California Nitroscapes: An Environmental, Social, and Economic Evaluation of the Fate and Consequence of Excess N Final Report

Due Sept. 30, 2011

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This collaborative research project sought to examine the environmental, social, and economic impacts of excess N in California – tracking N from creation to fate, and toward its ultimate influence on regional-scale economies and environments. Our approach attempted to create strong linkages between innovative models of key N-cycle processes, life cycle analysis (LCA) methods, and environmental-economic assessments. Fig. 1 demonstrates how Houlton's research on N-cycle modeling would inform the research of Kendall and Springborn.

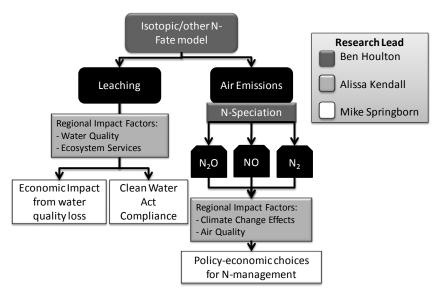


Fig. 1. Research Organization and Linkages

The following report is split into three parts, where each co-PI reports his/her research results.

Subproject led by Benjamin Z. Houlton: **Nitrogen Inputs, Outputs and Cycling in California: Natural vs. Anthropogenic Environments**

Executive Summary:

Nitrogen (N) is essential to all life and affects many different aspects of the Earth system as a whole. At the molecular scale, for instance, N is a significant component of nucleic acids, protein and other biomolecules that regulate a suite of cell functions. At larger scales, N influences the climate system via its direct impact on climate forcing and indirectly via its role in constraining CO₂ uptake and storage on land and in the sea. Consequently, biogeochemists, climatologists, and ecologists are fundamentally interested in understanding how N cycles among Earth's biomes and across a spectrum space-time scales – especially in terms of how much N enters and leaves the biosphere along dissolved vs. gaseous paths.

However, two principal factors have greatly challenged this objective. First, N_2 – likely the dominant gaseous N product of soil bacteria – is difficult to measure accurately because of the large background concentration of N_2 in air. This challenge has sparked controversies over the "missing N" in the global N budget. Second, emissions of NO, N_2 O or N_2 can vary significantly in space and time; hence, scaling up field measurements, using either empirical or computational models, imparts large, unexplained errors in estimates of gaseous N emissions. Consequently, modeling has become an essential tool for estimation of N gas emissions at regional to global scales.

The objective of this research was to devise new modeling techniques – coupled with empirical measurements – to place constraints on N balances and forms across California, including natural vs. human-altered sites. The originally proposed project outcomes included 2 to 3 peer-reviewed, multi-authored publications in both scientific and policy-relevant journals as well as a report and white paper. Funds allocated to Houlton's group have resulted in one publication (Morford et al., Nature, 2011), with an additional manuscript on California N budgets currently in preparation (Bai et al., in prep, Global Biogeochemical Cycles) to be submitted in the next month or so. In addition, funds from the grant were used to support three talks at scientific meetings – Liptzin et al., ESA, 2011, Morford et al., ESA, 2011, and Houlton, ACS 2011.

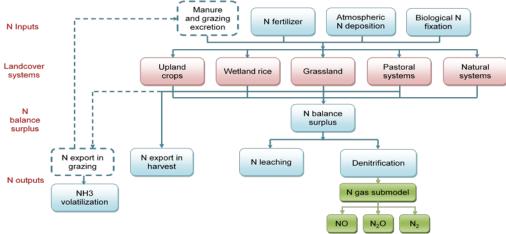


Fig. 2. Model framework developed for the statewide N assessment. **Specific Results:**

Results can be broken down into two core projects. The first involved new model development and application. Houlton's postdoc, E. Bai, was the principle researcher involved in modeling statewide N cycles. The new model is described in Fig. 2, based on the IMAGE model, but with the development of a sub-gas model.

