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Dryland Sorghum Nitrogen Management: Implications for Utilization as Ethanol Feedstock

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Summary

A study was initiated in 2018 to collect preliminary data to quantify nitrous oxide (N_2O) emissions from dryland grain sorghum in western Kansas. Results indicate that the greatest flux of N_2O occurred within the first 14 days after fertilization when plant uptake was minimal and soil moisture was elevated. During this time period, the timing and amount of rainfall was critical with respect to N_2O flux. Nitrous oxide flux during the fallow phase was negligible. The cumulative emissions factor for fertilizer-derived N_2O estimated for Colby (~0.3%) is well below the Intergovernmental Panel on Climate Change (IPCC) default estimate of 1.0%. These preliminary factors are very promising for documenting the sustainability of dryland grain sorghum as biofuel feedstock.

Introduction

A common dryland cropping system in western Kansas is a wheat-grain sorghum-fallow rotation. Sorghum is better adapted to dryland production than other row crops, particularly corn. This drought-tolerant crop offers farmers in western Kansas a viable choice to preserve regional resources. Approximately 1/3 of US grain sorghum is used for ethanol production. Grain sorghum produces an equivalent amount of ethanol compared to corn while using 1/3 less water during its life cycle (Wang et al., 2008). Recent changes in the life cycle assessment of corn has resulted in grain sorghum appearing less favorable as a biofuel crop. Nitrous oxide emissions (N_2O) have recently been identified as a critical research gap that is limiting the life cycle assessment for sorghum. Cumulative cropping system N_2O emissions from grain sorghum production are generated from two main inputs: 1) the conversion of applied inorganic fertilizer, and 2) decomposition of crop residue following harvest (fallow period). Based on the default emissions factor of 1% each from fertilizer and residue from the Intergovernmental Panel on Climate Change (IPCC), the cumulative cropping system emissions factor for grain sorghum is approximately 2.0% (amount of N_2O-N derived from fertilizer and residue). This has important implications for the competitiveness of grain sorghum for biofuel production. This research will provide data needed to understand the magnitude of potential N_2O emissions from dryland systems in the Southern Great Plains.

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Procedures

This field study was conducted at the Kansas State University State Northwest Research and Extension Center in Colby. Plots were established on a Keith silt loam under a standard rotation of wheat-fallow-grain sorghum-fallow such that the grain sorghum was no-till planted into wheat stubble from the 2017 wheat harvest. Treatments were designed based on a yield goal of 115 bu/a and included: 1) control (zero N applied); 2) 1.12 lb N (soil+applied)/bu, applied as 32-0-0 UAN solution at planting; 3) same rate as treatment 2 with the addition of a urease inhibitor (Agrotain) using 32-0-0 liquid fertilizer; and 4) 1.6 lb N (soil+applied)/bu, applied as 32-0-0 UAN solution at planting. All three fertilizer treatments were adjusted for profile nitrogen (N). In addition, treatment 4 was representative of a standard K-State recommendation and was adjusted for soil organic matter (lb N/a - % SOM × 20) (Leikam et al., 2003). The applied N rate for treatments 2 and 3 was 95 lb N/a and 110 lb N/a for treatment 4. Treatment 3 represented an N application method utilizing a common best management practice for nitrogen use. Plots were 20 × 40 ft with the treatments arranged in a complete randomized block design replicated four times. Precipitation was measured by a Kansas Mesonet weather station adjacent to the plots.

Emissions of N_2O were measured using a vented static chamber method described in the U.S. Department of Agriculture GRACEnet Project Protocols (Parkin and Venterea, 2010). Chambers were installed centered over the row, directly after planting and fertilization. Stainless steel chambers consisted of two components: an anchor that remained in the plot for the entire growing season and a lid that sealed to the anchor at time of sampling. The lid was equipped with a sampling port for manual gas extraction using a syringe. Each sampling event consisted of four gas measurements taken over a 45-minute time series (0, 15, 30, and 45 minutes). Gas samples were stored in the vials and shipped overnight to Oklahoma State University for analysis by gas chromatography to determine N_2O.

Emissions were measured every two days following fertilization for a period of seven days, followed by weekly measurements during the growing season. Additional gas measurements were taken within 24–48 hours following precipitation events at the research site. Chambers were left in place following harvest, and gas samples were taken during the fallow period when the plots were accessible.

Grain sorghum was planted on June 18 using the sorghum hybrid SP34A15 at a seeding rate of 55,250 seeds/a with a 30-inch row spacing, resulting in eight rows per plots. On November 13, two rows from the center of each plot were hand-harvested by removing the aboveground biomass (stalk and head) from 8 row-feet for grain yield and yield component analysis.

