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Short communication

Growing season greenhouse gas flux from switchgrass in the northern great plains☆

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ABSTRACT

Switchgrass (*Panicum virgatum* L.) is being evaluated as a bioenergy crop for the northern Great Plains. Field measurements of CO_2, CH_4, and N_2O flux are needed to estimate the net greenhouse gas (GHG) balance of this biofeedstock. The study objective was to determine effects of recommended Nitrogen (N) fertilization (67 kg ha^{-1} of N applied) and unfertilized switchgrass on growing season soil-atmosphere CO_2, CH_4, and N_2O flux using static chamber methodology. Mean hourly CO_2 flux was greatest during periods of active switchgrass growth and was similar between N fertilizer treatments ($P = 0.09$). Mean hourly N_2O flux was consistently greater under N fertilization than without N throughout the growing season. Overall, N fertilization of switchgrass affected cumulative growing-season N_2O flux (27.6 kg ha^{-1} ± 4.0 kg ha^{-1} vs. 86.3 kg ha^{-1} ± 14.3 kg ha^{-1} as CO_2 equivalents (CO_2eq) for 0 kg ha^{-1} and 67 kg ha^{-1} of N applied, respectively; $P < 0.01$), but not cumulative CO_2 or CH_4 flux ($P = 0.08$ and 0.51, respectively). Aboveground biomass production was greater with N application (6.8 Mg ha^{-1} ± 0.5 Mg ha^{-1} dry matter) than without N (3.2 Mg ha^{-1} ± 0.5 Mg ha^{-1}) ($P < 0.05$). Net greenhouse gas intensity (GHGI; kg GHG flux kg^{-1} harvest yield as CO_2eq) for switchgrass production was similar between N treatments (0.71 vs. 0.44 for 0 kg ha^{-1} and 67 kg ha^{-1} of N applied, respectively; $P = 0.18$).

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1. Introduction

Global energy demands have led to concerns about economic costs, sustainability, and environmental consequences from increased petroleum dependence to meet future transportation needs. Biofuels are seen as a near-term solution to reduce reliance on petroleum based transportation fuels in the United States and to potentially reduce greenhouse gas (GHG) emissions. The northern Great Plains region is expected to be economically viable for bioenergy production for perennial, herbaceous crops like switchgrass [1]. A sustainable perennial bioenergy system will require maximizing energy

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Abbreviations: Carbon dioxide, CO_2; Global warming potential, GWP; Greenhouse gas, GHG; Greenhouse gas intensity, GHGI; Methane, CH_4; Nitrous oxide, N_2O; Water-filled pore space, WFPS.

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output per unit of land, maximizing nutrient use efficiency, and minimizing GHG emissions.

Nitrogen is the primary limiting nutrient for C_4 perennial grasses requiring fertilizer for optimal yield production [2]. Inorganic N fertilizer is a major GHG contributor based on large fossil fuel energy requirements in the production phase and resultant N_2O soil emissions [3]. While numerous studies have evaluated GHG emissions from perennial bioenergy crops using life cycle assessment [3–7], there is a lack of field data on GHG fluxes for perennial bioenergy crops. Quantifying GHG fluxes from perennial bioenergy systems will be critical in evaluating the sustainability of these systems. The objective of this study was to determine effects of N fertilization on growing-season soil-atmosphere CO_2, CH_4, and N_2O flux from established switchgrass stands in the northern Great Plains.