Applying the IMAGE model at a spatial resolution of 12×12 km has revealed striking statewide patterns in N loss pathways. The major finding is that more N in California appears to be mobilized to the atmosphere than leaches to rivers (Fig. 3), a finding that fits well with the CA N assessment led by postdoc Liptzin. Moreover, the gas partitioning identifies NOx as a major loss of N – suggesting that Agricultural in the Central Valley has major human health implications (Fig. 3). NOx catalyzes the formation of photochemical smog, leading to poor air quality and human health concerns. These results have been presented at a national meeting (by Liptzin) and are being written up as a multi-author paper – involving all three PIs – to be submitted in the next month to Global Biogeochemical Cycles.

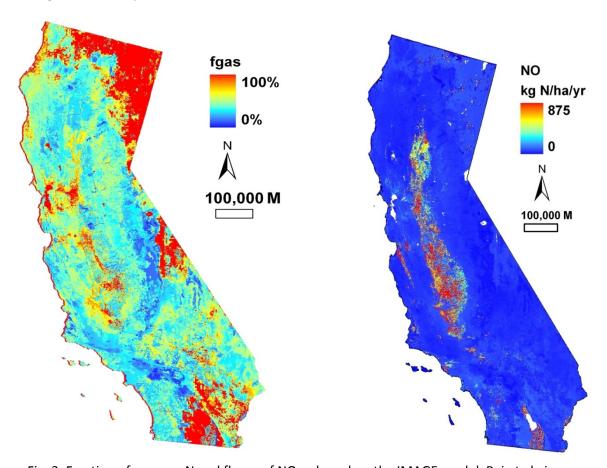


Fig. 3. Fraction of gaseous N and fluxes of NO as based on the IMAGE model. Bai et al., in prep.

The second project involved allocation of funds for students to analyze lab samples of N contents and stable isotopes across California ecosystems, supporting the work of graduate student S. Morford and various undergraduate assistants. This work led to a fundamental new discovery – that rocks are a significant source of N to California forests, more than doubling the budget of N inputs in certain natural sites (Fig. 4). This finding was described in a paper that appeared in the journal Nature (led by Houlton's student, Morford), and received considerable media coverage (e.g., NPR "Morning")

Edition", BBC's "The Naked Scientists", etc.). Moreover, results from this project were presented at several national meetings, including the Ecological Society of American meeting in Austin, TX and the American Geophysical Union meeting in San Francisco, CA.

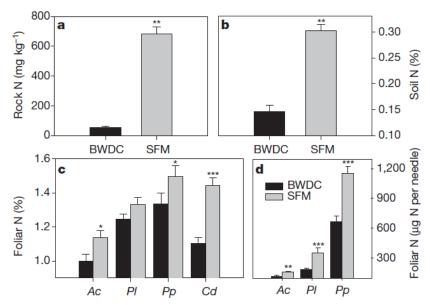


Fig. 4. Nitrogen contents of rocks, soil and foliage among forest ecosystems with (SFM) and without (BWDC) bedrock nitrogen in the Klamath Mts. From Morford et al, Nature, 2011.

Potential Implications

Nitrogen plays a duel role in the environment; in some cases there's too much, in some cases too little. Understanding this duality is fundamental to advancing our understanding of food security and thoughtful environmental stewardship. Results of this research indicate that much of the N used to grow crops escapes into California's broader environment, thereby altering ecosystem and human health — especially in terms of the airborne fraction of N leaving as NOx compounds. This leads too poor air quality for human health in areas surrounding the Central Valley. At the same time, not much N appears to make its way to the ocean, suggesting less risk in terms of coastal eutrophication. This marks California as an unusual case; unlike the Midwest or eastern seaboard of the US, much of the N added as fertilizer is transported in the air as opposed to the water. The challenges for management and policy thus hinge more on understanding how to reduce the airborne fraction of N in a way that's different from many other areas in which the N cycle has been impacted by humanity.

