Energy Agency, Vienna, Austria, to train scientists at National Atomic Energy Agency, Jakarta, Indonesia, in use of labelled materials to improve efficiency of fertilizer nitrogen for rice.
1996 CSIRO, Division of Plant Industry, Canberra, A.C.T. to establish and interpret field trials on new nitrification inhibitors in sugar cane at Mackay, Queensland
1997 International Fertilizer Development Center, Muscle Shoals, Alabama, to interpret results of field experiments with urease inhibitors on flooded rice, Los Banos, Philippines.
1997 International Atomic Energy Agency, Vienna, Austria, to train scientists at National Atomic Energy Agency, Jakarta, Indonesia, in use of labelled materials to improve efficiency of fertilizer nitrogen for rice.
2002 Editorial and scientific review of manuscript for Institute of Land and Food Research, University of Melbourne.
2002 Ministry of Agriculture and Forestry, Wellington, New Zealand to prepare a report on Abatement of Agricultural Non-Carbon Dioxide Greenhouse Gas Emissions.

2005 Australian Greenhouse Office preparation of workbook for farmers
2007 Editorial and scientific review of manuscripts for Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China

XIII. **PATENTS**

Dr. Freney, together with Drs J. Hodgkin and K. Harrington, has applied for a patent for an inhibitor to prevent the oxidation of ammonium to nitrate in soil. The compound, which provides a slow release of acetylene, prevented the oxidation of ammonium in a soil used for growing cotton for 90 days and considerably slowed nitrification for 180 days. Use of this inhibitor by farmers will considerably reduce the emission of the greenhouse gas nitrous oxide and contamination of groundwater with nitrate.

XIV. **TELEVISION PRESENTATIONS AND VIDEOS**

1991 "Inefficient Use of Fertilizer Nitrogen by Cotton", Queensland Cotton Corporation Ltd.
1992 "Ammonia Volatilization Following Fertilization of Sugar Cane", Bureau of Sugar Experiment Stations, Queensland.
1993 "Methane Emission from Grazing Cows", Towards 2000, Australia.
1995 "Ammonia, Nitrous Oxide and Methane Emission from Pastures after Topdressing with Pig Effluent", Agric Tech 2000, New Zealand

XV. **PUBLISHED PAPERS**

Published 239 papers or chapters in scientific journals and books.

XVI. **MEMBERSHIP OF SCIENTIFIC SOCIETIES**

1. International Soil Science Society.
2. Soil Science Society of America.
3. Australian Society of Soil Science, Incorporated.

BIOGRAPHICAL SKETCH

Name: ARVIN RAY MOSIER
1494 Oakhurst Dr.
Mount Pleasant, SC 29466
Phone: 843-881-3129
Cell Phone: 970-217-9693
Email: armosier@ufl.edu/a.mosier12@comcast.net

Academic Training:

B.S.	1967	Colorado State University, Chemistry
M.S.	1968	Colorado State University, Chemistry
Ph.D.	1974	Colorado State University, Soil Science

Professional Experience:

2006-present	Consultant	Private
2005-2007	Visiting Professor	University of Florida
1965-2004	Research Chemist	USDA-ARS, Fort Collins, CO
1970-2004	Faculty Affiliate	Soil & Crop Science Dept., CSU
1978 & 1983	Visiting Scientist	Braunschweig, Germany
1982-1986, 1992-1996	Joint Research	Braunschweig, Germany
1984, 1987, 1991	Visiting Scientist	CSIRO, Griffith, N.S.W. & Canberra, A.C.T., Australia
1985-1991	Joint Research	Indo/US Sci. & Tech.Initiative Cuttack and New Delhi, India
1985-2004	Editorial Board	GEODERMA
1990-2004	Managing Editor	Nutrient Cycling in Agroecosystems
1991-2004	Technical Advisor	International Atomic Energy Agency

Summary of National and International Science Activities:

Cochair, OECD/IPCC Expert Group National Inventory Methodology on N_2O from agriculture (1995); Cochair, on OECD/IPCC Expert Group on Good Practices in National Greenhouse Gas Inventory for the Agricultural Sector (2000); Chair, TRAGNET steering committee (1997-2001); Co-convener of IGAC terrestrial trace gas activity (BATREX) (2001-2003); Chair, SCOPE N Workgroup on Policy implications of human-accelerated N cycling; Executive committee (2000); Shortgrass Steppe LTER (1992-2004); IGAC Scientific Steering Committee member (1998-2003); Co-chair Global Emission Inventory Assessment N_2O Project (1998-2004).; Chair-SCOPE Fertilizer Nitrogen Rapid Assessment Project. Project Officer-Global Environmental Change and Food Systems Decision Support Systems (2004); Co-author of IPCC 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4, Chapter 11, "N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application; External advisor to the NitroEurope IP: A European wide research project on "The nitrogen cycle and its influence on the European greenhouse gas balance." (2005-2011). Consultant for program on "Improving the efficiency, profitability, and environmental friendliness of nitrogen fertilizers" at the University of Melbourne, Australia (2006-2013); USEPA Science Advisory Board

Committee on Integrated Nitrogen (2007-2009).

Summary of Science Career

Dr. Mosier conducted research as a research chemist with USDA/ARS on various aspects of agriculture, many of which were related to the impact of agriculture on air quality. During the late 1970s he was part of a team who quantified the emissions of ammonia and amines from cattle feedlots. During the last 20 years of his 39+ years with ARS he conducted research in the area of soil nitrogen transformations and their relationship to gaseous losses of nitrogen compounds (ammonia, nitric oxide, nitrous oxide) from the soil to the atmosphere. Collaborative research with scientists from around the USA, Europe, Australia and Asia resulted in the publication of more than 230 scientific publications, the majority of which were related in some way to air quality. During this time he mentored >15 graduate students and post doctoral fellows. Dr. Mosier co-chaired the Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Methodology for Agricultural Soils and led a group of 30 international scientists who developed a new methodology for estimating national emissions of nitrous oxide from agriculture (See IPCC National Inventory Methodology for Agricultural Soils, 1997).

More recently (2004) he chaired the Scientific Committee on Problems of the Environment (SCOPE) project on Fertilizer Nitrogen Rapid Assessment Project that led to the publication of a book entitled Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment, which was edited by A.R. Mosier, J. K. Syers and J.R. Freney. Since his retirement from USDA/ARS in December, 2004 Dr. Mosier has served as a science officer for the international program: Global Environmental Change and Food Systems—a joint project of IGBP, IHDP and WCRP in association with the Agricultural and Biological Engineering Department of the University of Florida. He currently serves an external advisor for a European wide research project on “The nitrogen cycle and its influence on the European greenhouse gas balance” (This 5 year project which began in January 2006, involves 65 different research institutions within the European Union). He is also serving as a consultant on a program within Melbourne University, Australia, on “Improving the efficiency, profitability, and environmental friendliness of nitrogen fertilizers.” This project received initial funding in 2006 and has acquired additional funding to extend the program through 2012. Since retirement he has published an additional >15 papers in international journals. He is currently serving on a United States Environmental Protection Agency science advisory committee on integrated nitrogen. Work on this committee began in January 2007 and should be completed by the end of 2009. During the past three years he has provided desk reviews of seven CDM methodology proposals for the UNFCCC Methodology Panel and authored a “Draft Tool for Estimating Emissions from Cultivation of Biomass” that was discussed by the Methodology Panel on 5 February 2007.

Papers Published After 2004 (Out of a total publication list of 240+):

Mosier, A.R.,A.D. Halvorson, G.A. Peterson, G.P. Robertson and L. Sherrod. 2005. Measurement of net global warming potential in three agroecosystems. Nutrient Cycling in Agroecosystems. 72:67-76.

Cai, Z.C., G.D. Kang, H. Tsuruta, and A. Mosier. 2005. Estimate of CH_4 emissions from year-round flooded rice fields during rice growing season in China. Pedosphere. 15:66-71.

