Nitrous oxide emissions in bioenergy cropping systems: Implications for life cycle assessment

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Introduction

The 2007 Energy Independence Security Act (EISA) mandates the production of 80 billion liters per year of advanced biofuel, including cellulosic ethanol, by 2022. EISA requires cellulosic biofuels to have Life Cycle Analysis (LCA) greenhouse gas (GHG) emissions 60% below those of gasoline/diesel. Therefore, it is important to identify dedicated crops for biofuel feedstock that provide maximum biomass with minimal GHG emissions. Nitrous oxide (N_2O) is a potent GHG, having a global warming potential (GWP) 298 times that of carbon dioxide. The Intergovernmental Panel on Climate Change estimates agriculture contributes 65-80% of total anthropogenic N_2O emissions. Therefore, accurate estimates of N_2O emissions from soils under different energy crops are essential in evaluating the lifecycle GHG balance of biofuel produced from different feedstocks.

Objectives

- Measure the cumulative N_2O flux from soils of prospective energy crop systems
- Determine how measured emissions impact the well-to-wheel lifecycle GHG balance of ethanol compared to IPCC Tier 1 protocol estimates

Research site

- Study initiated in 2007, located on the Kansas State University Agronomy North Farm in Manhattan, KS
- Soil: Ivan, Kennebec, and Kahola silt loams (fine-silty, mixed, superactive, mesic Cumulic Hapludolls)
- Randomized complete block design with four replicates
- Plant species
  - Annuals: corn (*Zea mays* L.) and photoperiod sensitive sorghum (*Sorghum bicolor (L.) Moench)* in 2 year rotation with soybeans (*Glycine max*)
  - Perennials: switchgrass (*Panicum virgatum* L.) and miscanthus (*Miscanthus x giganteus)*
  - N fertilizer: 179 kg-N/ha/y applied to all crops split into three applications
  - 100% of crop residue removed at the end of the growing season

Fig 1. Research plots

Fig 2. Sampling N_2O in field

Nitrous oxide measurements

- N_2O samples were collected weekly or after rainfall events from soils in the field using vented PVC chambers from Spring 2011 to Spring 2012
- N_2O concentrations determined by gas chromatography
- N_2O flux also estimated using IPCC Tier 1 protocol (assumes 1% of fertilizer and residue N emitted as N_2O)