In terms of our rock N discovery – this has implications for forest health and climate change. Nitrogen is a principal limiting resource in many natural ecosystems, indicative of the case of too little N. That rocks contain vast quantities of N that appear to feed many California forests allows for high productivity and more carbon storage on land, helping to alleviate some of the N limitations faced by growing vegetation. These areas – areas where sedimentary rocks contain ecologically available N – should be considered a conservation priority in terms of maximizing ecosystem services such as C storage. Moreover, weathering of rocks increases with increasing temperatures, meaning that rock N

releases may increase as the climate warms, allowing plants to assimilate more of the human CO₂ emissions than would otherwise be expected.

Cited Literature:

Morford, Houlton and Dahlgren. 2011. Increased forest ecosystem carbon and nitrogen storage from bedrock nitrogen. Nature, 477, 78-81.

Subproject led by Alissa Kendall: Exploring Improved Methods for Evaluating N2O Emissions in Life Cycle Assessment Applied to Agricultural Systems

Executive Summary:

Objectives

Kendall's research has focused on determining the current methods used by life cycle assessment (LCA) practitioners in their treatment of nitrogen use in agriculture, particularly in calculations of N_2O emissions from fertilizer application. Her research included identifying and testing potential methods and models that could be appropriate for these practitioners, including models generated by Houlton.

An extensive literature review confirmed that estimates of N_2O emissions from fertilized fields are usually highly simplified in LCA, primarily relying on IPCC Tier 1 methods or other global or regional estimates that ignore cultural practices, soil, climate, and other key factors controlling N_2O emissions from fertilized fields. A review of more than 20 LCA articles, reports and models shows that, where IPCC Tier 1 methods are not used, there is little consensus among LCA practitioners on appropriate methods for estimating emissions.

A number of articles have critiqued the current state-of-the-practice for N_2O estimation in LCA (most notably, (Smeets et al. 2009)), but many of their proposed solutions, such as the use of biogeochemical process models or the collection of field data, require expertise that is outside the knowledgebase of LCA practitioners and researchers. In fact the most recent critique published in the LCA literature offers no recommendation at all for how practitioners should estimate N_2O emissions, and simply emphasizes the uncertainty in current estimates (Reijnders and Huijbregts 2011). One particular challenge is that improved estimation techniques require site specific data, while the goal of an LCA is to categorize an 'average' or 'typical' product or system, e.g. 1 kg of U.S. corn, or 1 kg of California almonds. This leads to trade-offs between modeling and estimation techniques that require site-specific data, versus regional or national scale estimations that are less accurate, but may be more appropriate for characterizing average or typical production.

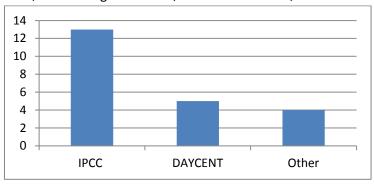
As part of Kendall's research she investigated whether Houlton's state-wide IMAGE modeling could be used to provide LCA practitioners with improved regional estimates of N_2O emissions from fertilized fields for specific crops. Unfortunately, the scale of IMAGE modeling output proved too course (i.e. the grid cells were too large) for crop-specific estimation of N_2O emissions. Creating a less course raster-based output from the IMAGE model could make this approach viable in the future, and demonstrated that regional estimates of N_2O emissions for *typical* production could be developed for use by non-experts.

After finding that IMAGE model output was not viable as a tool for N_2O emissions estimation methods in LCA, Kendall compared Tier 1 and Tier 2 IPCC methods to estimate the scale of potential error introduced by using Tier 1 methods. Tier 2 methods use field data or other regional data as a foundation for estimating N_2O emissions from fertilizer application. Tier 2 estimates hinge on the availability of data for a specific crop in a specific region. The comparison showed that for California, Tier 1 methods may over-estimate N_2O emissions, and demonstrates the importance of adopting alternative methods to IPCC Tier 1.