Using the cumulative flux values, grain yield, and applied fertilizer rates, three different emissions values were calculated (Table 1). Yield-scaled N_2O emissions (lb N_2O-N/bu) were estimated by dividing the cumulative N_2O flux by grain yield. Fertilizer-induced N_2O emissions (lb N_2O-N/a) were calculated as the difference between the cumulative flux of each fertilizer treatment and the cumulative flux for the 0 N control treatment. The emissions factor (%) for each fertilizer treatment was calculated as the % of applied fertilizer converted to N_2O during the year.

Results and Discussion

The highest daily N_2O flux values occurred during the first 14 days after planting and fertilization, when plant uptake of N was minimal and water-filled pore space (WFPS) averaged >70%. Elevated emissions of N_2O have been documented to begin upon reaching 60% WFPS (Sehy et al., 2003). During that 14-day period, several rainfall events were recorded, totaling 26% of the entire growing season rainfall amount (Figure 1). The flush of N_2O during that time period made up approximately 80–90% of the cumulative N_2O emissions for all treatments. A large precipitation event (2.4 inches) occurred on October 8 and 9, 2018, but a resulting flush of N_2O was not recorded at the next sampling date on October 16. Emissions were undetectable for all treatments. Resulting WFPS values were >80% following this rainfall event and remained above 80% for the remainder of October. The predominant gas released from denitrification processes at WFPS >80% is nitrogen gas (N_2), not N_2O. Also, at this point in the growing season, nutrient uptake by the crop has ceased and the inorganic pool of N in the upper profile was likely depleted.

Overall, cumulative flux was low for all treatments, ranging from 0.3 lb N_2O-N/a for the control (0 N) to 0.67 lb N_2O-N for treatment 2 (95 lb N/a) (Table 1). Statistical analysis of the cumulative flux values indicated there were no significant differences between treatments (Table 1). Daily N_2O flux values were low throughout the growing season.

Low daily and cumulative flux values could be explained by the timing of peak nutrient uptake by the crop. As described by Vanderlip (1993), sorghum enters a rapid growth phase approximately 20–25 days after it emerges. Plant nutrient demand increases, and nitrogen uptake is rapid as the sorghum enter growth stage 3 (30–40 days post-emergence). Nitrogen uptake remains high until stage 6 (half-bloom) when around 70% of the total N has been assimilated. Nutrient uptake essentially stops when the crop reaches stage 8 (hard dough).

Nitrous oxide flux activity during the fallow phase (after sorghum harvest and until wheat planting in the fall) was very low for all treatments. Cumulative flux values during the fallow phase were below 0.2 lb N_2O-N/a for all treatments. The only gas sampling event that recorded measurable N_2O emissions was May 16, 2019. During the winter and early spring months, gas flux was undetectable. Several factors could contribute to almost negligible flux values during the winter fallow period, including N removal by the crop and environmental conditions. Nitrogen removal by the sorghum grain ranged from 89 lb N/a for the control to approximately 130 lb N/a for the three applied N treatments. Nitrogen uptake by the stover ranged from 75 lb N/a for the control to 83 lb N/a for the other three treatments.

The control treatment had significantly lower yields than the treatments receiving a N application without a N stabilizer; however, there were no statistical differences between the applied N treatments (Table 1). No statistical differences were observed between the yield-scaled N_2O emissions or the fertilizer-induced N_2O emissions.

While no significant differences were observed, the emissions factor (N_2O-N derived from fertilizer) was less than 0.3% for all treatments, indicating that the IPCC emis-

sions value of 1.0% is potentially overestimating N_2O flux from dryland sorghum production in western Kansas. Preliminary estimates of N_2O-N derived from crop residue were also substantially lower than 1.0% (data not shown). Given that the IPCC cumulative cropping system emissions factor for grain sorghum is approximately 2.0%, these results are very promising for documenting the sustainability of ethanol produced using grain sorghum grown in the Southern Great Plains.

References

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Table 1. Effects of nitrogen (N) application rates on grain sorghum yield, cumulative nitrous oxide (N_2O) flux, and different N_2O emission factors during the 2018 growing season at the Kansas State University Northwest Area Research Station in Colby, KS

Treatment	Yield	Cumulative N_2O flux	Yield-scaled N_2O emissions	Fertilizer-induced N_2O emissions	N_2O emissions factor
	bu/a	lb N_2O-N/a	lb N_2O-N/bu	lb N_2O-N/a	
0 N applied	124 b	0.30 a	0.002 a		
95 lb N/a	146 a	0.67 a	0.005 a	0.36 a	0.38a
95 lb N/a + stabilizer	139 ab	0.51 a	0.004 a	0.21 a	0.22a
110 lb N/a (KSU N recommendation)	149 a	0.49 a	0.003 a	0.19 a	0.18a