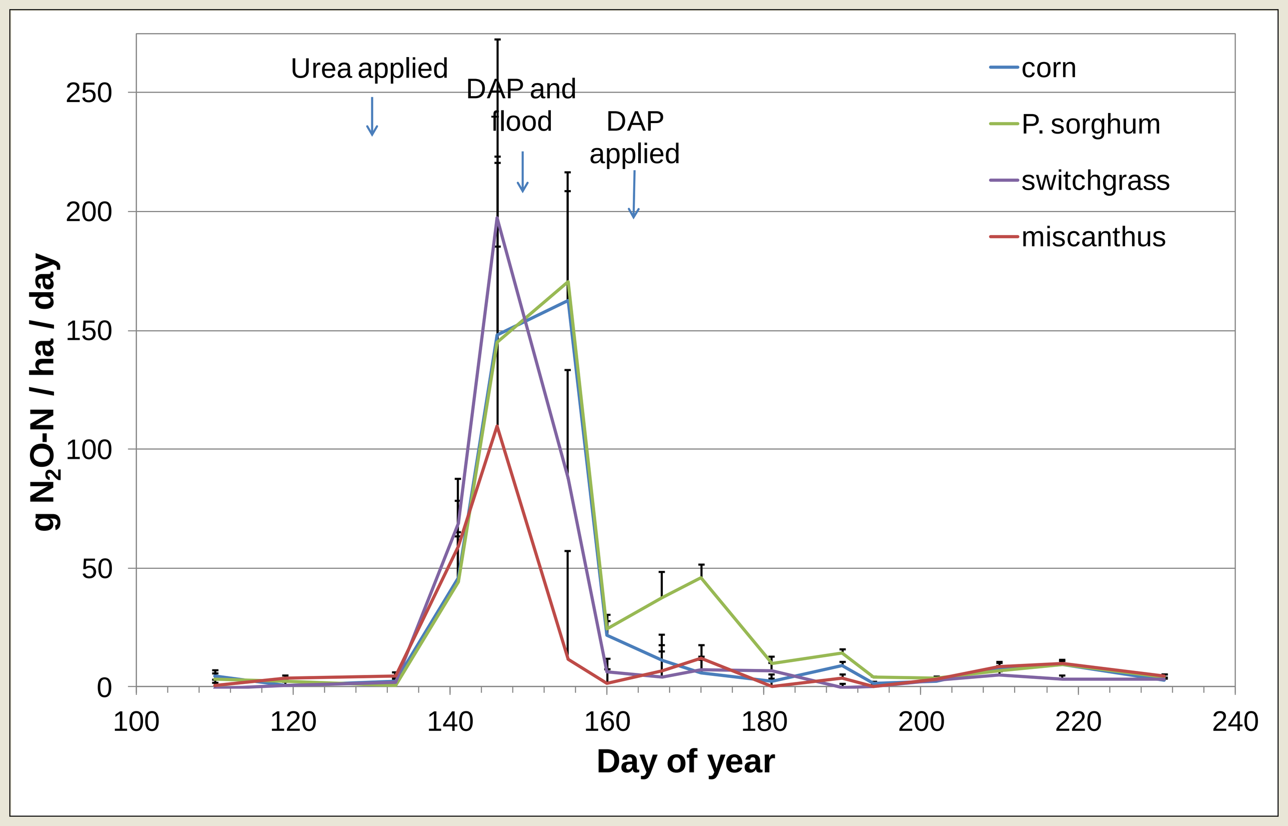

Fig 3. Daily N_2O flux from soil in corn, photoperiod sensitive sorghum, switchgrass and miscanthus. Blue arrows indicate the date of urea application, of diammonium phosphate (DAP) application, and of a flooding event that occurred on the research plots.