Specific Results:

Review of Current Practice: The literature review demonstrated a reliance on IPCC Tier one calculations (or sources such as Argonne National Lab's GREET model which are based on IPCC Tier 1 calculations). Fig. 5 summarizes the N₂O emissions calculation approach used by the reviewed studies (see Table A1 at the end of this report for more details) and shows that more than half of the studies reviewed (13 in total) used IPCC Tier 1 methods; five studies used the biogeochemical process model DAYCENT, however four of these five studies were by the same authors and three of the four address nearly identical topics; and the other studies used a variety of data sources, including statistical analyses of field data. The studies in Fig. 5 only include those that explicitly use LCA to characterize life cycle emissions from crop cultivation (or products, such as biofuels, produced from crops); a number of LCA studies, such as (Andersson and Ohlsson 1999; Pimentel and Patzek 2005), actually ignored field emissions altogether, but these were not included in our analysis.

Fig 5. Frequency of Different N_2O Emissions Calculation Methods in LCA (Kramer et al. 1999; Wang et al. 1999; Brentrup et al. 2001; van den Broek et al. 2001; Heller et al. 2003; Kim and Dale 2003; Kim and Dale 2005; Nielsen and Wenzel 2005; Spatari et al. 2005; Wu et al. 2006; Adler et al. 2007; Landis et al. 2007; Wang et al. 2007; Berry et al. 2008; Kim and Dale 2008; Kim and Dale 2008; Liska et al. 2009; Meisterling et al. 2009; Smeets et al. 2009; Erisman et al. 2010)



One interesting finding that we did not anticipate in this literature review was dominance of biofuel-related literature on the topic, particularly in recent years. Because the discussion has been framed as part of the biofuel debate, biofuel-related issues, particularly those related to corn-ethanol production in the U.S., have shaped the discourse on the potential methods for improving characterization of N_2O and other nitrogen effects from agricultural in LCA

Given the dominance of IPCC Tier 1 methods in LCA, the question is whether the use of this method could significantly alter the outcomes of LCAs of agricultural systems and products. Using a case study of one California crop, we can demonstrate that it does make a difference. Tier 1 (IPCC global emissions factor) and Tier 2 (emissions factors developed from data from field sampling) were applied to California almond orchards to ascertain whether N_2O emissions estimates might change significantly between Tier 1 and Tier 2 estimation methods. Tier 2 direct N_2O emissions rates were between 37% and 75% lower than Tier 1 estimates depending on irrigation technology used (Kendall et al. 2011). This demonstrates the critical need for complementary or alternative approaches to Tier 1 estimation methods in LCA and 'carbon footprinting' for N_2O emissions from agricultural fields.

Potential Impacts:

Continued collaboration between Houlton and Kendall could result in a new tool for LCA practitioners to estimate nitrogenous air emissions from fertilizer application on a regional basis. When this occurs, the proposed new method will be published in a peer-review journal for an LCA audience. In the shorter-term, Kendall is developing a number of LCAs and carbon footprints for California crops and will pursue peer-reviewed publications that include comparisons of Tier 1 and Tier 2 estimation techniques in the context of crop-specific LCAs to help communicate to the LCA community the importance of considering alternatives to Tier 1 estimates. One publication of this kind is expected by the end of the 2011 calendar year.

Cited Literature:

Adler, P. R., et al. (2007). "Life-cycle assessment of net greenhouse-gas flux for bioenergy cropping systems." *Ecological Applications* 17(3): 675-691.

Andersson, K. and T. Ohlsson (1999). "Life cycle assessment of bread produced on different scales." *The International Journal of Life Cycle Assessment* 4(1): 25-40.

Berry, P. M., et al. (2008). "Quantifying the effects of fungicides and disease resistance on greenhouse gas emissions associated with wheat production." *Plant Pathology* 57(6): 1000-1008.

Brentrup, F., et al. (2001). "Application of the Life Cycle Assessment methodology to agricultural production: an example of sugar beet production with different forms of nitrogen fertilisers." *European Journal of Agronomy* 14(3): 221-233.

Erisman, J., et al. (2010). "Nitrogen and biofuels; an overview of the current state of knowledge." *Nutrient Cycling in Agroecosystems* 86(2): 211-223.