2. Material and methods

The experimental site was 1 km southwest of Mandan, ND (46°46′ N, 100°55′ W) on a Parshall fine sandy loam (coarse-loamy, mixed, superactive, frigid Pachic Haplustoll). Annual precipitation from 1913 to 2010 averaged 416 mm with >75% of the total precipitation occurring from April to September. Mean temperature from April to September is 15.5 °C with mean minimum and maximum monthly temperatures being −0.6 °C and 28.7 °C, respectively. Experimental treatments consisted of switchgrass plots (9.1 m × 9.1 m) fertilized with N (67 kg ha^{-1}) and unfertilized (0 kg ha^{-1}) switchgrass plots. Switchgrass cultivar 'Sunburst' was established in 2006 and annual anthesis harvest treatments were implemented in 2007. Urea (46-0-0) was applied on 14 June 2010 (Day of Year 165). Switchgrass plots were harvested using a self-propelled plot harvester (1.2 m cutting width × 6.4 m harvest length) with a mounted weigh box. Harvest height for the plot harvester was 8 cm. Switchgrass was harvested on 15 September for the 67 kg ha^{-1} of N applied plots and 29 September for the 0 kg ha^{-1} of N applied plots with both harvests occurring at the same maturity stage (panicle fully headed; endosperm hard). To determine dry matter percentage, biomass subsamples from harvested plots were collected and placed in a forced-air oven at 50 °C until a constant weight was reached.

2.1. *Gas flux methodology*

Flux concentrations of CO_2, CH_4 and N_2O were measured approximately every week using static chamber methodology as outlined by Hutchinson and Mosier [8] from 24 May to 14 September 2010. Anchors were placed in plots on 23 April and were not removed until study completion. Within each plot, gas samples were collected from duplicate two-part chambers, each consisting of a permanent polyvinyl chloride (PVC) pipe anchor (20.3 cm i.d.; 5 cm height) and a PVC cap (20.3 cm i.d.; 10.0 cm height) with a vent tube and sampling port. Gas samples from inside the chambers were collected with a 20 mL syringe at 0, 20, and 40 min after cap installation (approximately 10:30 each sampling day). After collection, gas samples were injected into 12 mL evacuated glass vials sealed with butyl rubber septa. Carbon dioxide, CH_4 and N_2O concentrations were measured by gas chromatography (Varian Model 3800; Agilent Technologies Inc., Santa Clara, CA) with an attached auto sampler. Each vial sample was auto injected into a 1 mL sample loop and routed through detectors of a ^{65}Ni electrocapture detector (ultra-pure 95% Argon and 5% CH_4 carrier gas), a thermal conductivity detector (ultra-pure He carrier gas), and a flame ionization detector (ultra-pure He carrier gas). The gas chromatograph was calibrated with commercial blends of CO_2 (369.7 and 1682.1 μL L^{-1}), CH_4 (2.0 and 10 μL L^{-1}), and N_2O (363.7 and 1682.1 μL L^{-1}) balanced in N_2 (Scott Specialty Gases; Trenton, NJ). The precision of analysis, expressed as a coefficient of variation for 10 replicate injections of both low and high concentration standards, was consistently <2% for all three gases.

Greenhouse gas flux was calculated from the change in concentration in the chamber headspace with time [8]. Calculated flux rates were evaluated to determine if the diffusion gradient was altered causing a curvilinear response for analyte concentration vs. time [8]. Cumulative gas flux was calculated by linearly interpolating data points and integrating the underlying area [9].

Soil water content was measured in the surface 12 cm of soil using a time-domain reflectometry technique (Campbell CS620 Hydrosense; Campbell Sci. Logan, UT) and soil temperature was measured at a 6 cm depth using a T-type thermocouple probe (Omega HH81A digital thermometer; Omega Inc., Stamford, CT). Three measurements of soil water content and one measurement of soil temperature were made within 45 cm of the anchors per plot during the 20 min gas sampling period. Soil water content values were converted to water-filled pore space (WFPS) using field-measured soil bulk density for the surface 10 cm [10].

2.2. *Data analyses*

Greenhouse gas emissions associated with the production, distribution, and application processes of fertilizer N (upstream energy) were included in net GHG flux from fertilized switchgrass [5]. Upstream GHG emissions as CO_2eq for urea fertilizer were estimated at 273 kg ha^{-1} [11]. Based on radiative forcing potential for a 100 year time span, CH_4 was multiplied by 25 and N_2O by 298 to calculate net GHG flux in mass equivalents of CO_2 [12]. Global warming potential (GWP) was calculated as the summation of the cumulative growing season CO_2, CH_4, and N_2O with CH_4 and N_2O reported in CO_2eq based on radiative forcing potential described above. Net greenhouse gas intensity (GHGI) was calculated as GWP divided by harvested biomass yields (Mg ha^{-1} CO_2eq) for each N treatment. Switchgrass aboveground biomass C concentration was estimated to be 444 g kg^{-1} [13].