Nitrous oxide continued

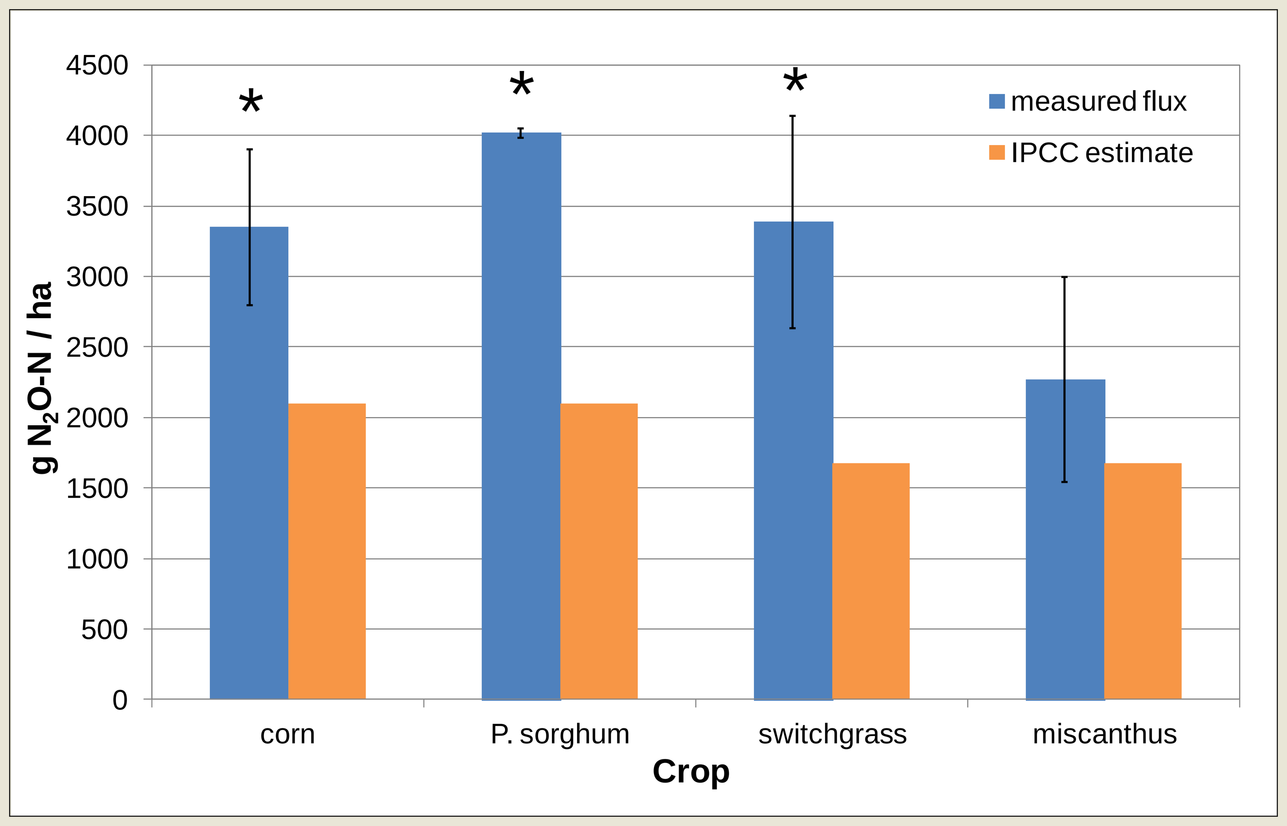

Fig 4. Cumulative N_2O flux (g N_2O-N/ha) from soil in corn, photoperiod sensitive sorghum, switchgrass and miscanthus from Spring 2011 to Spring 2012. Measured flux for each crop is compared with the N_2O flux predicted by the IPCC Tier 1 estimate. Asterisks indicate significant difference between measured flux and IPCC estimate ($p<0.10$).

Key findings: Nitrous oxide

- Highest daily fluxes were between May 13 and June 9, during which 67% of total N_2O flux occurred
- Measured N_2O fluxes varied greatly from the fluxes predicted by the IPCC Tier 1 protocol

Life cycle assessment

- Used GREET 2012 life cycle analysis program to model well-to-wheels (W2W) GHG emissions ethanol in E10 (10% ethanol, 90% gasoline) and for 2005 gasoline
- W2W emissions reported as GHG emitted from production, transport and use of one mega joule (MJ) of fuel in a passenger car
- GREET fertilizer rates and yield parameters were modified to match crops in this study (see table 1)
- Ran two simulations for each feedstock: one using the IPCC Tier 1 protocol for direct N_2O emissions and one using measured N_2O (see Table 1)

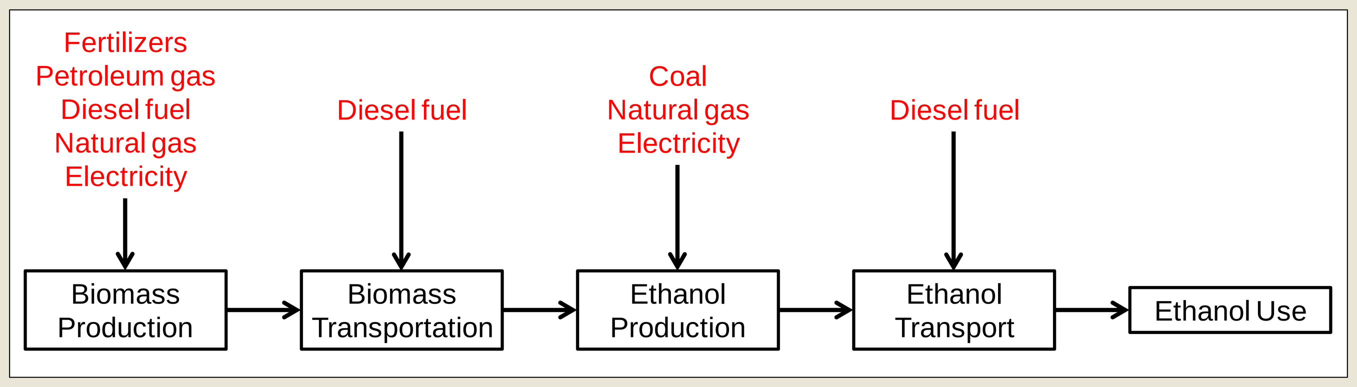

Fig 5. Flow diagram of well-to-wheels lifecycle of ethanol in GREET. Black boxes indicate primary phases in the production of ethanol. Red lettering indicates key material inputs that are included in the lifecycle model. Well-to-wheels GHG emissions are expressed as a function of one MJ fuel used in a mid-sized passenger car.

LCA inputs and assumptions

- Simulated life cycles:
  - Cellulosic ethanol produced from fermentation
  - Ethanol from corn starch (88.6% dry milling, 11.4% wet milling)
  - 2005 gasoline (35% reformulated, 65% conventional gasoline)
  - Assumed no indirect land use change

Input	Corn grain (per bushel)	Corn stover (per dry ton)	P. sorghum (per dry ton)	Switchgrass (per dry ton)	Miscanthus (per dry ton)
g direct N2O (measured)	39	0	271	382	154
g direct N2O (IPCC)	13.2	0	71.8	48	39
g nitrogen	1322	0	7183	10688	8627
g P2O5	597	0	3248	4833	3901
g K2O	0	0	0	0	0
g CaCO3	0	0	0	0	0
Energy use (Btu)	9608	188500	204693	123700	131476
Ethanol yield (gallons)	2.78	90	90	90	90
g CO2 from LUC	0	0	0	0	0

Table 1. Key inputs used in simulations.