Heller, M. C., et al. (2003). "Life cycle assessment of a willow bioenergy cropping system." *Biomass and Bioenergy* 25(2): 147-165.

Kendall, A., et al. (2011). Almond Board Annual Report: A Life Cycle Assessment of Greenhouse Gas Emissions for Almond Production in California.

Kim, S. and B. E. Dale (2003). "Cumulative Energy and Global Warming Impact from the Production of Biomass for Biobased Products." *Journal of Industrial Ecology* 7(3-4): 147-162.

Kim, S. and B. E. Dale (2005). "Environmental aspects of ethanol derived from no-tilled corn grain: nonrenewable energy consumption and greenhouse gas emissions." *Biomass and Bioenergy* 28(5): 475-489.

Kim, S. and B. E. Dale (2008). "Effects of Nitrogen Fertilizer Application on Greenhouse Gas Emissions and Economics of Corn Production." *Environmental Science & Technology* 42(16): 6028-6033.

Kim, S. and B. E. Dale (2008). "Life cycle assessment of fuel ethanol derived from corn grain via dry milling." *Bioresource Technology* 99(12): 5250-5260.

Kramer, K. J., et al. (1999). "Total greenhouse gas emissions related to the Dutch crop production system." *Agriculture, Ecosystems & Environment* 72(1): 9-16.

Landis, A. E., et al. (2007). "Life Cycle of the Corn–Soybean Agroecosystem for Biobased Production." *Environmental Science & Technology* 41(4): 1457-1464.

Liska, A. J., et al. (2009). "Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol." *Journal of Industrial Ecology* 13(1): 58-74.

Meisterling, K., et al. (2009). "Decisions to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat." *Journal of Cleaner Production* 17(2): 222-230.

Nielsen, P. H. and H. Wenzel (2005). Environmental Assessment of Ethanol Produced from Corn Starch and used as an Alternative to Conventional Gasoline for Car Driving.

Pimentel, D. and T. W. Patzek (2005). "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resources Research* 14(1): 65-76.

Reijnders, L. and M. A. J. Huijbregts (2011). "Nitrous oxide emissions from liquid biofuel production in life cycle assessment." *Current Opinion in Environmental Sustainability*(0).

Smeets, E. M. W., et al. (2009). "Contribution of N2O to the greenhouse gas balance of first-generation biofuels." *Global Change Biology* 15(1): 1-23.

Spatari, S., et al. (2005). "Life Cycle Assessment of Switchgrass- and Corn Stover-Derived Ethanol-Fueled Automobiles." *Environmental Science and Technology* 39(24): 9750-9758.

van den Broek, R., et al. (2001). "Green Energy or Organic Food?: A Life-Cycle Assessment Comparing Two Uses of Set-Aside Land." *Journal of Industrial Ecology* 5(3): 65-87.

Wang, M., et al. (1999). Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions. Argonne, IL, Argonne Energy Systems Division.

Wang, M., et al. (2007). "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types." *Environmental Research Letters*: 1-13.

Wu, M., et al. (2006). Fuel-Cycle Assessment of Selected Pathways in the United States. Argonne, Argonne National Laboratory.

Subproject led by Springborn: Regulatory Design for Agricultural Greenhouse Gas Offsets in California: the Role of Mitigation Modeling Uncertainty in Cost-Effective Policy

Executive Summary:

According to the IPCC, the agricultural and forestry sectors combine are seen as the most important sector in contributing to climate change mitigation (Trumper 2009). The use of greenhouse gas (GHG) offsets from the agricultural and forestry sector has been seen by many countries as one of the key strategic tools for reducing overall GHG emissions. However, one of the biggest impediments to such a system, especially for offsets steming from nutrient management, is the uncertainty associated with estimation mitigation. The true quantity of carbon mitigation generated from land management changes is uncertain due to imperfect measurement and modeling as well as stochastic factors like future weather conditions. Such uncertainty presents a challenge for decision-makers such as aggregators and offset buyers concerned with liability and regulators concerned with the overall credibility and efficacy of an environmental policy. Not taking uncertainty of environmental benefits into consideration when implementing GHG offset programs on agricultural and forestry lands may be "both scientifically unjustifiable and politically infeasible" (Rabotyagov 2010).