Analysis of variance was conducted on hourly and cumulative GHG flux, GWP, GHGI, and aboveground biomass yield using PROC MIXED in SAS (SAS Institute Inc., Cory, NC) with replication (4 replications) considered a random effect and N treatments a fixed effect [14]. Sampling date was the within-subject factor and N treatment was the between-subject factor. Effects of N treatment, soil temperature, and WFPS on hourly GHG flux were evaluated using a repeated measures model using a time-series covariance structure where correlations decline over time [15]. Significance criterion was set at $P < 0.05$.

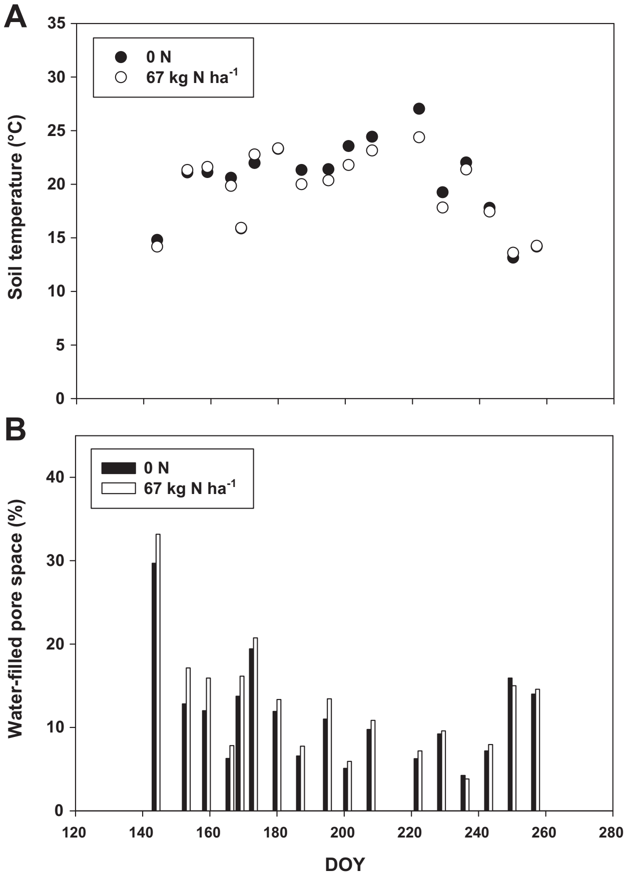

Fig. 1 – Soil temperature (A) and water-filled pore space (B) for fertilized switchgrass and unfertilized switchgrass managed for bioenergy in south central North Dakota.

3. Results and discussion

Mean daily air temperature averaged 19.1 °C from 24 April (DOY 144) to 15 September (DOY 258) with minimum and maximum temperatures of 10.5 °C and 29.7 °C, respectively. Total precipitation for the study period was 315 mm, with 38 d (33%) receiving detectable rainfall events. Fertilized switchgrass had slightly higher WFPS and lower soil temperature than unfertilized switchgrass (Fig. 1), but N treatment differences were statistically similar ($P = 0.2680$ and $P = 0.2463$) for WFPS and soil temperature, respectively.

