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Research paper

Conversion of grazed pastures to energy cane as a biofuel feedstock alters the emission of GHGs from soils in Southeastern United States

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ABSTRACT

The cultivation of energy cane throughout the Southeastern United States may displace grazed pastures on organic soil (Histosols) to meet growing demands for biofuels. We combined results from a field experiment with a biogeochemical model to improve our understanding of how the conversion of pasture to energy cane during early crop establishment affected soil GHG (CO_2, CH_4, and N_2O) exchange with the atmosphere. GHG fluxes were measured under both land uses during wet, hot and cool, dry times of year, and following a fertilization event. We also simulated the impact of changes in precipitation on GHG exchange. Higher fertilization of cane contributed to greater emission of N_2O than pasture during warmer and wetter times of the year. The model predicted that energy cane emitted more nitrogen than pasture during simulated wetter than drier years. The modeled emission factor for N_2O was 20 to 30-fold higher than the default value from IPCC (1%), suggesting that the default IPCC value could dramatically underestimate the consequences of this land conversion on the climate system. Predicted soil CH_4 and CO_2 fluxes were higher in pasture than energy cane, and this difference was not affected by increasing precipitation. Model simulations predicted that soils under first year cane emit more GHGs than pasture, particularly during wet years, but this difference disappeared two years after energy cane establishment. Our results suggest that management practices may be important in determining soil GHG emissions from energy cane on organic soils particularly during the first year of cane establishment.

1. Introduction

Land use change – transforming land cover or changing management practices – impacts climate by affecting the emission of greenhouse gases (GHGs; N_2O, CH_4 and CO_2) from ecosystems [1–3]. The need for alternative energies is accelerating the conversion of marginal land and managed ecosystems to biofuel crops [4], and these changes are likely to impact the exchange of GHGs with the atmosphere [5].

Currently, most renewable fuel in the US is derived from corn ethanol; however, the Renewable Fuel Standard mandates that 60.6 billion L of renewable fuels must be supplied by ligno-cellulosic sources or other advanced renewable fuels by 2022. Crops grown in the Southeastern USA will contribute to meet the demand for renewable fuels from ligno-cellulosic feedstocks [6,7]. Because of its high biomass yields [8,9], energy cane (*Saccharum* spp. L), a high-cellulose producing variety of sugarcane, is a promising perennial crop for ligno-cellulosic fuel production that can be grown in regions of the Southeastern US such as Florida [10–12].

In the subtropical and tropical regions of Florida, grazed pastures, which cover > 30% of the total land area (170405 km^2) [13], will potentially be replaced by energy cane plantations. Most of these grazed pastures are planted in the highly organic soil, Histosols [14–17]. The cultivation of Histosols is likely to emit substantial amounts of carbon and nitrogen to the atmosphere [18,19], although the impact of this conversion on climate is uncertain [20–22].

The changes in vegetation and management associated with converting grazed pasture to energy cane plantations could alter the emission of GHGs from soils, especially following cultivation after land conversion [11,23–26]. For example, soils are usually tilled during the establishment of new crops, which can accelerate soil organic matter mineralization increasing CO_2 and N_2O losses from soils [26,27]. Once energy cane is established on land previously occupied by grazed

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pastures, it will likely have higher yields and litter compared with pastures where grazers forage on plant biomass [23,28]. However, long-established grazed pastures will likely have higher root biomass than energy cane particularly during early establishment. Maximizing the productivity of energy cane will also require fertilization and irrigation [21], and the removal of grazers in energy cane plantations will eliminate dung and urine deposition [29].

Precipitation is a main driver of GHG emissions and will interact with land use change to modulate emission [30–32]. Most of Florida is sub-tropical (Cfa Köppen-Geiger climate, humid subtropical climate [33]) with distinct wet and dry seasons, and as in many subtropical and tropical regions, it has large interannual variation of precipitation which is predicted to become even larger during this century [34,35]. The influence of this land conversion on climate might be greater during wetter than drier times of the year as well as during wetter than drier years as increased precipitation enhances soil GHG emissions.

Here, we investigated how the conversion of pasture to energy cane affects the emission of GHGs from highly organic Histosols in Florida during early establishment by combining results from a field experiment and a mechanistic biogeochemical model. We hypothesize that the conversion of pasture to energy cane will increase the emission of N_2O, CH_4, and CO_2 from soils, particularly during warmer and wetter times of year. To test this hypothesis, we measured GHG fluxes from soils under pasture and energy cane during wet, hot and during cool, dry times of year and following a fertilization event. The fertilization event occurred during the dry season as typical for the cultivation of energy cane. We also examined whether changes in precipitation affect the magnitude of impact of land conversion on soil GHG emissions by simulating fluxes during wetter and drier years using the process-based biogeochemical model DayCent (v.4.5) [36,37].