A first step in this research involved developing a model of how uncertainty propagates as GHG mitigation from changes in agricultural practice are first aggregated over many plots by "offset bundlers", and then aggregated again in the accounting of overall mitigation from the sector. Such pooling of offsets has been advocated as a way to minimize the effect of uncertainty—this research demonstrates the degree to which pooling does and does not attenuate the effects of uncertainty depending on whether that uncertainty stems from imprecision ("noise") versus inaccuracy ("bias"). Given remaining uncertainty, a key policy design question faced by institutions such as CARB is how to credit GHG mitigation when unable to verify the true level of mitigation with absolute certainty (at least at reasonable cost). An approach garnering increasing attention is to allow policy makers to simply state a "margin of safety", i.e. specify the maximum acceptable probability that too much credit is given for uncertain offsets. The existing literature is currently silent on the question of where such a margin of safety should be imposed (e.g. at the farm, bundler or sectoral/regulatory level) and what the implications of such a choice are for market concentration (monopoly) in the offset aggregation services sector. These questions have a strong effect over the way farmers are likely to be compensated for offsets and thus participation and ultimate success of an offset program. Analytical results show a striking difference in incentives for participants in offset markets as the locus for imposing the margin of safety is shifts between different levels in the offset aggregation process. Results generally support instituting such rules for handling risk the top level (e.g. sectoral/regulatory level) rather than at lower levels as in the existing literature.

Specific Results:

First we find that aggregation or pooling of offsets over a number of sites will not necessarily lead to the attenuation of all types of uncertainty: offset pooling diminishes the effect of uncertainty due to imprecision but not uncertainty due to systematic bias (in estimation or prediction). A convenient way of summarizing the effect of imposing a margin of safety for uncertain offsets is to characterize what happens to the "uncertainty discount", a term that refers to the difference between the estimated level of mitigation and the (smaller) actual level of credit received. We find that:

- Additional uncertainty leads to a larger uncertainty discount but in increasingly smaller increments and therefore:
 - Depending on how the margin of safety is imposed, there can be strong incentives for entities in the offset aggregation sector to favor smaller numbers of larger offset pools, i.e. for the sector to become concentrated (monopolistic).
 - The effects of bias and imprecision (which both augment uncertainty) on the size of the uncertainty discount are *interdependent*; if one form is reduced the effect of the other becomes more important.

Additional results from the analysis, which depend on a deeper presentation of the model and assumptions is available upon request.

Potential Impacts:

In California, a key anticipated component for incentivizing GHG mitigation in agroecosystems in general and nutrient management in particular will likely be the construction of protocols for incorporating agricultural GHG offsets under AB 32. This research fills a gap in the current understanding of how different options for implementing rules with respect to the treatment of uncertainty could have profound implications for farmer participation and the ultimate success of protocols for GHG offsets from agriculture. We have initiated a collaboration with soil scientists at UC Davis to empirically demonstrate the mechanics and implications of the model for California agriculture. We anticipate that numerical estimates of the size of various effects will assist in communicating core insights to key agencies (i.e. CARB) and the collection of stakeholders involved in offset protocol design. Further, we anticipate that our rigorous general treatment of multiple uncertainties over different scales will be of interest to academic researchers working on policy design under uncertainty questions for other types of offsets (e.g. from forestry) and for ecosystem services more generally.

Cited Literature:

Rabotyagov, S. (2010). Ecosystem services under benefit and cost uncertainty: An application to soil carbon sequestration. *Land Economics* 86 (4), 668.

Trumper, K. (2009). *The natural fix? The role of ecosystem in climate mitigation*. Earthprint. Available online: http://www.unep.org/pdf/BioseqRRA_scr.pdf.