Del Grosso, S.J., W.J. Parton, A.R. Mosier, E.A. Holland, E. Pendall, D.S. Schimel and D.S. Ojima. 2005. Modeling soil CO_2 emissions from ecosystems. Biogeochemistry 73:71-91.

Kinney, C.A., K.W. Mandernack and A.R. Mosier. 2005. Laboratory investigations into the effects of the pesticides mancozeb, chlorothalonil, and prosulfuron on nitrous oxide and nitric oxide production in fertilized soil. Soil Biol. Biochem. 37: 837-850.

Milchunas, D.G., A.R. Mosier, J.A. Morgan, D.R. LeCain, J.Y. King and J.A. Nelson. 2005. Elevated CO_2 and defoliation effects on a shortgrass steppe: Forage quality versus quantity for ruminants. Agriculture Ecosystems & Environment. 111:166-184.

Milchunas, D.G., J.A. Morgan, A.R. Mosier and D.R. LeCain. 2005. Dynamics and demography of root growth and loss in a shortgrass steppe under CO_2 and comments on minirhizotron methodology. Global Change Biology 11:1837-1855.

Halvorson, A.D., A. R. Mosier, C. A. Reule, and W. C. Bausch. 2006. Nitrogen and tillage effects on irrigated continuous corn yields. Agronomy Journal. 98: 63-71.

Barger, N.N., Belnap, J., Ojima, D.S., and Mosier, A. 2005. NO gas loss from biologically crusted soils in Canyonlands National Park, Utah. Biogeochemistry, 75:373-391.

X.J. Liu, A.R. Mosier , A. D. Halvorson and F.S. Zhang . 2005. Tillage and Nitrogen Application Effects on Nitrous and Nitric Oxide Emissions from Irrigated Corn Fields. Plant and Soil 276:235-249.

Mosier, A.R., J.K. Syers, and J.R. Freney. 2005. Global assessment of nitrogen fertilizer: The SCOPE/IGBP nitrogen fertilizer rapid assessment project. Science in China Ser. C Life Sciences. 48:759-766.

LeCain, D.R., J.A. Morgan, D.G. Milchunas, A.R. Mosier, J.A. Nelson, D.P. Smith. 2006. Root biomass of individual species, and root size characteristics after five years of CO_2 enrichment on native shortgrass steppe. Plant and Soil 279:219-228.

Liu, X.J., A.R. Mosier , A.D. Halvorson and F.S. Zhang . 2006. Impact of Nitrogen Placement and tillage on NO, N_2O, CH_4 and CO_2 fluxes from a clay loam soil. Pant & Soil 177-188.

Mosier, A.R., A. D. Halvorson, C. A. Reule, and X. J. Liu. 2006. Net Global Warming Potential and Greenhouse Gas Intensity in Irrigated Cropping Systems in Northeastern Colorado. Journal of Environmental Quality. 35:1584-1598.

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

Mosier,A.R. and T. Parkin. 2007. Gaseous Emissions (CO_2, CH_4, N_2O and NO) from diverse agricultural production systems. In. Gero Genckiser and Sylvia Schnell (eds.) Biodiversity in Agricultural Production Systems. CRC Press, Boca Raton, pp 317-348.

Kandeler, Ellen, Arvin R. Mosier, Jack A. Morgan, Daniel G. Milchunas, Jennifer Y. King, Sabine Rudolph and Dagmar Tscherko. 2006. Response of soil microbial biomass and enzyme activities to the transient elevation of carbon dioxide in a semi-arid grassland. Soil Biology & Biochemistry 38:2448-2460.

Morgan, J.A., D.G. Milchunas, D.R. LeCain, M. West, and A.R. Mosier. 2007. Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. PNAS. 104:14724-14729. doi/10.1073/pnas.0703427104

Kandeler, E., A. Mosier, J. Morgan, D. Milchunas, J. King, S. Rudolph and D. Tscherko. 2008. Transient elevation of carbon dioxide modifies the microbial community composition in a semi-arid grassland. Soil Biology and Biochemistry, 40: 162-171. doi 10.1016/j.soilbio.2007.07.018.

Xiong, Z.Q., J.R. Freney, A.R. Mosier, Z.L. Zhu, Y. Lee and K. Yagi. 2008. Impacts of population growth, changing food preferences and agricultural practices on the nitrogen cycle in East Asia. Nutrient Cycling in Agroecosystems 80:189-198.

Crutzen, P.J., A.R. Mosier, K.A. Smith, and W. Winiwarter. 2008. N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics, Atmos. Chem. Phys., 8: 389–395.

Norton, U., A.R. Mosier, J.A. Morgan, J.D. Derner, L.J. Ingram, and P.D. Stahl,. 2008. Moisture pulses, trace gas emissions and soil C and N in cheatgrass and native grass-dominated sagebrush-steppe in Wyoming, USA. Soil Biology & Biochemistry 40 (2008) 1421–1431

Burke, I.C., A.R. Mosier, P.B. Hook, D.G. Milchunas, J. E. Barrett, M. A. Vinton. R. L. McCulley, J.P. Kaye, R.A. Gill, H.E. Epstein, R. H. Kelly, W.J. Parton, C.M. Yonker, P. Lowe and W.K. Lauenroth. 2008. Soil organic matter and nutrient dynamics of shortgrass steppe ecosystems. In W.K. Lauenroth and I.C. Burke (eds.) Ecology of the Shortgrass Steppe: A long-term perspective. Oxford University Press, Inc. New York, NY, USA. pp. 306-341.

Mosier, A.R., W.J. Parton, R.E. Martin, D.W. Valentine, D.S. Ojima, D.S. Schimel, I.C. Burke, E.C. Adair and S.J. DelGrosso. 2008. . Soil organic matter and nutrient dynamics of shortgrass steppe ecosystems. In W.K. Lauenroth and I.C. Burke (eds.) Ecology of the Shortgrass Steppe: A long-term perspective. Oxford University Press, Inc. New York, NY, USA. pp. 342-371.

Francis, D.D., M.F. Vigil and A.R. Mosier. 2008. Gaseous losses of nitrogen other than through denitrification. In J.S. Schepers and W.R. Raun (eds.) Nitrogen in Agricultural Systems. Agronomy Monograph 49. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. Madison, WI, USA pp. 255-279.

Eleven career-best publications

Mosier, A.R., Guenzi, W.D. and Miller, L.L. Photochemical decomposition of DDT by a free radical mechanism. Science 164:1083-1085. 1969.

Mosier, A.R. Inhibition of photosynthesis and nitrogen fixation in algae by volatile nitrogen bases. J. Environ. Qual. 7:237-240. 1978.

Mosier, A.R. and Mack, L. Gas chromatographic system for precise, rapid analysis of N_2O. Soil Sci. Soc. Am. J. 44:1121-1123. 1980.

Mosier, A.R., Schimel, D.S., Valentine, D.W., Bronson, K.F. and Parton, W.J. Methane and nitrous oxide fluxes in native, fertilized and cultivated grasslands. Nature. 350:330-332. 1991.

Sommerfeld, R.A., Mosier, A.R. and Musselman, R.C. CO_2, CH_4 and N_2O flux through a Wyoming snowpack and implications for global budgets. Nature. 361:140-142. 1993.

Mosier, A.R., Kroeze, C., Nevison, C., Oenema, O., Seitzinger, S., and Van Cleemput, O. Closing the global atmospheric N_2O budget: Nitrous oxide emissions through the agricultural nitrogen cycle. Nutrient Cycling in Agroecosystems. 52:225-248. 1998.

Mosier, A.R, Duxbury, J.M., Freney, J.R., Heinemeyer, O. and Minami, K. Assessing mitigating nitrous oxide emissions from agricultural soils. Climatic Change. 40:7-38. 1998.

