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 (N₂O) 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 N₂O emissions. Therefore, accurate estimates of N₂O 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 N₂O 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 Hapudollus)
- 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 (Panico virgatum L) and miscanthus (Miscanthus 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

Nitrous oxide measurements
- N₂O samples were collected weekly or after rainfall events from soils in the field using vented PVC chambers from Spring 2011 to Spring 2012
- N₂O concentrations determined by gas chromatography
- N₂O flux also estimated using IPCC Tier 1 protocol (assumes 1% of fertilizer and residue N emitted as N₂O)

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 joul (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 N₂O emissions and one using measured N₂O (see Table 1)

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

Key findings: Nitrogen oxide
- Highest daily fluxes were between May 13 and June 9, during which 67% of total N₂O flux occurred
- Measured N₂O fluxes varied greatly from the fluxes predicted by the IPCC Tier 1 protocol

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
- N₂O 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 N₂O emissions in GREET increased W2W GHG emissions, relative to IPCC protocol
- Reduction of N₂O emissions through improved fertilizer management could help reduce the GHG footprint of cellulosic ethanol

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