Greenhouse gas balance of cellulosic biofuel

Understanding the importance of nitrous oxide emissions from soils

Authors
Andrew McGowan[1], Aavudai Anandhi Swamy[2], Charles W. Rice[2]
[1]I-STAR Bioenergy IGERT, Department of Agronomy, Kansas State University, amagoo@k-state.edu
[2]Department of Agronomy, Kansas State University
Kansas State University

Background

27%

The transportation sector contributes around **27 percent** of total greenhouse gas emissions in the U.S. The substitution of fossil fuels with cellulosic biofuels has been proposed as one strategy to reduce greenhouse gas emissions in this sector. Accurately estimating the greenhouse gas (GHG) balance of cellulosic biofuels is critical to understanding biofuel's ability to reduce emissions.

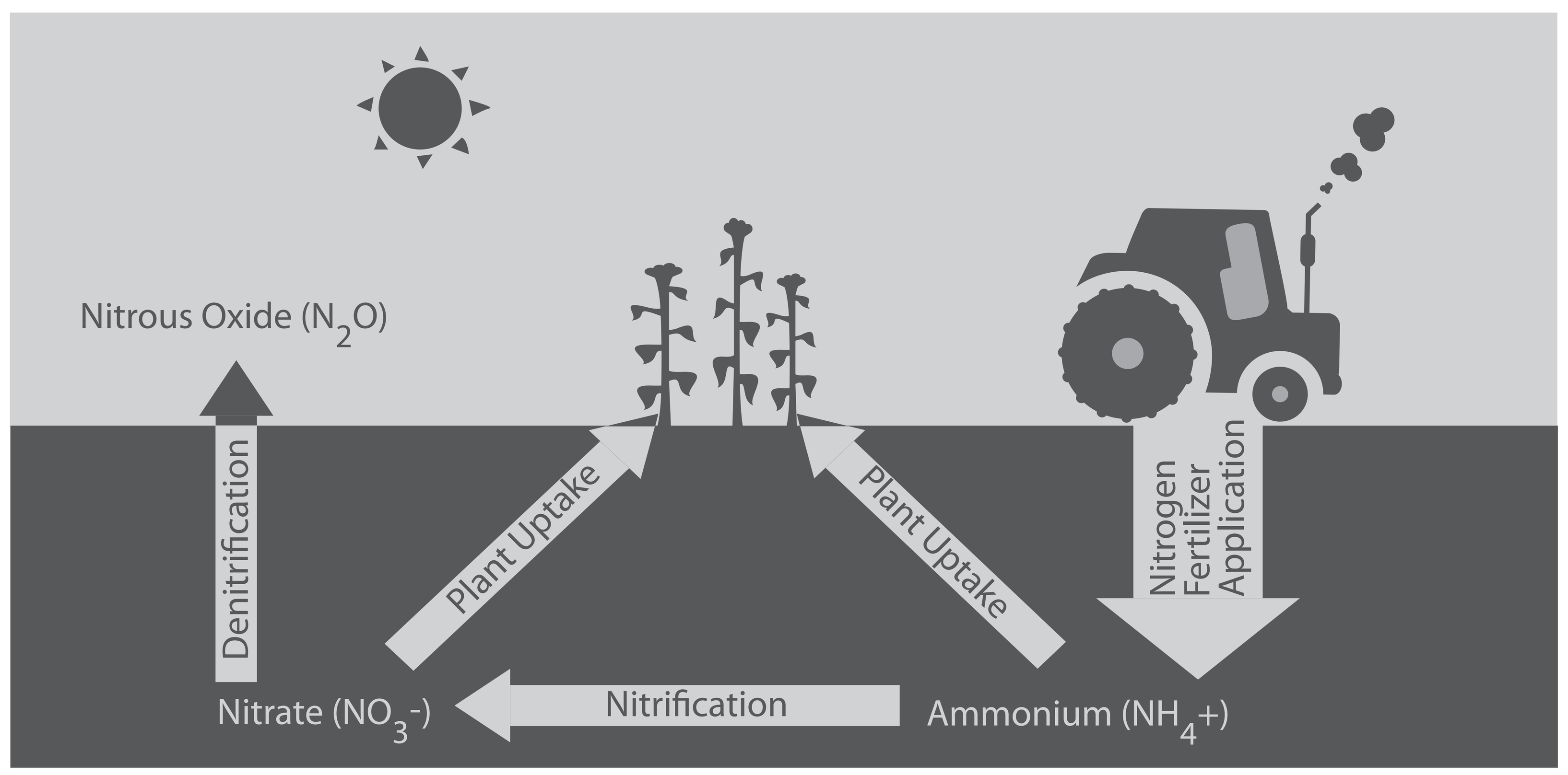


Diagram illustrating the flow of nitrogen fertilizer in agricultural soils. Two common fates of fertilizer nitrogen are uptake by plants and conversion to nitrous oxide by soil microorganisms.