Mosier, A.R., Bleken, M.A., Chaiwanakupt, P., Ellis, E.C., Freney, J.R. Freney, Howarth, R.B., Matson, P.A.. Minami, K., Naylor, R., Weeks, K.N. and Zhu, Z.L. Policy implications of human-accelerated nitrogen cycling. Biogeochemistry 52:281-320. 2000.

Mosier, Arvin R., J. Keith Syers and John R. Freney (eds.). 2004. Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment. SCOPE Volume 65, Island Press, Washington D.C. 296 p.

Mosier, A.R. A. D. Halvorson, C. A. Reule, and X. J. Liu. 2006. Net Global Warming Potential and Greenhouse Gas Intensity in Irrigated Cropping Systems in Northeastern Colorado. Journal of Environmental Quality. 35:1584-1598.

Crutzen, P.J., A.R. Mosier, K.A. Smith, and W. Winiwarter. 2008. N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics, Atmos. Chem. Phys., 8: 389–395.

MEMORANDUM

To: Vincent Camobreco and Elizabeth Etchells, EPA

From: John Venezia, Erin Gray, Victoria Thompson, and Sarah Menassian, ICF

Date: December 12, 2008

Re: International Agriculture GHG Emissions and GHG Metrics (revised) V.3

The 2007 Energy Independence and Security Act significantly increases the amount of renewable fuels required to be sold in the U.S. under EPA's Renewable Fuel Standard (RFS). This mandated increase in biofuel consumption could have significant lifecycle greenhouse gas (GHG) impacts due to global shifts in land use for the production of biofuel crops due to changes in demand for energy, fertilizer and pesticides. There is significant data available on domestic energy, fertilizer, and pesticide used in agriculture. The work described here focuses on compiling information on international (non-U.S.) agricultural inputs.

This memorandum summarizes the methodology used to estimate GHG emission factors and changes in GHG emissions related to international agricultural energy use, fertilizer and pesticide consumption, and rice cultivation due to potential changes in land use to meet increased demand for biofuels. Data were obtained and analyzed from various agricultural and energy datasets. Intergovernmental Panel on Climate Change (IPCC) methodologies were used to estimate GHG emissions.

Specifically, ICF developed the following:

I. Fertilizer and Pesticide Consumption Projections
II. N_2O Emissions from Fertilizer Consumption and Crop Residues
III. GHG Emission Rates for Agricultural Energy Use
IV. CH_4 Emission Factors for Rice Cultivation

We provide a detailed explanation of the methodologies and data sources used below.

I. Fertilizer and Pesticide Consumption Projections

Fertilizer Consumption Projections

Historical fertilizer application rates (kilograms of fertilizer applied per hectare) and consumption (tonnes), as well as agricultural area, were primarily obtained from the Food and Agriculture Organization's (FAO) Fertistat Dataset.[1] Fertistat is a publicly available, international fertilizer dataset containing consumption data by crop and country. Fertistat data are available for nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) fertilizers, and are based on surveyed observations for a single year or period between planting and harvesting.[2] Survey data were collected between 1988 to 2004, with the year 2000 being the most frequent

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[1] Food and Agricultural Organization. Fertistat Database. http://www.fao.org/ag/agl/fertistat/. Last accessed October 10, 2008.

[2] Personal correspondence. Wolfgang Prante, Information Management Officer. Food and Agriculture Organization. July 15th, 2008.

year of survey data collection.[3] Application rates are calculated by Fertistat as total fertilizer consumption per country divided by agricultural area fertilized.[4] Application rates for the baseline 2022 scenario are assumed to be equal to rates reported by Fertistat. Tables 1 through 3 in the Appendix present fertilizer application rates by country and crop.

Fertistat did not report data for several crops of interest for certain countries, including Russia wheat, China wheat, and India soybean. Fertilizer application rates for wheat cultivation in Russia and China were obtained from Harris, 1998.[5] Application rates for soybean production in India were obtained from the Fertilizer Association of India.[6]

To determine the difference in fertilizer consumption between an increased biofuels demand scenario and the 2022 baseline scenario, application rates by country and crop were multiplied by projected acreage changes for crop production from the Food and Agricultural Policy Research Institute (FAPRI) agricultural models. Change in fertilizer consumption was calculated for 33 individual countries and for 8 regions (as shown in Table 1) to match the crop production change data from the FAPRI model results. As FAPRI region definitions were largely unavailable by crop, FAO regional definitions were used.[7,8]

Table 1: Country and Region Definitions

Individual Countries			European Union		Other Africa
Algeria	India	Paraguay	Austria	Hungary	Ethiopia
Argentina	Indonesia	Philippines	Belgium	Ireland	Kenya
Australia	Iran	Russia	Czech Republic	Italy	Madagascar
Bangladesh	Japan	South Africa	Germany	Lithuania	Malawi
Brazil	South Korea	Taiwan	Denmark	Latvia	Tanzania
Canada	Malaysia	Thailand	Spain	Netherlands	Zambia
China	Mexico	Turkey	Estonia	Poland	Zimbabwe
Colombia	Morocco	Uruguay	Finland	Portugal	
Cuba	Myanmar	Uzbekistan	France	Sweden	
Egypt	Nigeria	Venezuela	United Kingdom		
Guatemala	Pakistan	Vietnam	Greece		

Other Asia	CIS	Other Eastern Europe	Other Latin America	Other Middle East	Western Africa
Cambodia	Azerbaijan, Republic of	Albania	Bolivia	Israel	Ghana
Laos	Belarus	Bulgaria	Chile	Jordan	Guinea
Sri Lanka	Moldova, Republic of	Croatia	Costa Rica	Kuwait	Mauritania
Korea, Dem People's Rep		Slovakia	Dominican Republic	Lebanon	Togo
			Ecuador	Saudi Arabia	
			Honduras	Sudan	
			Nicaragua	Syrian Arab Republic	
			El Salvador		

[3] For several countries, Fertistat reported two or three years of data collection to represent growing periods for crops or yearly averages for a range of years. Data does not refer to fertilizer consumption over a two or three year timespan. For crop data with two years mentioned, the data refer to the period between planting and harvesting, and the latter year is used in the analysis. For crop data with three years mentioned, values reported are yearly averages, and the middle year was used in the analysis.

[4] Where the percentage of total agricultural area fertilized is not available, application rates are calculated by Fertistat as consumption divided by agricultural area planted (i.e. this assumes all area is fertilized). Personal correspondence. Jan Poulisse, Senior Manager. Food and Agriculture Organization.

[5] Harris, Gene. 1998. An Analysis of Global Fertilizer Application Rates for Major Crops. Agro-Economics Committee. Fertilizer Demand Meeting. Toronto, Canada.

[6] Fertilizer Association of India. "Usage of Fertilisers by Various Crops: 1996-97."

[7] Region definitions: Switzerland and Norway are included in the "Rest of World" category for land use change. Sudan is included in "Other Middle East." "Russia and Ukraine" category applies only to Russia. The United States is excluded from the dataset.

[8] FAPRI regions vary by crop type, so "Other" categories (e.g. Other Latin America") could potentially differ in the countries they include.

Pesticide Consumption Projections

Pesticide consumption projections are calculated using the same methodology as fertilizer projections. Historical data were taken from FAO's FAOSTAT database for pesticide consumption, including fungicides and bactericides, herbicides, and insecticides. Data were available by country, but not by crop. Data refers to the quantity of pesticides used in or sold to the agricultural sector for crops and seeds.[9] Rates of pesticide application were determined by dividing FAOSTAT's pesticide data by "agricultural area," a variable found in FAO's ResourceStat - Land dataset[10] (see Appendix, Table 4). Agricultural area is defined as arable land (land under temporary crops), land cultivated with permanent crops (e.g. coffee), and permanent pastures (land used for five or more years for herbaceous forage crops).[11] Change in pesticide consumption by country was calculated by multiplying pesticide application rates by the change in crop production acreage due to increased U.S. demand for biofuels.

