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Nitrous oxide and methane fluxes from cattle excrement on C3 pasture and C4-dominated shortgrass steppe

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ABSTRACT

Cattle play a major role in nutrient cycling of grassland ecosystems through biomass removal and excrement deposition (urine and feces). We studied the effects of cattle excrement patches (urine at 430 and feces at 940 kg N ha^{-1}) on nitrous oxide (N_2O) and methane (CH_4) fluxes using semi-static chambers on cool-season (C3), Bozoisky-select (*Psathyrostachys juncea*) pasture, and warm-season (C4)-dominated native rangeland of the shortgrass steppe (SGS) in northeastern Colorado. Nitrous oxide emission factors (EF; i.e., percent of added N emitted as N_2O—N) did not differ between urine and feces on the C4-dominated native rangeland (0.11 and 0.10%) and C3 pasture (0.13 and 0.10%). These EFs are substantially less than the Intergovernmental Panel on Climate Change (IPCC) Tier 1 Default EF (2%) for manure deposited on pasture, indicating that during dry years the IPCC Tier 1 Default EF would result in a significant overestimation of emissions from excrement patches deposited on SGS C4-dominated native rangeland and C3 pasture. Over the first year of the study (19 June 2012–18 June 2013), cumulative CH_4 uptake was 38% greater for urine (−1.49 vs. −1.08 kg CH_4—C ha^{-1}) and 28% greater for control plots (−2.09 vs. −1.63 kg CH_4—C ha^{-1}) on C4-dominated native rangeland compared to C3 pasture. In contrast, feces patches were net sources of CH_4 with emissions from the C3 pasture (0.64 kg CH_4—C ha^{-1}) 113% greater than the C4-dominated native rangeland (0.30 kg CH_4—C ha^{-1}). Conversion of C4-dominated native rangeland to C3 pasture can have long term effects on CH_4 uptake; therefore consideration should be taken before implementing this management practice.

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1. Introduction

Cattle play a significant role in the nitrogen (N) cycle of grassland ecosystems by redistributing up to 80% of consumed N through their excrement in urine and feces patches (Milchunas et al., 1988; Wachendorf et al., 2008). The high N rate deposited through excrement patches greatly exceeds the demands of semi-arid grassland flora, thereby subjecting excrement-N to losses through nitrification, denitrification, ammonia (NH_3) volatilization, and leaching (Williams et al., 1999; de Klein et al., 2003; Maljanen et al., 2007; Wachendorf et al., 2008). Leaching is minimal in semi-arid grasslands such as the shortgrass steppe (SGS) since potential evapotranspiration (PET) is substantially larger than the amount of precipitation received and hence water movement below the rooting zone rarely occurs (Schimel et al., 1986; Augustine et al., 2013). Direct nitrous oxide (N_2O) emissions on grazing lands range from 0.1–3.8% for urine and 0.05–0.7% for feces patches of total excrement N applied (Milchunas et al., 1988; Oenema et al., 1997; Follett, 2008; Yao et al., 2010; van der Weerden et al., 2011; Hoeft et al., 2012). The Intergovernmental Panel on Climate Change (IPCC) Tier 1 Default Emission Factor (EF;

Abbreviations: N_2O, nitrous oxide; CH_4, methane; EF, emission factor; GHG, greenhouse gas; SGS, shortgrass steppe; DOY, day of year; WFPS, water-filled pore space.

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i.e., percent of added N emitted as $N_2O—N$) for manure deposited on pasture is 2%. This method assumes that the applied-N is entirely cycled within one year (IPCC, 2006).

Currently, knowledge on greenhouse gas (GHG) fluxes from feces patches is based on studies conducted over a short time period (<1 year) (van der Weerden et al., 2011; Lessa et al., 2014; Mori and Hojito, 2015). Short-term studies, encompassing a single growing season, may underestimate cumulative N_2O emissions from feces patches since organic N is the predominant form of feces-N. Depending on environmental conditions, feces composition, and microbial community composition, organic forms of feces-N may take more than a single growing season to mineralize (Wachendorf et al., 2008). Wachendorf et al. (2005) found that a year after cattle feces deposition on a sandy soil in Germany, 70% of the feces-N remained in the soil, accounting for 15% of the soil organic-N. In addition, lysed microbial cells following freeze-thaw cycles may release excrement-derived N previously assimilated in microbial biomass, which can lead to pulses of N_2O emissions (Koponen and Martikainen, 2004; Holst et al., 2008; Wu et al., 2012). Therefore, when studying cumulative GHG fluxes from feces patches, it is important to conduct measurements for >1 year to allow adequate time for mineralization of feces organic N.