Life cycle assessment results

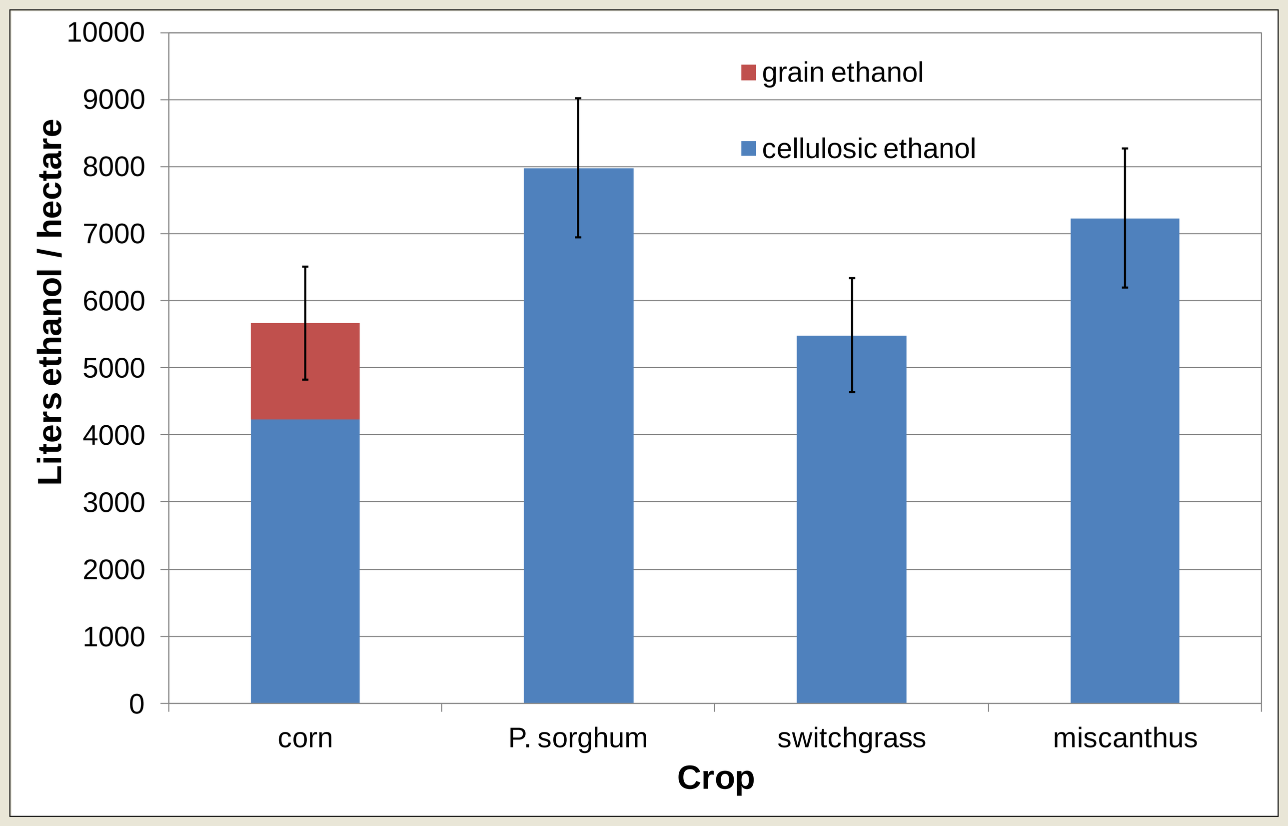

Fig 6. Potential volumetric ethanol yields from corn, photoperiod sensitive sorghum, switchgrass and miscanthus expressed on a per hectare basis, based on 2011 yields. The blue bars represent ethanol produced from biomass, and the red bar represents ethanol produced from grain. No significant difference in ethanol yield was found between crops ($p=0.05$).

Feedstock used for ethanol production	% of total CO_2 – eq / MJ from direct N_2O emissions (measured N_2O)	% increase in total CO_2 – eq / MJ from measured N_2O relative to IPCC N_2O
Corn grain	50.8%	15.6%
P. sorghum	51.3%	32.0%
Switchgrass	55.8%	45.6%
Miscanthus	61.5%	7.9%

Table 2. Left column shows percentage of W2W GHG emissions (in CO_2 – equivalents per MJ) of ethanol in E10 blends derived from direct N_2O emissions. Right column shows percent change in W2W GHG emissions when measured N_2O is used as input in GREET instead of IPCC N_2O estimate.