To ensure that pesticide application rates were representative of a typical year, an average of pesticide consumption was calculated from 1995 through 2003. If data were not available during this period, data were averaged from 1990 through 1995.

II. N_2O Emissions from Fertilizer Consumption and Crop Residues

Change in fertilizer consumption and associated nitrous oxide (N_2O) emissions due to increased U.S. biofuel demand are projected based on crop production acreage for priority crops and countries. GHG emissions are calculated based on nitrogen (N) inputs from synthetic N fertilizer consumption and crop residues, both of which cause direct and indirect N_2O emissions from agricultural soils. Emission estimates are based on the IPCC 2006 default emissions factors and emissions equations for Tier 1 methodology.[12]

Projections of Changes in GHG Emissions from Fertilizer Consumption

Changes in fertilizer consumption cause changes in the amount of N added to soils, which change the amount of N_2O eventually emitted to the atmosphere. For this analysis, we estimate changes in N_2O emissions due to changes in synthetic fertilizer consumption and changes in crop residue application for certain crops. As Fertistat reports only mineral (or synthetic) fertilizer consumption data, we did not estimate changes in GHG emissions from organic fertilizer consumption. Emissions from organic fertilizer were handled separately by EPA through analysis of manure management changes from livestock operations. Calculations are based on Tier 1 methodologies for managed soils from the IPCC 2006 Guidelines. Tier 1 methodologies do not consider different land cover, soil type, climatic conditions, or management practices, and also do not consider any lag time for direct emissions from crop residues.[13]

The pathways of N in the soil are complex, but can be summarized as follows: N_2O emissions from soils occur either directly or indirectly. Direct emissions occur when N is applied to soil (from fertilizer, crop residues, or other sources), and eventually N_2O is emitted through the processes of nitrification and denitrification. Indirect emissions occur in two ways: (1) N applied to soils can be volatilized in a non- N_2O form, and redeposited in another location, where N_2O emissions will occur and (2) applied N can be leached by water in a non- N_2O form, and the N transported in the runoff will emit N_2O in a different location from

[9] FAO. FAOSTAT: Pesticide Consumption. http://faostat.fao.org/site/424/default.aspx#ancor. Last accessed: October 9, 2008.
[10] FAO. ResourceStat-Land. http://faostat.fao.org/site/377/default.aspx#ancor. Last accessed: October 15, 2008.
[11] FAO. FAOSTAT: Glossary. http://faostat.fao.org/site/379/DesktopDefault.aspx?PageID=379. Last accessed: October 10, 2008.
[12] Intergovernmental Panel on Climate Change. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry, and Other Land Use.
[13] IPCC. op. cit., pg. 11.6

that where the N was applied. This analysis looks at direct and indirect emissions from synthetic N fertilizer application and crop residues. GHG emissions from fertilizer consumption are determined based on the annual amount of synthetic fertilizer applied. Crop residue emissions are based on the N content of above- and below-ground crop residues (including N-fixing crops) that are returned to soils. Indirect crop residue emissions only include leaching/runoff emissions, as crop residue N is not thought to volatilize. In summary, GHG emission pathways include:

1. Direct emissions from N additions to soils from synthetic fertilizers
2. Indirect emissions from N additions to soils from synthetic fertilizers from volatilization and leaching/runoff.
3. Direct emissions from N in crop residues
4. Indirect emissions from N in crop residues due to leaching and runoff.

Emissions were estimated using IPCC default emission factors and default crop residue parameters (see Appendix, Tables 5 and 6). Emissions were calculated using the following Tier 1 equations:

Direct Emissions:

1. Direct N_2O emissions from synthetic fertilizers:

$$\text{(1)} \quad \text{Emissions} = F_{SN} \times EF_1 \times 44/28$$

Where:

F_{SN} = the annual amount of synthetic fertilizer N applied to soils (kg N)
EF_1 = emission factor,(equal to 0.1 kg N_2O-N/kg N input)
44/28 = conversion of N_2O -N to N_2O

2. Direct N_2O emissions from crop residues:

$$\text{(2)} \quad \text{Emissions} = F_{CR} \times EF_1 \times 44/28$$

Where

F_{CR} = the annual amount of N in crop residues and forage/pasture renewal, kg N_2O-N.
EF_1 = emission factor,(equal to 0.1 kg N_2O-N/kg N input)
44/28 = conversion of N_2O -N to N_2O

N additions to soils from crop residues depend on the crop type and yield, since different crop types have different N contents and different amounts of residue typically left in the soil. The equation for F_{CR} is:

$$\text{(3)} \quad F_{CR} = \sum (\text{Yield Fresh}_T \times DRY_T \times S_T + I_T) \times \text{Area}_T \times (N_{ag(T)} + R_{bg(T)} \times N_{bg(T)})$$

Where:

T = crop or forage type
Yield Fresh = fresh weight yield of crop (kg fresh weight/ha)
DRY = dry matter fraction of harvested crop (kg dry matter/kg fresh weight)
S = Slope for above-ground residue dry matter
I = Intercept for above-ground residue dry matter
Area = total annual area harvested (ha)
N_{ag} = N content of above-ground residues (kg N/kg dry matter)
R_{bg} = ratio of below-ground residues to harvested yield
N_{bg} = N content of below-ground residues (kg N/kg dry matter)

Table 6 in the Appendix presents crop residue factors by crop type. If default factors were not available for a particular crop, then proxies were used based on "major crop type" categories. Rice and sorghum estimates are based on default factors for grains; and peanut and sugarbeet estimates are based on root crops default factors. IPCC default factors were not available for cotton, palm oil, rapeseed, sugarcane and sunflower. As a result, direct and indirect emissions from crop residues for these crops are not included in total N_2O emissions estimates.

To determine the fresh weight yield for priority crops and countries, the change in crop production provided from the FAPRI model results in the year 2022 was divided by the change in crop production acreage. Area in the F_{CR} equation refers to the change in crop production acreage. Changes in crop acreage were obtained from the FAPRI model forecasts for key crops, countries, and regions.

Indirect emissions:

The two pathways for indirect emissions from managed soils are: (1) volatilization of N as NH_3 and oxides of N (NO_x), and the deposition of these gases and their products NH_4 and NO_3 onto soils and the surface of lakes and other waters; and (2) the leaching and runoff from land of N from synthetic fertilizer and crop residues. Leaching and runoff refers to the inorganic N in or on soils which bypasses biological retention mechanisms by transport in runoff, or overland water flow, and through flow through soil macropores or pipe drains.[14]

3. Indirect emissions from synthetic fertilizer consumption:

$$(4) \quad \text{Emissions} = [(F_{SN} \times Frac_{GASF} \times EF_2) + (F_{SN} \times Frac_{leach} \times EF_3)] \times 44/28$$

Where:

F_{SN} = annual amount of synthetic fertilizer N applied to soils (kg N)
$Frac_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x (equal to 0.10 kg N volatilized/kg N applied)
EF_2 = emission factor for N_2O emissions from N volatilization (equal to 0.01 kg N_2O-N/(kg NH3-N + NOx-N volatilized))
$Frac_{leach}$ = N lost from leaching and runoff (equal to 0.30 kg N/kg N applied)
EF_3 = emission factor for N_2O emissions from N leaching and runoff (equal to 0.0075 kg N_2O-N/kg N leached or runoff)
44/28 = conversion of N_2O -N to N_2O

4. Indirect emissions from crop residues:

$$(5) \quad \text{Emissions} = F_{CR} \times Frac_{leach} \times EF_3 \times 44/28$$

Where:

$Frac_{leach}$ = N lost from leaching and runoff (equal to 0.30 kg N/kg N applied)
EF_3 = emission factor for N_2O emissions from N leaching and runoff (equal to 0.0075 kg N_2O-N/kg N leached or runoff)
44/28 = conversion of N_2O -N to N_2O

Total Emissions

To derive total N_2O emissions from changes in fertilizer consumption due to changes in crop acreage, emissions were summed across these four pathways.

