LEGACY IMPACTS OF CATTLE GRAZING ON SOIL N_2O AND CH_4 FLUXES IN SHORTGRASS STEPPE: A CASE STUDY

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ABSTRACT

Grazing cattle directly emit CH_4 from enteric fermentation and contribute to soil nitrogen (N) gas emissions related to N and organic matter additions from urine and manure deposits. Grazed soils can be sources or sinks of CH_4, depending on moisture levels and localized manure patches. N_2O emissions are related to availability of water as well as mineral N and labile C substrates in soil. Previously, we observed higher N_2O and NH_3 losses from fresh patches of urine and manure compared to controls receiving no waste inputs. In this paper we investigate legacy impacts of more than 75 years of cattle congregating in pasture hotspots near corners and water tanks on soil N_2O and CH_4 fluxes. To minimize the effects of fresh excreta deposition, exclosures were installed around the gas sampling chambers to keep cattle off the experimental plots during grazing periods. We hypothesized that hotspots have higher soil mineral N concentrations, more N_2O emissions, and less CH_4 uptake compared to pasture centers. Soil NO_3 was indeed elevated in hotspots but not NH_4. We also observed consistently higher N_2O emissions from hotspots over all three years of the study (2015-2017) but CH_4 uptake was less than pasture centers only during 2015. N_2O emissions on average were an order of magnitude higher in hotpots than centers. Consequently, although hotspots make up a small portion (e.g., 1-4%) of total pasture area, they were responsible for about 23% of emissions at the pasture level.

INTRODUCTION

Grasslands comprise approximately 40% of the terrestrial land surface area, with the majority of this area under grazing management (Cai and Akiyama, 2016). Grazing animals contribute to soil nitrous oxide (N_2O) emissions related to nitrogen (N) additions associated with animal waste deposition. While methane emissions from cattle are primarily due to enteric fermentation and manure management systems, anaerobic fermentation occurs within feces patches as they dry. In arid rangelands, feces patches act as a source of CH_4 for approximately a week until the patch has dried out (Nichols et al., 2016). In contrast to localized patches, bulk soil is typical a CH_4 sink in arid grasslands

Grazing cattle redistribute approximately 70-95% of N consumed in forage through urine and feces patches (Oenema et al., 2005; van der Weerden et al., 2011. While areas near pasture corners and water tanks comprise a relatively small proportion (1-4%) of the total pasture area in arid rangelands, cattle spend a significant amount of time (about 27%) in these areas (Augustine et al., 2013) creating hotspots with enhanced soil mineral

N concentrations due to a high portion of urine and feces patches deposited at these locations. In addition, these areas also experience soil compaction from cattle treading, resulting in reduced soil pore diameter and increased water-filled pore space (WFPS) which increase the prevalence of anaerobic microsites. Nitrous oxide emissions also tend to be greater from compacted soils (Bhandral et al., 2007).

Previous work quantified N_2O and CH_4 emissions from freshly deposited urine and feces patches for a shortgrass steppe system in northeastern Colorado (Nichols et al., 2016). In this paper, we investigate legacy impacts of more than 75 years of cattle congregating in pasture hotspots near corners and water tanks on soil N_2O and CH_4 fluxes. We hypothesize that hotspots will have higher soil mineral N concentrations, more N_2O emissions, and less CH_4 uptake compared to pasture centers.

MATERIALS AND METHODS

The study was conducted in northeastern Colorado at the USDA-Agricultural Research Service Central Plains Experimental Range (CPER), located approximately 12 km northeast of Nunn, Colorado. The soil types of the experimental sites are Ascalon fine sandy loam and Cascajo gravelly sandy loam. Climate at the region is semi-arid with a mean annual precipitation (1939 – 2016; n = 78) of 341 mm. The typical growing season is approximately 133 days with the dominant vegetation being the C4 perennial grass, blue grama (*Bouteloua gracilis*). Randomized blocks were established in a130-ha pasture that had been moderately grazed since 1939 near a water tank, “hotspot” and at the center of the pasture. The pasture center site was located approximately one km from the hotspot location. To isolate legacy impacts from fresh excreta deposition, exclosures were installed around the randomized blocks to keep cattle off of the experimental plots during grazing periods.