298x

- Nitrous oxide (N_2O) has a global warming potential **298 times** greater than carbon dioxide.

- Nitrous oxide production is mediated by soil microorganisms, which can reduce nitrate to nitrous oxide under anaerobic soil conditions.
- N_2O emissions vary greatly over time and space, being dependent upon factors like nitrogen fertilizer rates, crop type, soil texture, land use and climate.
- High variability in N_2O emissions causes high uncertainty in estimates of N_2O in Life Cycle Assessment (LCA).
- Few studies have measured N_2O emissions from cellulosic biofuel crops.

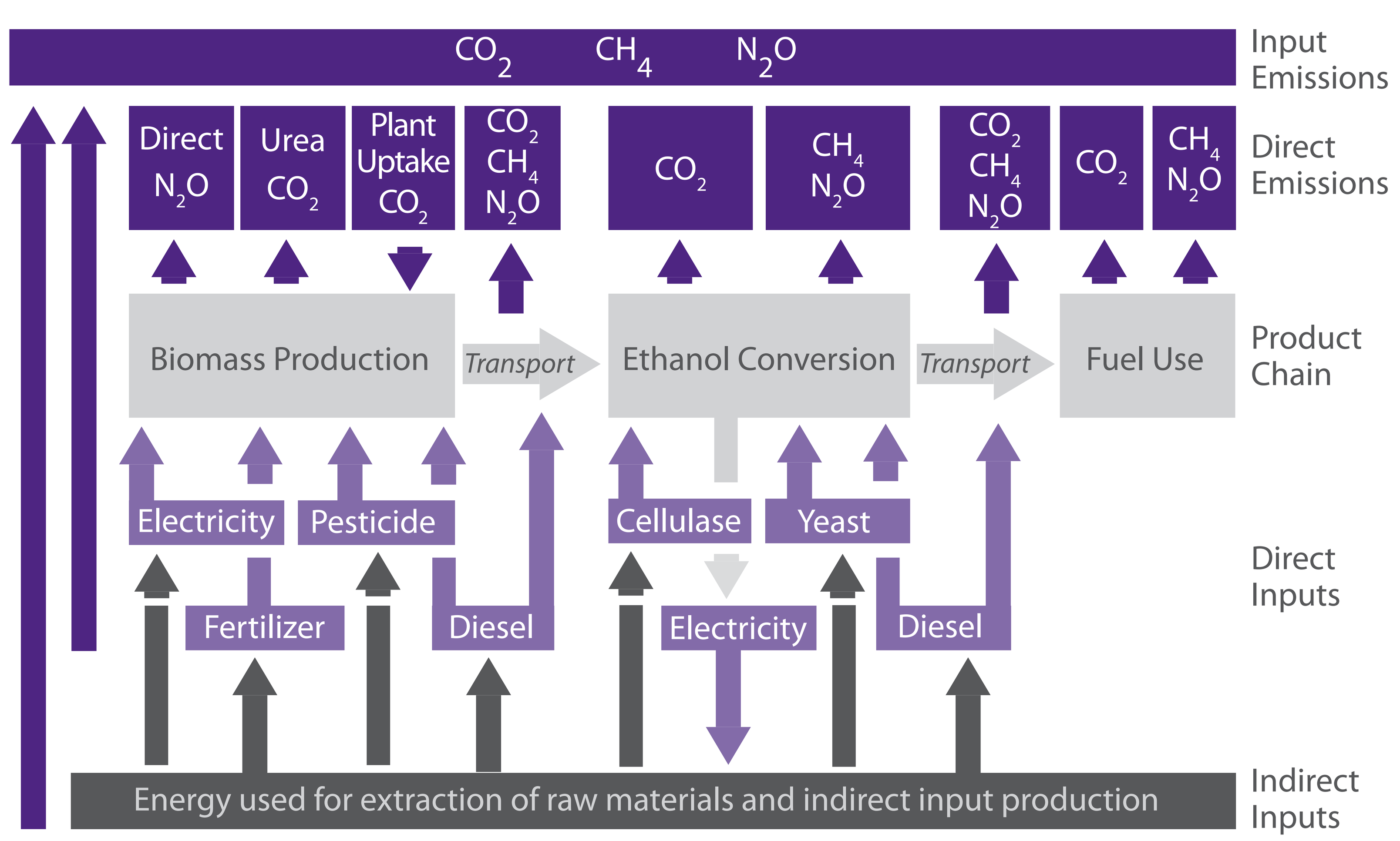
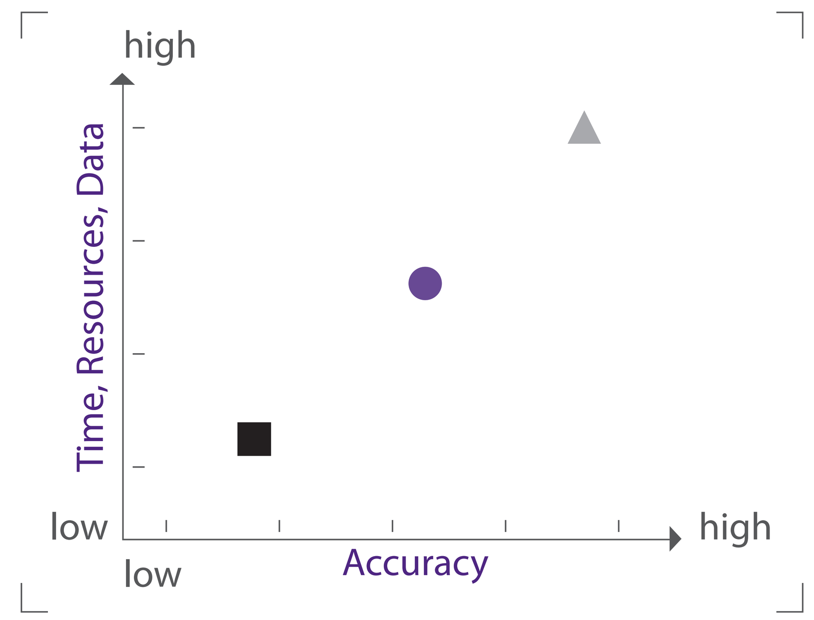