[14] IPCC, op. cit., pg. 11.19

III. GHG Emission Rates for Agricultural Energy Use

We estimated GHG emissions per area of agricultural land by country, due to agricultural energy inputs in the form of direct emissions from fuel consumption and indirect emissions from electricity and heat.

Total CO_2 emissions from fuel combustion in the agriculture/forestry/fishing sector of each country for 2005 and 2006 were taken from the International Energy Agency's (IEA) CO_2 Emissions from Fuel Combustion 2007.[15] As these estimates also include forestry and fishing activities, using these estimates for agriculture results in an overestimate of emissions. However, we believe this overestimate to be small, as agriculture is by far the largest consumer of energy use of these sectors. Furthermore, emissions were determined per acre of cropland, no distinction was made between different types of crops. Emissions from the use of the following fuel types are minimal and were therefore not included in each country's total CO_2 emissions: Biogas, Charcoal, Gas Works Gas, Geothermal, Other liquid biofuels, Primary Solid Biomass, Solar thermal.

To estimate indirect emissions from the generation of electricity and heat, 2005/2006 data on electricity and heat consumption in the agriculture/forestry/fishing sector were obtained from IEA's Energy Statistics of Non-OECD Countries, 2008 and Energy Statistics of OECD Countries, 2008. [16, 17] CO_2 emissions were estimated by multiplying consumption by the average rate of CO_2 produced per kWh of electricity or heat generated (provided by IEA's CO2 Emissions from Fuel Combustion, 2007).

Lifecycle GHG emission factors[18] were applied to all calculated emissions to estimate GHG emissions from fuel exploration, production, transportation, and distribution (see Appendix, Table 7). To estimate CO_2 emissions per agricultural area, emissions estimates were divided by total agricultural area for each country (see Appendix, Table 8).[19]

IV. CH_4 Emission Factors for Rice Cultivation

For this analysis, we developed country- and region specific emission factors for rice cultivation. We also provided rice growing season lengths.

Calculating emissions from rice cultivation, per the IPCC 2006 guidelines, requires the following data: area of rice harvested, an emissions factor, and planting to harvesting season length. Changes in area of rice harvested were provided from the FAPRI model results. Emissions from rice cultivation can be affected by a number of factors, namely water regimes during the cultivation period, water regimes before the cultivation period, and organic amendments. If country-specific data are available on these, the data can be used to scale the IPCC default emission factor.

For countries in this analysis, country-specific data on organic amendments and the water regime before the cultivation period were not available. Data were available, however, for the water regimes used during the cultivation period. Therefore, the default IPCC emission factor was scaled for each cropping regime: irrigated, rainfed lowland, upland and deepwater. Default factors are presented in the Appendix, Table 9.

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[15] International Energy Agency. 2007. CO_2 Emissions from Fuel Combustion: 1971-2005. IEA Statistics. IEA reports 2006 data for OECD countries and 2005 data for OECD countries.

[16] International Energy Agency. 2008. Energy Statistics of Non-OECD Countries. IEA Statistics.

[17] International Energy Agency. 2008. Energy Statistics of OECD Countries. IEA Statistics.

[18] Factors provided by Vincent Camobreco, EPA, based on "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" (GREET) model results for different fuels and scaling combustion vs. upstream GHG emissions.

[19] FAO: ResourceStat-Land. Dec. 2007. http://faostat.fao.org/site/377/default.aspx#ancor. Last accessed: October 17, 2008.

Rice cultivation season lengths were available from the International Rice Research Institute (IRRI) for priority countries.[20]

To be able to apply the cropping practice-specific emission factor, the area harvested under each cropping regime must be known. Data were collected from IRRI regarding the cropping practices in the major rice growing countries of the world. Data covers the percentage of area cultivated under each cropping regime (irrigated, rainfed lowland, upland and deepwater) in each country (see Appendix, Table 10). To calculate emissions from rice cultivation, the IRRI cropping regime percentages for each country can be applied to area harvested to determine the area grown under each regime in the country. Then, using the season length for the country and the scaled emission factors for each cropping regime, emissions can be calculated for each cropping regime, and then summed to produce the total emission estimate for each country. These country totals were multiplied by the changes in rice production acres from the FAPRI model results to determine overall rice methane emission changes.

[20] International Rice Research Institute. www.iri.org. Last accessed: October 15, 2008.

Appendix Tables

Table 1: Nitrogen (N) fertilizer rate of application (kg/acre) by country and crop[1]													
Country	**Barley**	**Corn**	**Cotton**	**Palm**	**Peanut**	**Rapeseed**	**Rice**	**Sorghum**	**Soybean**	**Sugarbeet**	**Sugarcane**	**Sunflower**	**Wheat**
Algeria													
Argentina		9.6	0.3				13.1		0.2		21.0	1.2	14.2
Australia			49.0								92.7		
Bangladesh		12.1	28.3				29.1				34.4		18.2
Brazil		16.2	33.6				10.9		3.2		22.3		4.9
Canada	27.1	63.1				30.4			10.1				20.2
China	32.4	52.6				50.6	58.7	36.4	23.8	48.6	60.7	32.4	48.6
CIS		0.6	8.5				-		3.1	20.4			4.2
Colombia	21.9	20.2	48.3				43.7	36.4	5.3		28.3		
Cuba							61.1				14.4		
Egypt	25.0	94.4	21.7				48.2		43.3	9.3	32.4	43.3	68.4
EU	38.1	67.1				25.1	20.8		21.0	50.2	40.5	19.7	48.6
Guatemala		49.7	24.3	32.4			29.1	36.4	4.9		28.3		38.8
India		0.4	2.2			1.0	10.5	0.3	2.7		2.7		8.5
Indonesia		1.6		30.8			38.2			25.5	29.1		
Iran	44.5												22.8
Iraq													
Ivory Coast													
Japan	31.2	80.9				47.8	31.6		12.1	71.2	91.5		
Malaysia		37.1		0.0			1.5						
Mexico	12.9	24.3	36.4				43.7		11.5		36.4	24.3	42.1
Morocco												24.3	3.0
Myanmar		4.2					8.7		-		7.1		
Nigeria		2.4	14.2					0.6	1.1				

[1] Blanks cell indicate Fertistat does not report data for that country/crop combination

Table 1: Nitrogen (N) fertilizer rate of application (kg/acre) by country and crop (cont'd)													
Country	**Barley**	**Corn**	**Cotton**	**Palm**	**Peanut**	**Rapeseed**	**Rice**	**Sorghum**	**Soybean**	**Sugarbeet**	**Sugarcane**	**Sunflower**	**Wheat**
Other Africa	8.1	10.3	7.3				1.7	14.4	2.7		8.6		10.3
Other Asia		20.0					15.3				2.4		16.5
Other CIS		0.6	8.5				-		3.1	20.4			4.2
Other Eastern Europe	6.1	18.7				32.1			12.2	31.6	60.7	4.2	11.8
Other Latin America	11.4	29.3	20.4	34.2		56.7	24.9	14.4	1.1	76.9	23.2	36.4	39.1
Other Middle East	16.4	33.5	14.8				42.0	0.0		22.6	0.1		26.2
Pakistan			48.6				40.5				50.6		67.3
Paraguay		3.6	1.6	19.4			10.1	14.6	1.2		12.1	11.3	6.5
Peru													
Philippines		18.8		24.3			17.5		1.6		27.5		
Rest of World	39.2	58.1				24.3	24.3			57.9		16.6	54.5
Russia													5.6
Russia and Ukraine													5.6
South Africa		21.1	7.3						1.1		35.4	5.2	12.1
South Korea	48.6												60.7
Taiwan		0.0					0.0	0.0	0.0		0.1		
Thailand		18.1		41.6			22.6		2.9		26.9		
Tunisia													
Turkey	18.5	50.5	50.6						12.1		42.5	36.6	23.1
Ukraine													
Uruguay	24.3	8.1					32.4	24.3	2.0		60.7	19.4	24.3
Uzbekistan			85.0										
Venezuela		32.4	24.3	20.6			54.6	32.4	4.9		42.5	14.6	19.4
Vietnam		38.2					41.9		14.6		36.1		
Western Africa		4.5	21.4	0.0			4.0	1.6					

Source: Food and Agriculture Organization. Fertistat Database. Retrieved Aug. 15, 2008 from: http://www.fao.org/ag/agl/fertistat/.