Trace gas sampling was conducted using rectangular aluminum chambers. Anchors (8 per block) were installed in designated trace gas sampling plots and were left for the duration of the study, April 2015 to November 2017. Chambers were deployed for 30 minutes with samples collected at 0, 15, and 30 minutes. Trace gas sampling was conducted once or twice per week between 0900 and 1200 hours, the air temperature during this period has been found to approximate the daily average. Trace gas samples were analyzed for CH_4 and N_2O on an automated gas chromatograph (Varian model 3800, Varian Inc., Palo Alto, CA) equipped with a thermal couple detector (TCD), flame ionization detector (FID), and electron capture detector (ECD). Nitrous oxide and CH_4 flux rates were calculated using the linear equation with gas concentrations taken at three time points. Cumulative emissions were calculated by linearly interpolating between sampling days and summing for the year. Soil core samples for the top 20 cm were collected frequently (every five to six weeks) throughout the spring, summer, and fall to measure soil mineral N (NH_4^+ and NO_3^-). Statistical differences in the annual gas flux rates and mineral N between the hotspot and pasture center were determined using the GLIMMIX procedure with repeated measures for location in SAS (SAS Institute, 2013).

RESULTS AND DISCUSSION

Cumulative N_2O emissions from the pasture hotspot were significantly greater ($P < 0.0001$) than the center during all three years of the study. On average, emissions were approximately 10 times greater from the pasture hotspot than the center (Figure 1). Consequently, even though hotspots comprise a relatively small proportion of the total pasture area, 1.1 – 3.9%, depending on pasture size (Augustine et al., 2013), these regions have an important effect (~23%) on the overall pasture level emissions. Strong positive correlations were observed between soil WFPS and N_2O flux on the pasture center ($r = 0.33$; $P = 0.002$) and hotspot ($r = 0.30$; $P = 0.005$). While positive correlations between soil temperature and N_2O flux were also observed, the relationships were not significant.

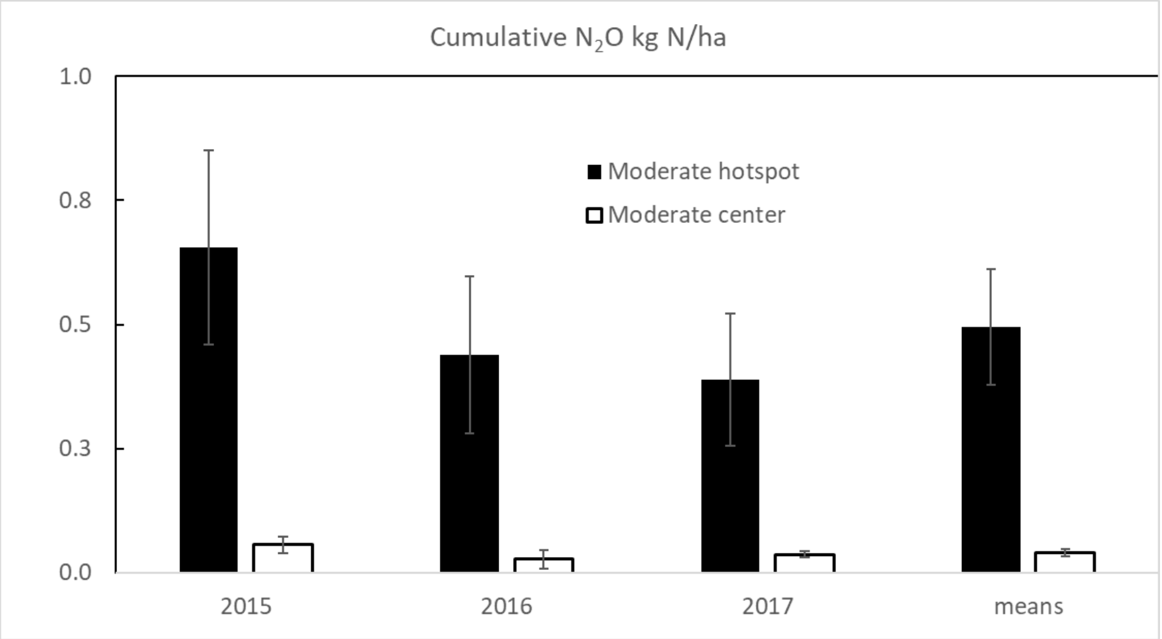

Figure 1. Cumulative annual N_2O emissions from moderately grazed pasture hot spots near water tank vs. pasture center. Bars are standard deviations.

Cumulative CH_4 uptake from the pasture hotspot was significantly less than the center during the first year of the study but not different the subsequent two years (Figure 2). This observation may result from recovery of the methanotroph population and increased soil gas diffusion due to the absence of disturbances in enclosures by cattle treading (i.e., soil compaction and vegetative growth) (Liu et al., 2007).