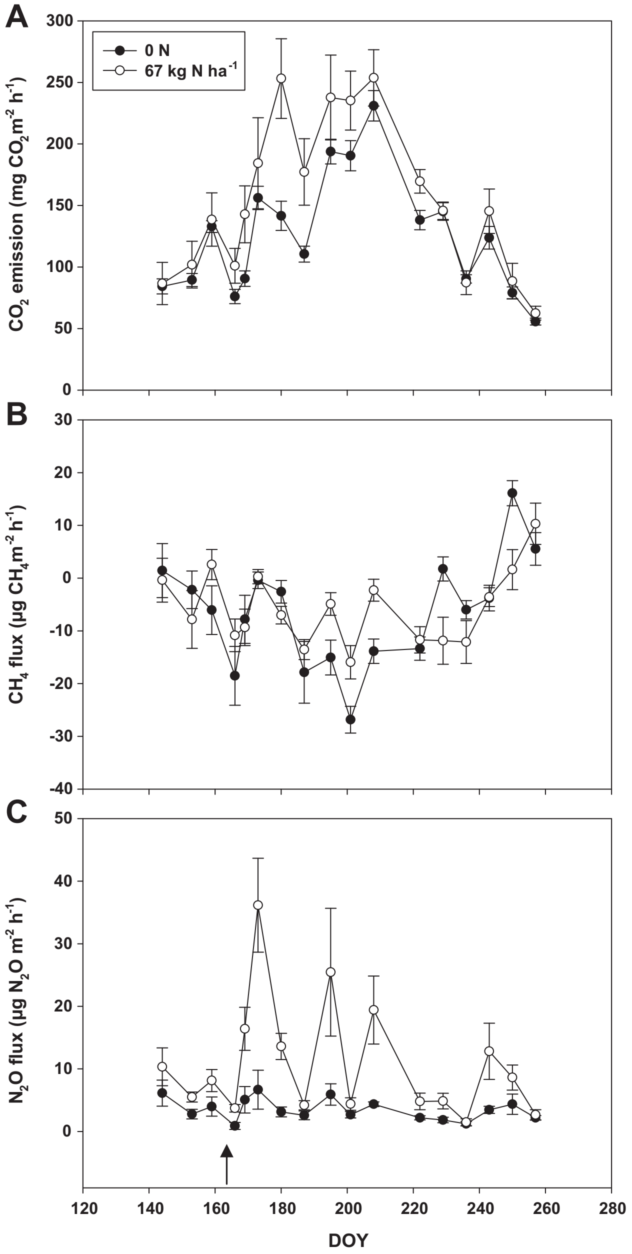

Fig. 2 – Mean hourly flux of CO_2 (A), CH_4 flux (B), and N_2O flux (C) for fertilized and unfertilized switchgrass managed for bioenergy in south central North Dakota. Arrow indicates date of N fertilizer application.

Table 1 – P-values and F statistics for effects of N treatment, time, soil temperature, and water-filled pore space (WFPS) on mean hourly GHG flux from switchgrass.

Effect	CO_2		CH_4		N_2O	
	P-value	F statistic	P-value	F statistic	P-value	F statistic
N treatment	0.0898	2.9	0.5062	0.4	<0.0001	32.5
Time	0.4492	0.6	<0.0001	21.4	0.4039	0.7
Soil temperature	<0.0001	28.7	0.0651	3.4	0.0028	9.1
WFPS	0.0003	13.5	<0.0001	36.1	<0.0001	16.5

Table 2 – Cumulative growing season CO_2 flux, CH_4 flux, N_2O flux, total greenhouse gas (GHG) flux, and harvest yield (±SE) from fertilized and unfertilized switchgrass bioenergy plots expressed as kg ha^{-1} CO_2 equivalents (CO_2eq) and greenhouse gas intensity expressed as GHG flux per harvest yield (kg kg^{-1} as CO_2eq).

N treatment (kg ha^{-1})	CO_2	CH_4	N_2O	GHG	Harvest yield
(kg ha^{-1} as CO_2eq)					
0	3605 (±146)	−4.9 (±0.69)	27.6 (±4.0)	3628 (±145)	5145 (±1211)
67	4392 (±386)	−4.3 (±0.61)	86.3 (±14.3)	4474 (±389)	11,021 (±1155)
P-value	0.08	0.51	<0.01	0.06	<0.05
Greenhouse gas intensity					
0	0.700	−0.0009	0.005	0.705	–
67	0.399	−0.0004	0.008	0.406	–
P-value	0.18	0.17	0.54	0.18	–

Soil temperature and WFPS affected mean hourly CO_2 flux (Table 1). Mean hourly CO_2 flux followed a positive trend with soil temperature while maximum CO_2 flux occurred when WFPS was <15%. Highest rates of mean hourly CO_2 flux occurred under fertilized switchgrass with ranges from 62 mg m^{-2} h^{-1} to 250 mg m^{-2} h^{-1} (Fig. 2a). Though numerically higher under N application, cumulative CO_2 flux was similar by N treatment (Table 2) which corresponded to previous findings of growing season switchgrass CO_2 fluxes between unfertilized and inorganic N fertilization in northern temperate climates [16,17].