Table 2: Phosphorus (P_2O_5) fertilizer rate of application (kg/acre) by country and crop													
Country	**Barley**	**Corn**	**Cotton**	**Palm**	**Peanut**	**Rapeseed**	**Rice**	**Sorghum**	**Soybean**	**Sugarbeet**	**Sugarcane**	**Sunflower**	**Wheat**
Algeria													
Argentina		6.5	0.0				6.9		0.7		0.5	0.8	9.3
Australia			8.0								26.5		
Bangladesh		4.0	19.0				6.1				27.9		4.0
Brazil		14.2	52.6				14.2		26.7		20.6		20.2
Canada	10.5	21.0				8.1			20.2				10.5
China	14.2	16.2				24.3	24.3	12.1	27.8	26.3	30.4	12.1	33.7
CIS		0.2	5.3				0.0		0.0	7.8			4.2
Colombia	21.9	28.3	28.1				29.1	29.1	7.9		42.5		
Cuba							21.4				11.4		
Egypt	8.3	14.4	23.1				14.4		21.7	3.2	8.1	21.7	14.4
EU	14.1	26.3				10.7	5.1		7.7	23.7	16.2	12.0	13.3
Guatemala		22.7	14.6	16.2			14.6	21.9	14.6		22.7		25.9
India		0.1	0.5			0.3	3.1	0.2	2.6		1.0		2.6
Indonesia		8.1		9.7			8.0			21.4	11.3		
Iran	24.3												12.5
Iraq													
Ivory Coast													
Japan	29.1	80.9				87.4	37.2		40.5	131.1	36.8		
Malaysia		16.2		0.0			0.6						
Mexico	4.9	6.1	9.1				14.6		11.5		16.4	3.2	12.9
Morocco												24.3	0.2
Myanmar		1.2					2.9		0.0		3.0		
Nigeria		0.6	0.0					0.2	0.8				
Other Africa	25.9	3.3	2.0				0.9	5.5	3.2		5.9		12.6
Other Asia		4.3					9.5				0.8		10.9
Other CIS		0.2	5.3				0.0		0.0	7.8			4.2
Other Eastern Europe	3.6	5.7				22.2			18.3	16.0	16.2	1.6	3.0

Table 2: Phosphorus (P_2O_5) fertilizer rate of application (kg/acre) by country and crop (cont'd)													
Country	**Barley**	**Corn**	**Cotton**	**Palm**	**Peanut**	**Rapeseed**	**Rice**	**Sorghum**	**Soybean**	**Sugarbeet**	**Sugarcane**	**Sunflower**	**Wheat**
Other Latin America	9.3	13.0	4.4	11.1		60.7	10.6	12.4	2.0	96.1	11.9	29.1	19.8
Other Middle East	15.9	16.6	11.7				5.6	0.0		26.0	0.0		22.1
Pakistan			20.2				19.2				22.7		18.3
Paraguay		3.6	1.2	12.9			8.1	10.9	3.6		8.1	17.0	8.1
Peru													
Philippines		5.2		8.1			5.2		2.4		17.8		
Rest of World	17.9	41.6				18.2	12.1			30.4		19.0	19.0
Russia													3.4
Russia and Ukraine													3.4
South Africa		11.5	4.5						4.0		21.9	7.2	16.2
South Korea	44.5												60.7
Taiwan		0.0					0.0	0.0	0.0		0.0		
Thailand		10.4		13.9			12.0		6.1		21.1		
Tunisia													
Turkey	9.7	12.7	15.5						3.5		25.0	14.9	10.6
Ukraine													
Uruguay	28.3	12.1					32.4	24.3	12.1		32.4	19.4	32.4
Uzbekistan			18.2										
Venezuela		12.9	14.6	13.8			21.9	12.9	9.7		28.3	14.6	9.7
Vietnam		21.9					16.4		12.9		17.2		
Western Africa		2.6	8.8	0.0			1.6	1.2					

Source: Food and Agriculture Organization. Fertistat Database. Retrieved Aug. 15, 2008 from: http://www.fao.org/ag/agl/fertistat/.

Table 3: Potassium (K_2O) fertilizer rate of application (kg/acre) by country and crop													
Country	**Barley**	**Corn**	**Cotton**	**Palm**	**Peanut**	**Rapeseed**	**Rice**	**Sorghum**	**Soybean**	**Sugarbeet**	**Sugarcane**	**Sunflower**	**Wheat**
Algeria													
Argentina		0.0	0.0				7.3		0.0		0.0	0.0	0.0
Australia			5.0								66.4		
Bangladesh		3.2	20.6				4.0				29.1		3.2
Brazil		13.4	49.4				8.1		25.1		44.5		19.0
Canada	4.0	38.4				6.1			34.4				2.4
China	10.1	16.2				20.2	16.2	0.0	11.9	14.2	26.3	20.2	1.3
CIS		0.1	2.9				0.0		0.0	23.5			2.0
Colombia	10.9	4.0	10.1				25.5	18.2	10.5		28.3		
Cuba							15.0				19.8		
Egypt	13.5	0.0	23.1				0.0		23.1	46.2	0.0	23.1	0.0
EU	10.7	19.2				11.7	2.3		8.5	39.3	32.8	18.2	13.2
Guatemala		18.6	14.6	48.6			25.5	14.6	9.7		14.2		25.9
India		0.0	0.1			0.0	1.7	0.0	0.0		0.8		0.6
Indonesia		2.6		24.3			5.1			45.7	9.7		
Iran	28.3												4.4
Iraq													
Ivory Coast													
Japan	25.9	60.7				43.3	29.1		40.5	64.7	24.7		
Malaysia		3.2		2.0			0.0						
Mexico	0.0	3.0	0.0				0.0		0.0		14.6	0.0	0.0
Morocco												40.5	0.0
Myanmar		0.0					1.0		0.0		2.0		
Nigeria		0.0	0.0					0.0	0.0				
Other Africa	12.9	1.1	1.5				0.2	0.1	1.6		5.0		0.9
Other Asia		3.7					9.8				0.0		4.3
Other CIS		0.1	2.9				0.0		0.0	23.5			2.0
Other Eastern Europe	2.7	5.7				27.2			24.4	20.2	40.5	1.7	2.3

Table 3: Potassium (K_2O) fertilizer rate of application (kg/acre) by country and crop (cont'd)													
Country	**Barley**	**Corn**	**Cotton**	**Palm**	**Peanut**	**Rapeseed**	**Rice**	**Sorghum**	**Soybean**	**Sugarbeet**	**Sugarcane**	**Sunflower**	**Wheat**
Other Latin America	3.2	10.2	6.3	42.3		12.1	9.1	7.4	1.3	34.6	12.5	14.6	6.0
Other Middle East	0.5	18.0	3.5				10.3	0.0		20.4	0.0		8.0
Pakistan			0.0				0.1				0.1		0.0
Paraguay		3.6	1.2	19.4			8.1	10.9	3.6		8.1	22.7	4.9
Peru													
Philippines		3.2		22.7			3.8		0.8		9.7		
Rest of World	20.2	43.4				0.0	28.3			82.6		23.5	24.0
Russia													1.2
Russia and Ukraine													1.2
South Africa		2.3	0.6						1.3		51.1	0.7	1.6
South Korea	28.3												60.7
Taiwan		0.0					0.0	0.0	0.0		0.0		
Thailand		15.5		67.4			6.2		3.6		25.0		
Tunisia													
Turkey	0.0	2.0	1.4						0.0		13.7	1.9	0.2
Ukraine													
Uruguay	0.0	2.0					8.1	4.0	6.1		48.6	12.9	8.1
Uzbekistan			0.5										
Venezuela		9.7	14.6	34.4			14.6	12.9	14.6		28.3	9.7	4.9
Vietnam		20.0					15.3		8.1		18.9		
Western Africa		1.8	5.9	4.3			1.6	0.4					

Source: Food and Agriculture Organization. Fertistat Database. Retrieved Aug. 15, 2008 from: http://www.fao.org/ag/agl/fertistat/.