Table A1. Literature Review of N₂O Modeling in LCA

Author and Year of Publication	Country or Region	Crop	Nitrogen Emissions considered	Indirect N2O emissions	Data sources
Adler et al. 2007	U.S.	corn, soybean, alfalfa, hybrid poplar, reed canarygrass, and switchgrass	N2O emissions	Yes	DAYCENT outputs are combined with IPCC 1997 for N2O from indirect N- losses.
Berry et al. 2008	UK	wheat	N2O emissions	Yes	IPCC 2006 tier 1 method for direct and indirect N emissions
Brentrup et al .2001	Germany	sugar beet	Include NH3, N2O, N removal from beets, and N content of leaves	Yes	ECETOC 1994 (Bouwman 1995, DBG 1992)
Erisman et al.	the world	bioenergy crops	NH3 and N2O	Yes	IPCC and literature
Heller, Keoleian, Volk 2003	U.S.	willow bioenergy cropping system	NH3 emissions from application of ammonium sulfate, and application of biosolids; N2O emissions from application of fertilizer and crop residues	No	IPCC 1996 tier 1 method for direct N2O emissions
Kim and Dale 2003	U.S.	Biobased products: corn, soybeans, alfalfa, switchgrass	N2O emissions	No	GREET 1.5a (IPCC Tier 1 methods)
Kim and Dale 2005	U.S. Corn Belt	corn grain	N2O emissions	No	DAYCENT
Kim and Dale 2005	U.S. Corn Belt	corn	N2O emissions	No	DAYCENT

Author and Year of Publication	Country or Region	Crop	Nitrogen Emissions considered	Indirect N2O emissions	Data sources
Kim and Dale 2008	U.S.	corn	N2O emissions	No	DAYCENT
Kim and Dale 2008	U.S. Corn Belt	corn	N2O emissions	No	DAYCENT
Kramer, Moll, Nonhebel, 1999	Netherlands	Dutch crop production system	N fertilizer is considered as an emissions source, but not clear what is considered	Unknown	Unclear
Landis, Miller, Theis, 2007	U.S.	Corn and soybean	N2O emissions	Yes	GREET 1.6 (IPCC Tier 1 methods)
Liska et al. 2009	U.S.	corn	N2O emissions from N fertilizer and manure, losses from volatilization, leaching and runoff, and crop residue	Yes	IPCC 2006 tier 1 method for direct and indirect N emissions
Meisterling et al. 2009	U.S.	wheat	N2O emissions	Yes	IPCC 2006 tier 1 method for direct and indirect N emissions
Nielsen and Wenzel 2005	U.S. Corn Belt	corn	N2O emissions	Yes	IPCC 1996 tier 1 method for direct and indirect N emissions
Spatari et al. 2005	Canada	Switchgrass and corn	N2O emissions	Yes	IPCC 1996 tier 1 method for direct and indirect N emissions
Smeets et al. 2009	Global	Bioenergy crops (ethanol and biodiesel)	N2O emissions due to the storage of manure applied to the cropland; from manure	No	A statistical model based on 1008 N2O emission measurements for ag

Author and Year of Publication	Country or Region	Crop	Nitrogen Emissions considered	Indirect N2O emissions	Data sources
			deposited on grassland during the grazing of animals; from ag soils and soils under natural vegetation.		fields and 210 measurements for areas under natural vegetation (Bouwman, multiple publications).
van den Broek et al. 2002	Netherlands	Winter wheat	N2O emissions	Yes	Audsley 1999, Van Zeijs and Reus 1996
Wang et al. 1999	U.S. Corn Belt	corn	N2O emissions	Yes	IPCC 1996 tier 1 method for direct and indirect N emissions
Wang et al. 2007	U.S. Corn Belt	corn	N2O emissions	Yes	GREET 1.6 (IPCC Tier 1)
Wu et al. 2006	U.S. Corn Belt	corn	N2O emissions	Yes	GREET 1.6 (IPCC Tier 1)