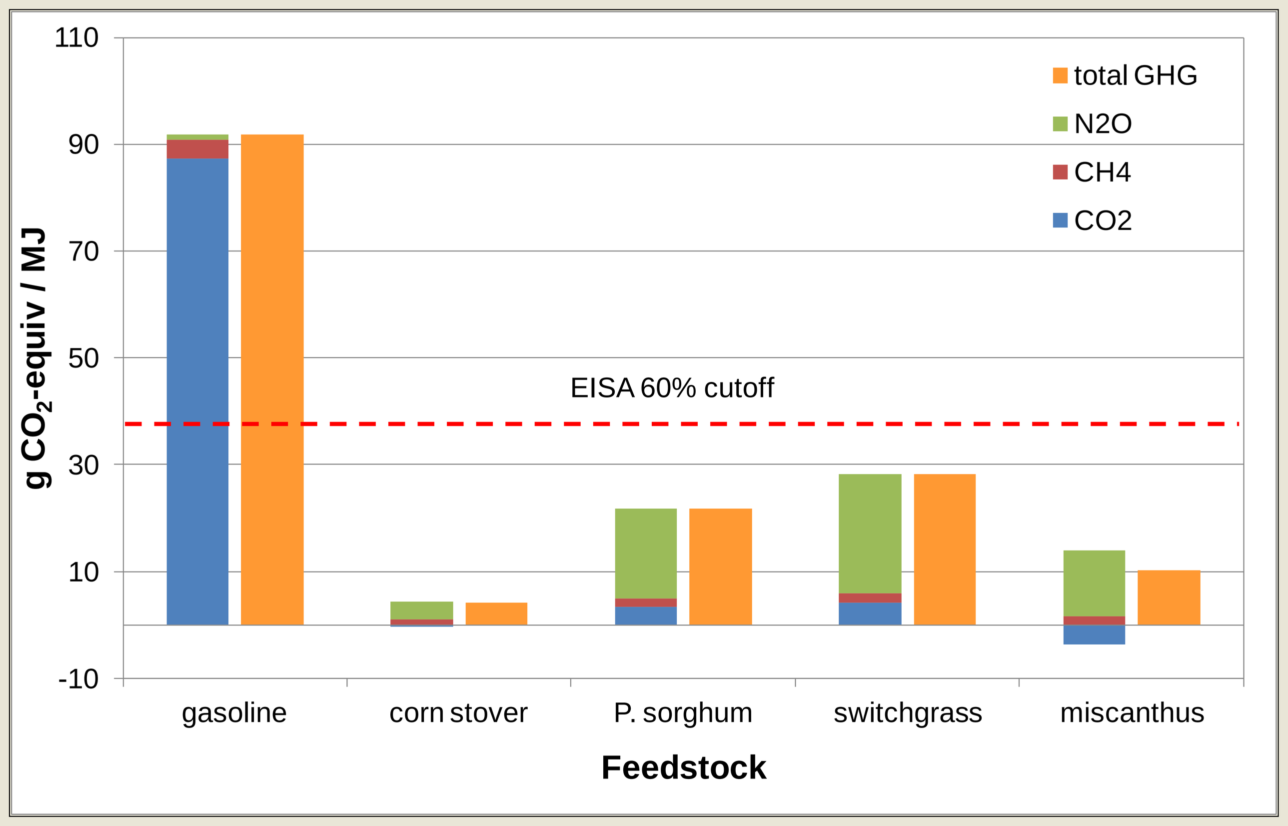

Fig 7. W2W GHG emissions of 2005 gasoline and ethanol in E10 blends from different feedstocks using measured N_2O emissions. Green, red and blue bars represent contribution of N_2O, CH_4 and CO_2 to total GHG emissions, respectively. Orange bar represents net GHG emissions. Dashed red line represents the EISA cutoff of 60% reduction in LCA GHG emissions compared to 2005 gasoline.

Key findings: Life cycle assessment

- In 2011, no significant differences in ethanol yields were observed between crops
- Ethanol from all four feedstocks had well-to-wheel GHG emissions less than 60% those of 2005 gasoline, excluding effects from indirect land use change
- N_2O represented a major portion of the W2W GHG emissions of ethanol, making up as much as 61.5% of the emissions
- For several feedstocks, using measured N_2O emissions in GREET increased W2W GHG emissions, relative to W2W emissions using the IPCC protocol
- Reduction of N_2O emissions through improved fertilizer management could help reduce the GHG footprint of cellulosic ethanol

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