Table 4: Pesticides fertilizer rate of application (kg/acre) by country			
Country	Fungicides & Bactericides	Herbicides	Insecticides
Algeria	0.015	0.005	0.019
Argentina	0.022	0.130	0.028
Australia	0.084	0.016	0.007
Bangladesh	0.031	0.003	0.066
Brazil	0.010	0.049	0.029
Canada	0.017	0.139	0.019
China	0.000	0.000	0.000
CIS	0.016	0.030	0.020
Colombia	0.170	0.144	0.065
Cuba	0.000	0.000	0.000
Egypt	0.303	0.061	0.429
EU	0.374	0.278	0.088
Guatemala	0.080	0.029	0.026
India	0.020	0.016	0.073
Indonesia	0.002	0.008	0.006
Iran	0.023	0.011	0.011
Iraq	0.003	0.014	0.010
Ivory Coast	0.000	0.000	0.002
Japan	0.000	0.000	0.000
Malaysia	0.066	0.365	0.086
Mexico	0.000	0.000	0.000
Morocco	0.064	0.012	0.048
Myanmar	0.000	0.000	0.006
Nigeria	0.000	0.000	0.000
Other Africa	0.007	0.005	0.006
Other Asia	0.016	0.027	0.013
Other CIS	0.016	0.030	0.020
Other Eastern Europe	0.099	0.219	0.034
Other Latin America	0.073	0.096	0.074
Other Middle East	0.004	0.004	0.004
Pakistan	0.004	0.014	0.148
Paraguay	0.005	0.081	0.063
Peru	0.028	0.019	0.029
Philippines	0.000	0.000	0.000
Rest of World	0.040	0.065	0.015
Russia	0.023	0.023	0.003
Russia and Ukraine	0.023	0.023	0.003
South Africa	0.027	0.037	0.022
South Korea	1.585	1.162	1.830

Table 4: Pesticides fertilizer rate of application (kg/acre) by country			
Country	**Fungicides & Bactericides**	**Herbicides**	**Insecticides**
Thailand	0.072	0.221	0.136

Table 4: Pesticides fertilizer rate of application (kg/acre) by country (cont'd)			
Country	**Fungicides & Bactericides**	**Herbicides**	**Insecticides**
Tunisia	0.024	0.007	
Turkey	0.070	0.067	0.147
Ukraine	0.162	0.350	0.139
Uruguay	0.026	0.055	0.005
Uzbekistan	0.000	0.000	0.000
Venezuela	0.026	0.013	0.011
Vietnam	0.268	0.237	0.599
Western Africa	0.000	0.000	0.003

Source: Food and Agriculture Organization. FAOSTAT: Pesticide Consumption. Retrieved Aug. 15, 2008 from http://faostat.fao.org/site/424/default.aspx#ancor.

Table 5: Emission factors for direct and indirect fertilizer emission sources		
Variable	**Description**	**Value**
	Direct Emissions: EF_1	
EF_1	N additions from mineral fertilizer and crop residues	0.01 kg N_2O-N / kg N added
	Indirect Emissions from Volatilization	
$Frac_{GASF}$	N lost (from synthetic fertilizer additions) through volatilization	0.1 (kg NH_3–N + NO_x–N) / kg N applied
EF_2	N lost through volatilization	0.010 kg N_2O–N / (kg NH_3–N + NO_X–N volatilized)
	Indirect Emissions from Leaching/Runoff	
EF_3	N lost through leaching/runoff	0.0075 kg N_20-N / kg N leaching or runoff
$Frac_{leach}$	N lost through leaching/runoff (from all N sources)	0.3 N losses by leaching or runoff / kg N addition

Source: IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4 Chpt. 11. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change, H.S. Eggleston, L. Buendia, K. Miwa, T Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan.

Table 6: Default factors for estimation of N added to soils from crop residues[2]

Crop	Dry matter fraction of harvested product (DRY)	Above-ground residue dry matter AGDM$_{(t)}$ (Mg/ha): AGDM$_{(t)}$ = Crop$_{(t)}$ * Slope$_{(t)}$ + Intercept$_{(t)}$					N content of above-ground residues (N_{ag})	Ratio of below-ground residues to above-ground biomass (R_{bg})	N content of below-ground residues (N_{bg})
		Slope (S)	± 2 s.d. as % of mean	Intercept (I)	± 2 s.d. as % of mean	R2 adj.			
Major crop types									
Grains	0.88	1.09	± 2%	0.88	± 6%	0.65	0.006	0.22	0.009
Beans & pulses	0.91	1.13	± 19%	0.85	± 56%	0.28	0.008	0.19	0.008
Tubers	0.22	0.1	± 69%	1.06	± 70%	0.18	0.019	0.2	0.014
Root crops, other[3]	0.94	1.07	± 19%	1.54	± 41%	0.63	0.016	0.2	0.014
N-fixing forages	0.9	0.3	± 50% default	0	-	-	0.027	0.4	0.022
Non-N-fixing forages	0.9	0.3	± 50% default	0	-	-	0.015	0.54	0.012
Perennial grasses	0.9	0.3	± 50% default	0	-	-	0.015	0.8	0.012
Grass-clover mixtures	0.9	0.3	± 50% default	0	-	-	0.025	0.8	0.016
Individual crops									
Maize	0.87	1.03	± 3%	0.61	± 19%	0.76	0.006	0.22	0.007
Wheat	0.89	1.51	± 3%	0.52	± 17%	0.68	0.006	0.24	0.009
Rice	0.89	0.95	±19%	2.46	± 41%	0.47	0.007	0.16	NA
Barley	0.89	0.98	± 8%	0.59	± 41%	0.68	0.007	0.22	0.014
Oats	0.89	0.91	± 5%	0.89	± 8%	0.45	0.007	0.25	0.008
Millet	0.9	1.43	± 18%	0.14	± 308%	0.5	0.007	NA	NA
Sorghum	0.89	0.88	± 13%	1.33	± 27%	0.36	0.007	NA	0.006
Rye	0.88	1.09	± 50% default	0.88	± 50% default	-	0.005	NA	0.011
Soybean[4]	0.91	0.93	± 31%	1.35	± 49%	0.16	0.008	0.19	0.008
Dry bean	0.9	0.36	± 100%	0.68	± 47%	0.15	0.01	NA	0.01
Potato	0.22	0.1	± 69%	1.06	± 70%	0.18	0.019	0.2	0.014

[2] Source: Literature review by Stephen A. Williams, Natural Resource Ecology Laboratory, Colorado State University. (Email: stevewi@warnercnr.colostate.edu) for CASMGS (http://www.casmgs.colostate.edu/). A list of the original references is given in Annex 11A.1.
[3] Modeled after peanuts.
[4] The average above-ground residue:grain ratio from all data used was 1.9.

Table 6: Default factors for estimation of N added to soils from crop residues (cont'd)										
Crop	**Dry matter fraction of harvested product (DRY)**	**Above-ground residue dry matter AGDM(t) (Mg/ha): AGDM(t) = Crop(t) * Slope(t) + Intercept(t)**					**N content of above-ground residues (N_{ag})**	**Ratio of below-ground residues to above-ground biomass (R_{bg})**	**N content of below-ground residues (N_{bg})**
		Slope (S)	**± 2 s.d. as % of mean**	**Intercept (I)**	**± 2 s.d. as % of mean**	**R2 adj.**			
Peanut (w/pod)[5]	0.94	1.07	± 19%	1.54	± 41%	0.63	0.016	NA	NA
Alfalfa	0.9	0.29	± 31%	0	-	-	0.027	0.4	0.019
Non-legume hay	0.9	0.18	± 50% default	0	-	-	0.15	0.54	0.012

Source: IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4, p. 11-17 - 11-18. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change, H.S. Eggleston, L. Buendia, K. Miwa, T Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan.