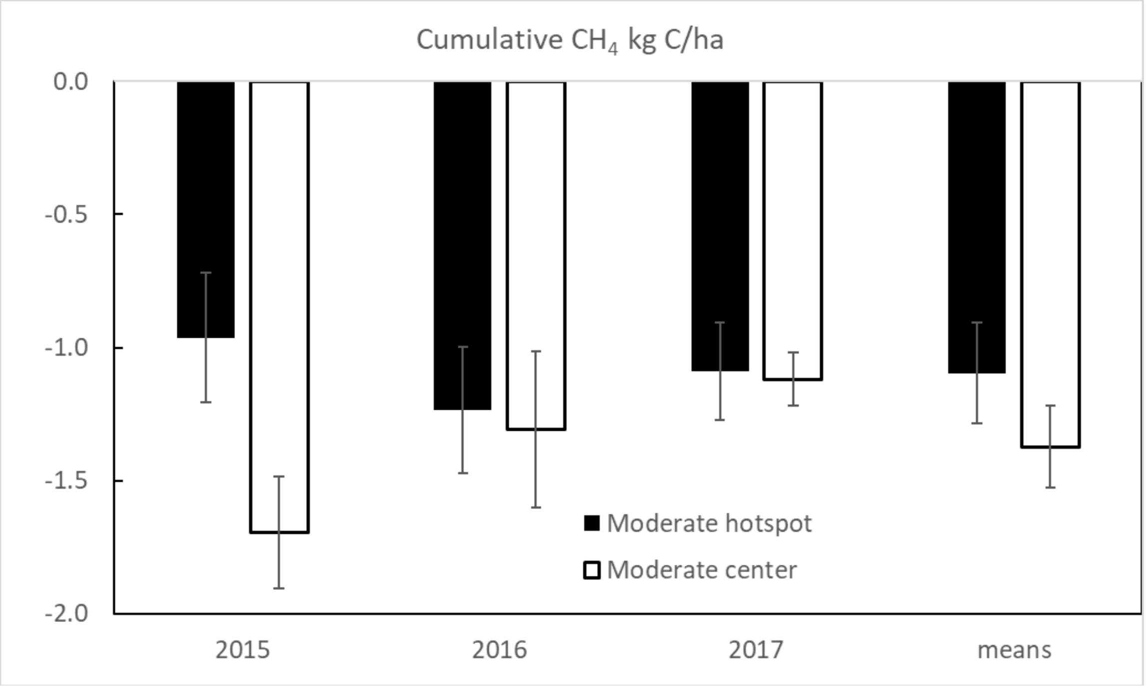

Figure 2. Cumulative annual CH_4 uptakes from moderately grazed pasture hot spots near water tank vs. pasture center. Bars are standard deviations.

As expected, average NO_3 in 0-20 cm layer was substantially (5.6-fold) greater in the hot spot (34 kg N/ha for hotspot vs. 6 kg N/ha for center). In contrast, NH_4 in the 0-20 cm layer did not differ on average (10 kg N/ha for center, 11 kg N/ha for hotspot). However, NH_4 levels were significantly higher for the initial sampling at the beginning of the study in spring 2015.

Hypotheses regarding N_2O emissions and NO_3 levels were supported, but those related to CH_4 uptake and NH_4 levels largely were not; only the first year of the study showed lower CH_4 uptake and higher NH_4 levels in the hotspot. Figure 1 suggests that the ability of hotpots to absorb CH_4 recovers quickly when cattle traffic and waste deposition are prohibited by enclosers. This finding contrasts with an earlier study by Mosier et al. (1996) who found that plots amended with urea to simulate urine patches had lower CH_4 uptake than control plots > 5 years after treatment. Enhanced N_2O emissions persisted for three years from the hotspot, although there is some evidence of a gradual decline across years suggesting that fresh manure and urine inputs contribute to emissions (Figure 2).

The patterns we observed are consistent with those from a study in Australia where Mitchell et al. (2021) found that N_2O emissions and NO_3 levels were much higher in hotspots. Only one of three sites analyzed in their study showed differences in CH_4 fluxes and no sites showed differences in NH_4 levels. Although trends were similar, N_2O emissions from their more mesic system (MAP = 854-1133 mm for the three sites) were much greater than our values. It is also interesting that although hotspots occupied a small portion of pasture area (~3 %) they were responsible for a significant potion (~27%) of pasture level emissions which is similar to our estimation of hotspots being responsible for ~23% of pasture level N_2O emissions. Further research is required to better assess how important hotspots are for pasture level emissions across climate and stocking rate gradients and if the IPCC (de Klein et al. 2006) soil N_2O emission factors commonly used to calculate emissions reported in national greenhouse gas inventories should be adjusted.

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