Methane uptake in both N treatments followed similar trends to consumption rates in grazing land and cropping systems in the Northern Great Plains [15,18]. Mean hourly CH_4 flux was similar by N treatments and soil temperature but differed by WFPS (Table 1). Methane fluxes were affected by sample date (Table 1) but not by fertilizer treatment *X* sample date (data not shown). Methane fluxes were primarily negative for both N treatments until DOY 250 (Fig. 2b). Flux of CH_4 ranged from −16 μg m^{-2} h^{-1} to 10 μg m^{-2} h^{-1} for fertilized switchgrass and −27 μg m^{-2} h^{-1} to −16 μg m^{-2} h^{-1} for unfertilized switchgrass. Switchgrass with N application and without N application had cumulative CH_4 uptakes of −4.3 kg ha^{-1} and −20 kg ha^{-1} as CO_2eq, respectively (Table 2). Similar to mean hourly flux, cumulative CH_4 flux did not differ by N treatment ($P = 0.5110$).

Nitrous oxide flux was affected by N treatment, soil temperature and WFPS (Table 1). Flux of N_2O ranged from 1 μg m^{-2} h^{-1} to 36 μg m^{-2} h^{-1} for fertilized switchgrass treatments (Fig. 2c). Nitrous oxide flux was fairly consistent throughout the growing season for unfertilized switchgrass with cumulative flux reaching 27.6 kg ha^{-1} as CO_2eq (Table 2). In contrast, fertilized switchgrass N_2O flux was highly variable with cumulative flux reaching 86.3 kg ha^{-1} as CO_2eq (Table 2). Overall, N fertilization of switchgrass affected cumulative growing-season N_2O flux ($P < 0.0001$). The increase in N_2O flux by fertilizer application from this study differs from Nikièma et al. [17] which showed no differences in N_2O flux between N fertilizer applications (56 kg ha^{-1} and 112 kg ha^{-1}) compared with unfertilized switchgrass.

Aboveground biomass yield was greater with N application (6.8 Mg ha^{-1} ± 0.5 Mg ha^{-1}) than without N (3.2 Mg ha^{-1} ± 0.5 Mg ha^{-1}) ($P < 0.05$). Global warming potential, in CO_2eq, was similar by N treatments with growing season values of 4474 kg ha^{-1} and 3628 kg ha^{-1} for fertilized and unfertilized switchgrass, respectively (Table 2). Soil CO_2 flux accounted for >98% of total GWP for fertilized or unfertilized switchgrass. Net GHGI for switchgrass production was less with N application (0.41 kg GHG flux kg^{-1} harvest yield as CO_2eq) than without N (0.71 kg GHG flux kg^{-1} harvest yield as CO_2eq) excluding the upstream energy requirement to manufacture and distribute inorganic N (Table 2). Inclusion of upstream GHG emissions from urea manufacturing, distribution, and application increased the GHGI of fertilized switchgrass to 0.44 kg GHG flux kg^{-1} harvest yield as CO_2eq. However, GHGI from the flux data with or without upstream fertilizer N energy values was statistically similar by N treatments ($P > 0.18$).

4. Conclusion

Nitrogen fertilization of switchgrass affected growing-season N_2O flux but not cumulative CO_2 or CH_4 flux. Overall, N application resulted in 113% higher switchgrass biomass yields than unfertilized switchgrass plots resulting in similar cumulative GHGI between N fertilizer treatments. Results from this study pertain to growing season GHG fluxes for switchgrass managed for bioenergy in a northern climate. Further research is warranted on GHG fluxes and indirect N losses for switchgrass managed for bioenergy across a wider spatial and temporal scale.

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