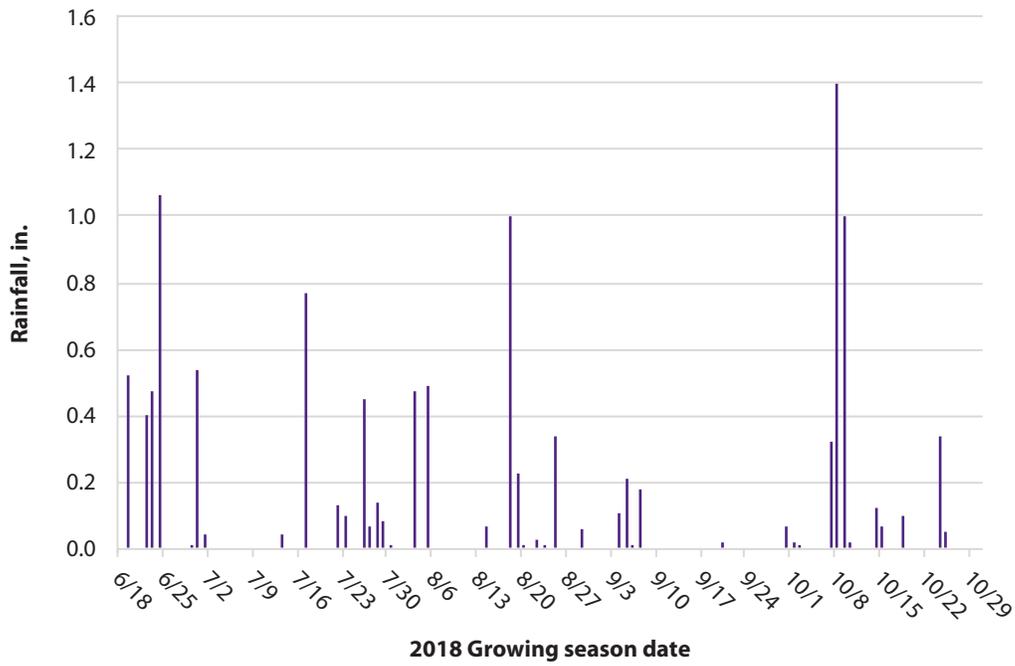Letters within a column represent a significant difference at LSD (0.05).

Figure 1. Daily rainfall (inches) during the 2018 growing season at the Kansas State University Northwest Area Research Station in Colby, KS. Rainfall was measured by a Kansas Mesonet weather station adjacent to the plots.
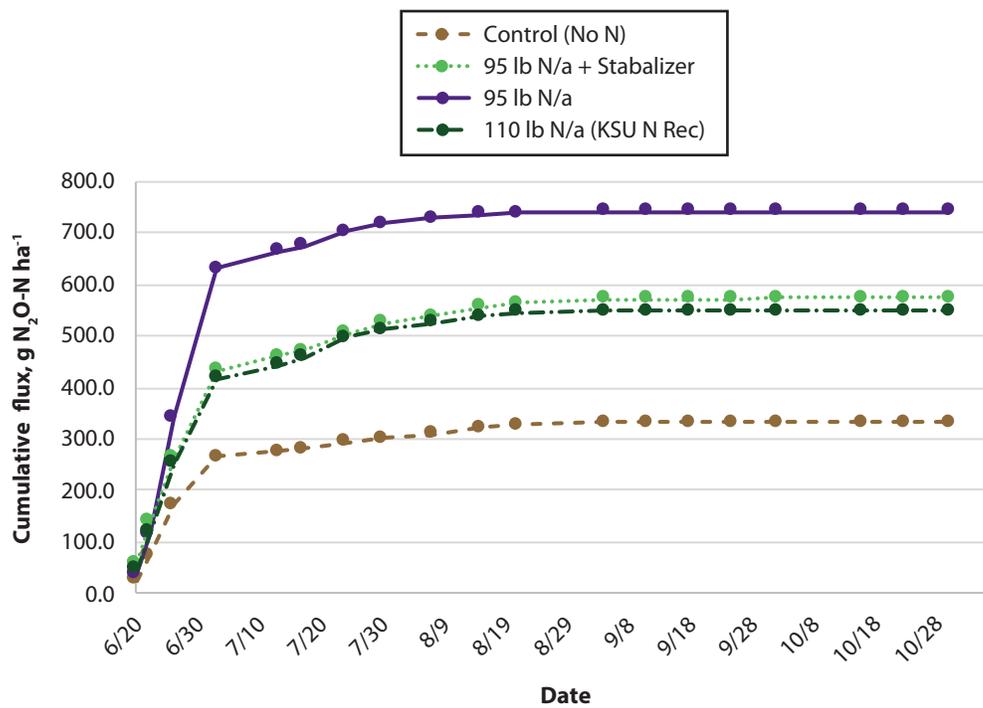
Figure 2. Cumulative nitrous oxide (N_2O) flux during the 2018 growing season as affected by nitrogen (N) fertilizer treatment at the Northwest Area Research Station in Colby, KS.