Table 7: Lifecycle GHG emission factors applied to emissions from agricultural energy use	
Lifecycle GHG/Tailpipe CO_2 factors	
Gasoline	1.25
Diesel	1.22
Gas/Diesel[6]	1.235
Natural Gas	1.3
LPG	1.19
Coal	1.04
Total GHG/power plant CO_2	1.07

Source: Camobreco, Vincent, Environmental Protection Agency: Office of Transportation and Air Quality. Washington, D.C.. Personal correspondence. Sept, 2008.

[5] The mean value for above-ground residue: pod yield in the sources used was 1.80 with a standard error of 0.10.
[6] Calculated as the average of the gasoline and diesel lifecycle emission factors.

Table 8: Agricultural energy use greenhouse gas factors (GHGs/Agricultural Area)

Country	MMTCO$_2$ Eq./1000 ha
Albania	0.00027
Algeria	0.00000
Angola	0.00000
Argentina	0.00010
Armenia	0.00010
Australia	0.00002
Austria	0.00046
Azerbaijan	0.00021
Bahrain	0.00390
Bangladesh	0.00037
Belarus	0.00042
Belgium	0.00245
Benin	0.00000
Bolivia	0.00000
Bosnia-Herzegovina	0.00000
Botswana	0.00001
Brazil	0.00008
Brunei Darussalam	0.00000
Bulgaria	0.00022
Cambodia	0.00008
Cameroon	0.00000
Canada	0.00018
Chile	0.00004
China	0.00037
Colombia	0.00004
Congo	0.00000
Democratic Republic of Congo	0.00000
Costa Rica	0.00006
Ivory Coast	0.00001
Croatia	0.00034
Cuba	0.00013
Cyprus	0.00128
Czech Republic	0.00026

Country	MMTCO$_2$ Eq./1000 ha
Denmark	0.00091
Dominican Republic	0.00008
Ecuador	0.00001
Egypt	0.00236
El Salvador	0.00001
Eritrea	0.00000
Estonia	0.00054
Ethiopia	0.00000
Finland	0.00095
France	0.00033
Gabon	0.00000
Georgia	0.00006
Germany	0.00059
Ghana	0.00006
Greece	0.00067
Guatemala	0.00005
Haiti	0.00000
Honduras	0.00000
Hungary	0.00032
Iceland	0.00001
India	0.00067
Indonesia	0.00019
Iran	0.00048
Iraq	0.00000
Ireland	0.00033
Israel	0.00283
Italy	0.00081
Jamaica	0.00342
Japan	0.00249
Jordan	0.00091
Kazakhstan	0.00004
Kenya	0.00001
North Korea	0.00000
Korea	0.00424
Kuwait	0.00000

Table 8: Agricultural energy use greenhouse gas factors (GHGs/Agricultural Area) (cont'd)	
Country	**MMTCO$_2$ Eq./1000 ha**
Kyrgyzstan	0.00002
Latvia	0.00009
Lebanon	0.00000
Libya	0.00014
Lithuania	0.00010
Luxembourg	0.00079
FYR of Macedonia	0.00009
Malaysia	0.00005
Malta	0.00000
Mexico	0.00013
Republic of Moldova	0.00014
Mongolia	0.00000
Morocco	0.00006
Mozambique	0.00000
Myanmar	0.00000
Namibia	0.00002
Nepal	0.00006
Netherlands	0.00772
Netherlands Antilles	0.00000
New Zealand	0.00007
Nicaragua	0.00001
Nigeria	0.00000
Norway	0.00055
Oman	0.00000
Pakistan	0.00013
Panama	0.00004
Paraguay	0.00000
Peru	0.00007
Philippines	0.00009
Poland	0.00101
Portugal	0.00058
Qatar	0.00000

Country	MMTCO$_2$ Eq./1000 ha
Romania	0.00005
Russia	0.00018
Saudi Arabia	0.00001
Senegal	0.00000
Serbia and Montenegro	0.00017
Singapore	0.03128
Slovak Republic	0.00028
Slovenia	0.00056
South Africa	0.00009
Spain	0.00042
Sri Lanka	0.00002
Sudan	0.00000
Sweden	0.00035
Switzerland	0.00002
Syria	0.00005
Tajikistan	0.00003
United Republic of Tanzania	0.00000
Thailand	0.00066
Togo	0.00000
Trinidad and Tobago	0.00000
Tunisia	0.00017
Turkey	0.00032
Turkmenistan	0.00005
Ukraine	0.00025
United Arab Emirates	0.00000
United Kingdom	0.00023
United States	0.00015
Uruguay	0.00005
Uzbekistan	0.00034
Venezuela	0.00002
Vietnam	0.00022
Yemen	0.00015
Zambia	0.00000
Zimbabwe	0.00011

Derived from IEA and FAO data. International Energy Agency (IEA) © OECD/IEA, 2008: Energy Statistics of Non-OECD Countries, 2008; Energy Statistics of OECD Countries, 2008; and CO2 Emissions from Fuel Combustion, 2007. Food and Agriculture Organization, 2008. ResourcesStat-Land. Retrieved Aug. 30, 2008 from http://faostat.fao.org/

Table 9: Calculated emission factors (kg CH_4/ha/day) for each cropping regime[7]

Irrigated	Rainfed lowland	Upland	Deepwater
1.2371	0.4441	0	0.4917

Source: IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change, H.S. Eggleston, L. Buendia, K. Miwa, T Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan.

[7] Emission factors calculated using the IPCC 2006 guidelines.

Table 10: Percentage of cropping area under each cropping regime in major rice-consuming and producing countries of the world				
Major rice-consuming and producing countries	**Percent Fields Irrigated**	**Percent Fields Rainfed lowland**	**Percent Fields Upland**	**Percent Fields Deepwater**
Bangladesh	40	42	7	11
Brazil	35.5	2.8	61.7	0
Burkina Faso	9	6	0	85
Cambodia	16	75	1	8
Chad	0	11	89	0
China	93	5	2	0
Colombia	70	10	20	0
Congo, Dem Rep of	7	19	74	0
Cote d'Ivoire	7	15	78	0
Dominican Rep	93	7	0	0
Ecuador	38.4	0	61.6	0
Ghana	10	81	9	0
Guinea	1	19	69	11
Guyana	71	29	0	0
India	52.6	32.4	12	3
Indonesia	60.1	25.3	0	14.6
Lao PDR	8.3	77.4	14.3	0
Liberia	2	6	82	10
Madagascar	52	18	29	1
Malaysia	66	21	12	1
Mali	32	25	3	40
Myanmar	30	59	4	7
Nepal	21	66	5	8
Nigeria	16	52	30	2
North Korea	67	20	13	0
Peru	80	20	0	0
Philippines	68	29.2	2.8	
Senegal	45	43	5	7
Sierra Leone	0	28	68	4
Sri Lanka	75	25	0	0
Suriname	93	7	0	0
Tanzania	4	73	23	0
Thailand	25	72.8	1.7	0.5
Uganda	2	53	45	0
Vietnam	53	39	5	3
The following countries use only one cropping regime, 'irrigated'				
Australia	100	0	0	0
Cuba	100	0	0	0
Egypt	100	0	0	0
Europe	100	0	0	0
Japan	100	0	0	0
Pakistan	100	0	0	0
South Korea	100	0	0	0
Uruguay	100	0	0	0
US	100	0	0	0

Source: International Rice Research Institute. Retrieved Aug. 15, 2008 from www.iri.org.