2. Material and methods

2.1. Study site

Measurements were made in 2011, 2012 and 2013 on private land in Highlands County, FL (27°21′49″ N, 81°14′56″ W). This area has a subtropical climate with two distinct seasons, a wet, hot season from June through September, with relatively dry and cool conditions during the rest of the year. Mean annual precipitation (1980–2012) was 1310 mm, with two-thirds of total annual precipitation falling from June to September [38]. Mean annual temperature (1980–2012) was 22 °C [38].

To investigate how the conversion of pasture to energy cane influenced point soil GHG fluxes we established experimental plots (300 m^2) in commercial energy cane plantations and nearby pastures (< 1 km). The experiment consisted of 12 plots, providing replicates of each of the following three land uses: 1) grazed pasture (GP); 2) energy cane planted in 2010 and harvested in Nov 2011 (EC-2010); and, 3) energy cane planted in 2011 (EC-2011) (Table 1). Plots within each of the four replicates of each land use were 250 m apart.

The dominant vegetation at the GP sites was bahiagrass (*Paspalum notatum* Flueggé) that served as forage for cattle (*Bos taurus* L.) (Table 1). Bahiagrass is a C_4 perennial grass that was first introduced in Florida in 1913 and covers approximately 8094 km^2 of the state [39]. The GP sites were drained during 1960–1980, and were established in 1981. Since their establishment, the sites have been grazed by cattle at stocking rates of 0.01 km^{-2} (or 1 ha^{-1} [23]). The GP sites have not been fertilized in the last 10 years. Prior to land conversion, the energy cane sites were managed identically to the GP sites. Soils in energy cane plantations and pastures were hyperthermic Terric Haplosaprists that belong to the Histosol order. Soils have a bulk density of 0.5 g cm^{-3}, and a carbon and nitrogen content in the top 0.3 meters of 12.35 ± 3.0% and 0.96 ± 0.3%, respectively.

Energy cane plantations were established according to typical agronomic practices for this region (Fig. 1 [15]). Six months before planting energy cane, soils were tilled to a depth of 0.25 m to 0.30 m. After tillage, beds were kept weed free until planting by using an herbicide (Atrazine 50 FW; applied 5 and 1 months before planting at a rate of 0.2 g m^{-2}). Three-budded cane stalk cuttings were hand planted at a row spacing of 1.5 m and with 4 cm to 6 cm distance between stalk cuttings.

Table 1
DayCent simulation site characteristics and model parameters that vary or do not vary by land use (GP and energy cane).

Parameters that do not vary by land use	
Latitude, Longitude	27°21′49″ N, 81°14′56″ W
Soil type	Histosol
Soil carbon, nitrogen (%)	12.35 ± 3.0%; 0.96 ± 0.3%
Soil bulk density	0.5 g cm-3
Site history	Before 1982, mix of perennial grasses species From 1982 to 2010, warm season pasture with grazing. After Nov, 2010 wetter and drier years simulations were run on GP and energy cane for two full years
Historical climate record	Daily climate from 1982-2010 with mean annual precipitation of 1270 mm, and mean annual temperature of 22 °C.
Simulated wetter year	1145 mm of water during wet season, 296 mm of water during dry season Average annual temperature of 22 °C
Simulated drier year	824 mm of water during wet season, 296 mm of water during dry season Average annual temperature of 22 °C

Parameters that vary by land use	GP	Energy cane
Symbiotic N fixation	Yes	No
Non-symbiotic N fixation	Yes	Yes
Grazing	Yes	No
Maximum C:N	120	120
Minimum C:N	70	70
Maximum belowground allocation (%)	30	30
Minimum belowground allocation (%)	20	5

Energy cane typically is fertilized annually near the end of the dry season [39]. The timing of fertilization varied between different energy cane stands (Fig. 1). At each fertilization event, 2.8 g m^{-2} of nitrogen as ammonium sulfate was applied. Dolomite ($CaMg(CO_3)_2$) was applied to energy cane plantations before the establishment of the crops at a rate of 9.1 g km^{-2}. In addition to natural rainfall, energy cane sites were irrigated with a linear move sprinkler system equivalent to 305 mm of additional precipitation applied over the canopy from January to June.

The EC-2010 crops were harvested by hand between 5 cm and 10 cm above the ground level, one year after planting using machetes in Nov 2011 (Fig. 1). Only aboveground biomass was harvested, leaving belowground biomass intact. These crops were not tilled after harvest, and post-harvest residues were left on the field.

2.2. Soil GHG measurements

To capture the effect of climate variation, soil N_2O, CH_4, and CO_2 fluxes were measured three times during the wet-hot season (July 11, 2011, September 4, 2011, and June 14, 2012), and twice during the dry-cool season (December 7, 2011 and March 1, 2011) (Fig. 1). At each sampling period, measurements were made between 11:00 and 15:00 (UTC - 5) over 3 days to 4 days. Measurements at each plot for each land use were sampled randomly at each sampling period to minimize confounding effects on soil GHG fluxes resulting from daily variability.

An experiment was also conducted to determine soil GHG emissions following fertilization. Fluxes of N_2O, CH_4, and CO_2 were measured in a total of 16 unfertilized plots and 16 fertilized plots at both GP and EC-