Diagram of LCA model used in this study to simulate GHG emissions from cellulosic ethanol

- LCA is an environmental accounting method that has been widely used to quantify GHG balance of different biofuels.
- LCAs of biofuels generally include GHG emissions from the production and transportation of the feedstock, conversion of the feedstock to biofuel, fuel transportation and distribution and tailpipe emissions.

Dilemma

N_2O Accounting



A variety of methods can be used to estimate N_2O emissions in LCA.

■ **Emission Factors:** Most commonly used estimate in LCA. Most assume a certain fraction of fertilizer nitrogen is lost as N_2O. A common example is the IPCC Tier 1 Protocol.

● **Process-based models:** Generate estimates of N_2O emissions that account for differences in drivers behind N_2O production. Not commonly used because greater knowledge and data inputs are required.

▲ **Field measurements:** Not practical for widespread use in LCA because of tremendous time, energy and resources required. However, they are necessary for verification of N_2O models.

Objectives

Measure

Measure the cumulative N_2O flux from soils of prospective energy crop systems for Kansas

Compare

Compare measured fluxes to common emission factors

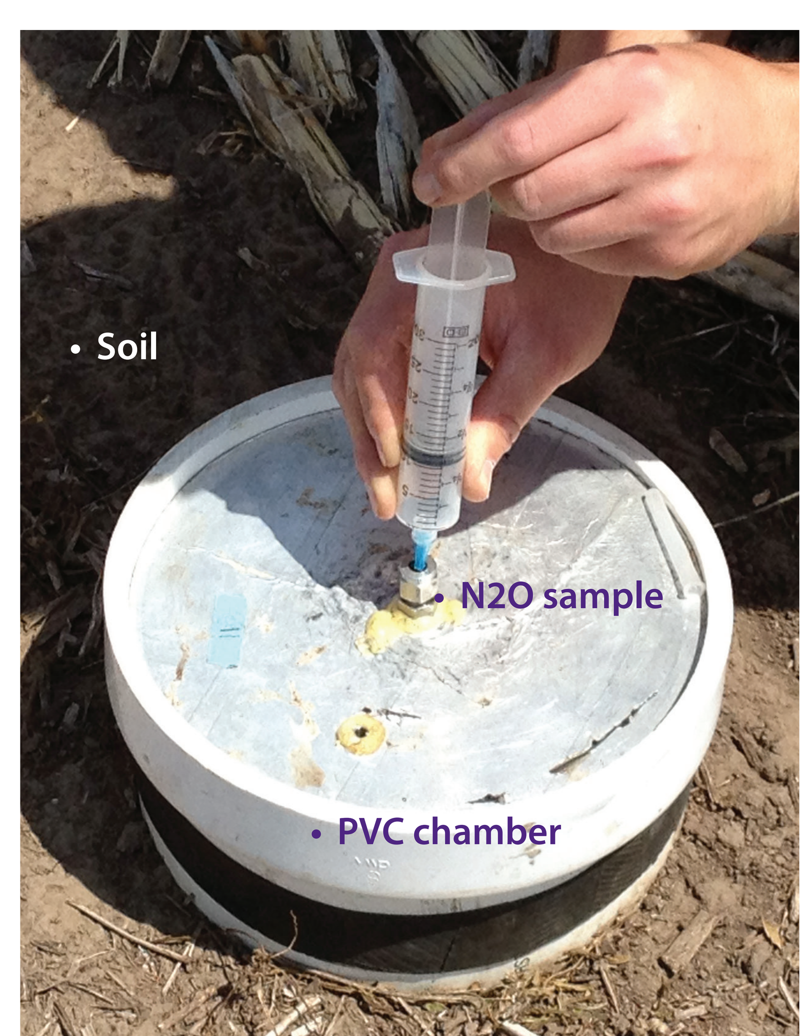
Determine

Determine how measured emissions and emission factor estimates impact the well-to-wheel lifecycle GHG balance of cellulosic ethanol