Due to the vast land area that the SGS encompasses, 11% (3.4×10^5 km^2) of the central grasslands in North America, land management practices on the SGS can have a significant impact on the North American GHG budget (Lauenroth et al., 2008). While grazing is the dominant land management practice on the SGS, the impacts are relatively un-documented. Conversion of SGS C4-dominated native rangeland to cool-season (C3) pasture species has been found to be economically beneficial for ranchers (Derner and Hart, 2010), by lengthening the growing season and providing more sustained forage for cattle. However, data on the impacts of such conversions on GHG emissions are lacking. Prior research has shown that conversion of C4-dominated native rangeland to a winter wheat-fallow production system increased N_2O emissions and decreased CH_4 uptake (Mosier et al., 1997). Mosier et al. (1997) found that three years following a tillage event, CH_4 uptake was 35% less and N_2O emissions 25–50% greater than undisturbed C4-dominated native rangeland. Once cultivated soils of the SGS are allowed to revert back to grassland, it takes 8–50 years for CH_4 and N_2O soil-atmosphere gas exchange rates to return to that of undisturbed native rangeland (Mosier et al., 1997).

The primary goal of this study was to evaluate effects of cattle excrement patches on CH_4 and N_2O flux rates over a two year period on a site representative of typical SGS C4-dominated native rangeland and C3, Bozoisky-select, pasture. We tested the following hypotheses for each plant community: (1) a greater proportion of the urine-N will be emitted as N_2O compared to feces-N, (2) CH_4 uptake rates will be less for urine and feces compared to control plots, and (3) N_2O emissions will be greater from feces compared to the urine and control plots following the spring freeze-thaw cycle.

2. Materials and methods

2.1. Study site and experimental design

The study was conducted at the USDA—Agricultural Research Service Central Plains Experimental Range (CPER), located about 12 km northeast of Nunn, (40.841801,−104.70621; 1650 m above sea level) on the western portion of the Pawnee National Grasslands in north-central Colorado. The soil is a Zigweid (Fine-loamy, mixed, superactive, mesic Ustic Haplocambids). Mean annual precipitation (1939–2012) was 341 mm yr^{-1}, with 80% occurring between May-September. Mean annual temperature was 8.6 °C, with lowest temperatures in January (−1.5 °C) and highest in July (22.2 °C).

This project focused on two plant communities, C3 pasture and C4-dominated native rangeland, which were directly adjacent to one another. The native rangeland site was characteristic of SGS native rangeland, dominated by the C4 grass, blue grama (*Bouteloua gracilis*). Other common plants were fringed sagebrush (*Artemisia frigida*), buffalo grass (*B. dactyloides*), and plains prickly pear (*Opuntia polyacantha*). The C3 pasture was plowed and seeded to Bozoisky-select in 1994, after having been 'go-back', or abandoned cropland that was allowed to naturally revegetate following prior cultivation in the 1930s and 1950s with winter wheat. Bozoisky-select, a C3 bunch grass adapted to semi-arid grasslands, is a cultivar of *Psathyrostachys juncea*, selected for improved seedling vigor, winter hardiness, and drought-resistance. Bozoisky-select soils were significantly sandier and contained less C and N than C4-dominated native rangeland soils for the top 10 cm (Table 1). Soil organic C accounted for the majority (≥89%) of the total soil C (0–10 cm) for C4-dominated native rangeland and C3 pasture soils, with carbonate-C making up <11% of total C (data not shown). The C4-dominated native rangeland was typically grazed from mid-May to early-October, while the C3 pasture was grazed in both the spring (mid-April to mid-May) and fall (late-October to early-December). Both plant communities had been grazed annually leading up to the experiment, with the exception of 2007 and 2008 on the C3 pasture.

In the spring of 2012, we established a randomized complete block design on each plant community with four blocks, or replicates. Exclosures (7.3 m^2) were constructed around each block using panels to exclude cattle. Four treatments 1) urine (U), 2) feces (F), 3) control water (Cw), and 4) control blank (Cb), were randomly assigned to plots within each block. Treatment plots were 3 m^2 in area and were separated by a 0.5 m buffer. To simulate grazing, vegetation within the exclosures was periodically clipped to five cm, removed from the study area, and kept for C and N analysis. Due to minimal aboveground biomass production in 2012, vegetation was clipped just once in the C4-dominated native rangeland, and no clipping occurred in the C3 pasture.

Excrement was collected in May 2012 at Colorado State University's (CSU) Agricultural Research, Development and

Table 1
Soil properties (texture n = 2; bulk density and total N and C n = 16) for the 0–10 cm depth of plant communities, C4-dominated native rangeland and C3 pasture.

Site	Depth Increment (cm)	Sand (% ± SE)	Clay (% ± SE)	Bulk Density (g cm^{-3} ± SE)	Total N (Avg.% ± SE)	Total C (Avg.% ± SE)
C4-dominated Native Rangeland						
	0–5	63 ± 7.1	9 ± 1.0	1.16 ± 0.03	0.12 ± 0.008	1.32 ± 0.13
	5–10	72 ± 2.0	10 ± 0.0	1.37 ± 0.03	0.07 ± 0.002	0.66 ± 0.02
C3 Pasture						
	0–5	83 ± 0.6	5 ± 0.8	1.46 ± 0.04	0.08 ± 0.011	0.76 ± 0.14
	5–10	83 ± 0.8	5 ± 1.0	1.45 ± 0.03	0.06 ± 0.002	0.53 ± 0.02