Methods

Nitrous oxide measurements

- N_2O samples were collected weekly from soils in the field using vented PVC chambers from spring 2011 to spring 2012.
- N_2O concentrations were determined by gas chromatography.



Life cycle assessment

- Used a modified version of GREET 2012 life cycle analysis program to model the GHG balance of ethanol in E10 (10 percent ethanol, 90 percent gasoline) and gasoline.
- LCA GHG results reported as CO_2-equivalents emitted from production, transport and use of ethanol required to transport a passenger car one kilometer.
- GREET fertilizer rates and biomass yields were modified to match those of crops measured in this study.

Simulated Life cycle:
- Cellulosic ethanol produced from fermentation with co-production of electricity.
- 2005 gasoline (35 percent reformulated, 65 percent conventional gasoline).

Three simulations run for each cellulosic ethanol feedstock, using different estimates for N_2O emissions:
- IPCC Tier 1 protocol emission factor (1 percent of N applied).
- Emission factor of 4 percent of N applied.
- N_2O emissions measured in this study.

Research site

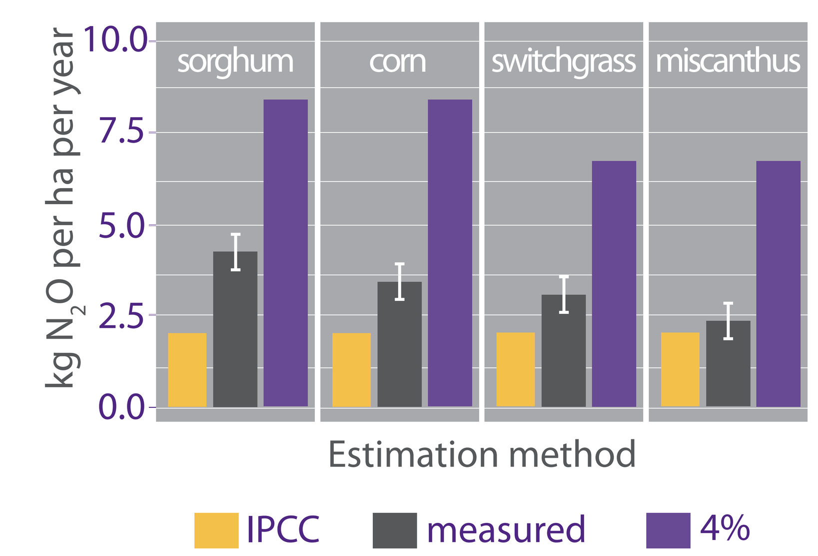
This project is being conducted on a long-term bioenergy crop study initiated in 2007, located on the Kansas State University Agronomy North Farm in Manhattan, Kan. It includes the following biofuel crops:

- **Annuals:** corn (Zea mays L.) and photoperiod sensitive sorghum [Sorghum bicolor (L.) Moench] in two-year rotation with soybeans (Glycine max).
- **Perennials:** switchgrass (Panicum virgatum L.) and miscanthus (Miscanthus x giganteus).

Yields are measured and 100 percent of crop residue is removed at the end of every growing season to simulate harvest for biofuel production. In 2011, 167 kilograms of nitrogen/ha/year were applied to all crops split into three applications.

Results

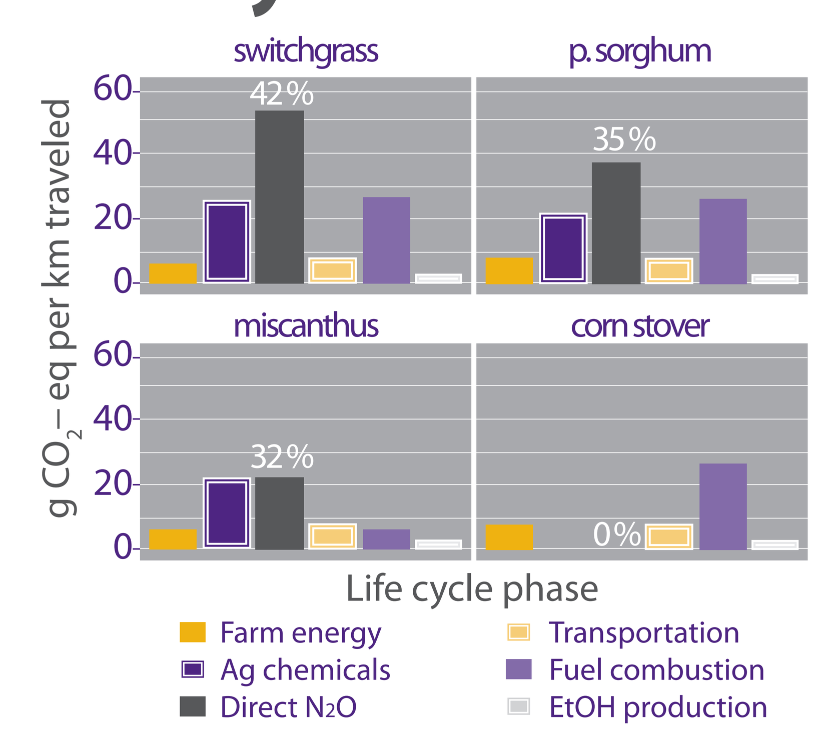
Nitrous oxide emissions



Total annual flux estimated using the IPCC Tier 1 Protocol (IPCC), the total measured emissions and an emission factor of 4% from soils in photoperiod sensitive sorghum, corn, switchgrass and miscanthus.

Key findings
- Large quantities of nitrous oxide were emitted from the soils in this study.
- Measured N_2O fluxes varied greatly from the fluxes predicted by the two emission factors.

Life cycle assessment



Greenhouse gas emissions from different sources in the life cycle of cellulosic ethanol in E10 from photoperiod sensitive sorghum, corn stover, switchgrass and miscanthus. White numbers represent the percent of total GHG emissions from measured emissions.

Key findings
- N_2O represented a major portion of the life cycle GHG emissions of ethanol, making up as much as **42 percent** of the emissions.

Discussion

- N_2O emissions from soils can have a large impact on the greenhouse gas balance of cellulosic ethanol.
- In this study, commonly used emission factors did not accurately predict N_2O emissions. This caused large differences in LCA GHG emissions (data not shown).
- These results suggest that more complex methods of estimating N_2O emissions, such as process-based models, should be utilized for LCAs of cellulosic biofuel.

Future Work

- Develop parameters for cellulosic biofuel crops in the process based model DNDC.
- Use DNDC to estimate the N_2O fluxes from the crops in this study.
- Incorporate spatial crop and soil data with DNDC to model N_2O emissions over different spatial scales.

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