THE EFFECT OF NITROGEN MANAGEMENT IN WINTER WHEAT ON NITROUS OXIDE EMISSIONS IN A WHEAT-SOYBEAN DOUBLE CROPPING SYSTEM

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ABSTRACT

Nitrogen fertilizer management plays a critical role in emissions of nitrous oxide (N_2O) in agricultural production systems. This study investigated the impact of nitrogen application in a winter wheat (*Triticum aestivum* L.)-soybean (*Glycine max* L.) double cropping system on winter wheat biomass production, grain yield, and N_2O emissions. The experiment was conducted at the Agronomy Research Center (ARC), Carbondale in Southern Illinois University, IL using a Randomized Complete Block Design (RCBD) with treatments representing varying nitrogen input levels (low, medium, and high) in double cropping systems. Results indicated that nitrogen application in the medium-input treatment did not significantly affect winter wheat biomass, grain yield, and cumulative N_2O fluxes compared to the high-input treatment, which included a fall fertilizer application. Similar results were observed in soybeans concerning grain yield and cumulative N_2O fluxes. While the total nitrogen applied in both the medium and high treatments was the same, the removal of fall fertilization is beneficial in reducing N_2O fluxes without compromising yield or environmental performance. Soil N_2O fluxes varied significantly across sampling dates, but no significant treatment-by-sampling dates interaction was observed. These findings suggest that fall nitrogen application may not be necessary for optimizing winter wheat yield in this site, offering an effective nitrogen management strategy for winter wheat-based cropping systems. This research serves as evidence in supporting the refinement of nitrogen application timing to enhance environmental sustainability in agricultural systems. Future studies shall continue to explore the impact of these treatments and the economic implications on nitrous gas emissions in the long term.

INTRODUCTION

Nitrous oxide (N_2O) is the most potent greenhouse gas playing a significant role in climate change, with agricultural crop production being a primary source of concern. The USEPA reports that agricultural soil management practices are the main contributor to total N_2O emissions in the USA (USEPA, 2024). Therefore, reducing N_2O emissions through sustainable management strategies and processes is essential to minimize environmental impact.

The emission of N_2O from soil is primarily driven by microbial processes, specifically nitrification and denitrification. These processes involve the conversion of nitrate-N (NO_3-N) into various nitrogen gases, including nitrogen oxide (NO), nitrous oxide (N_2O), and nitrogen (N_2) gases (Meisinger et al., 2008; Sadeghpour et al., 2017).Thus, moist soils with warm temperatures, NO_3-N availability, and soils rich in labile carbon (C) serving as energy reservoirs are some of the factors that enhance the emissions of N_2O through the processes of nitrification and denitrification (Butterbach-Bahl et al., 2013). This study examined the impact of cultivating winter wheat (WW) as a double crop to soybeans and the timing/rate of nitrogen (N) management in WW phase on its dry biomass, yield, and N_2O emissions. We hypothesize that cultivating WW as a double crop in soybeans could increase N_2O emissions due to addition of N as fertilizer to WW and low nitrogen use efficiency (NUE) of N fertilizers.

MATERIALS AND METHODS

Experimental site, design, and treatments

The study was laid out in a Randomized Complete Block Design (RCBD) with four replicates at the Agronomy Research Center (ARC), Carbondale, and Belleville Research Center (BRC), IL. The eight treatments, applied at the same time were (1) corn-soybean rotation with no-CC (control), (2) corn-rye-soybean-rye rotation (maximum nitrate-N reduction control), (3) corn-wheat (low input)-soybean-no-CC, (4) corn-wheat (medium input)-soybean-no-CC, (5) corn-wheat (high input; NREC growers suggestions)-soybean-no-CC, (6) corn-wheat (low input)-soybean-rye CC, (7) corn-wheat (medium input)-soybean-rye CC, and (8) corn-wheat (high input; NREC growers suggestions)-soybean-rye CC. However, N_2O emissions were measured in the following treatment plots: (1) corn-soybean rotation with no-CC (control), (6) corn-wheat (low input)-soybean-rye CC, (7) corn-wheat (medium input)-soybean-rye CC, and (8) corn-wheat (high input; NREC growers suggestions)-soybean-rye CC.

Nitrogen management for winter wheat

The low input treatments (3 and 6) were subjected to a nitrogen (N) application regimen, wherein 40 lbs of N ac^{-1} was administered as Urea Ammonium Nitrate (UAN) both at the tillering stage and during the jointing stage. In contrast, the medium input treatments (4 and 7) received a total of 70 lbs of N ac^{-1} of UAN, with applications taking place at the tillering and jointing stages. Conversely, the high input treatments (5 and 8) had a distinct N application strategy. These treatments involved the application of 27 lbs of N ac^{-1} of Diammonium Phosphate (DAP) during the fall season, in addition to 70 lbs of N ac^{-1} in the form of UAN, administered at both tillering and jointing stages (Table 1).

Winter wheat, soybean, and cereal rye establishment

A no-till drill was used to plant WW (var. AgriMaxx 495) and cereal rye (CR) Guardian VNS (variety not specified) at 125 lbs ac^{-1} and 78 lbs ac^{-1}, respectively in October 2021. CR was terminated in May 2022 while WW was harvested in June 2022. Soybeans (var. Asgrow 47xF0) were planted after the termination of CR and harvesting of WW in May (single season) and June 2022 (double crop). Soybean was harvested and CR was planted on October 2022.

Data collection

Before WW harvest, 7.26 ft^2 (3 frames of 2.42 ft^2) of fresh biomass in each plot were sampled using the grass shears at about 2 inches above the ground surface. The fresh biomass was oven-dried at 140 degrees Fahrenheit for 72 hours and weighed for dry biomass. Plant heights were measured using a graduated ruler from the ground to the canopy top. The Normalized Difference Vegetation Index (NDVI) for each treatment was measured using the GreenSeeker Handheld Crop Sensor HCS 100 (Trimble Ltd., Sunnyvale, CA) device. This was done by passing the device over the full length of the two rows of crops at the middle of each plot. The AccuPAR (LP–80; METER Group, Pullman, USA) ceptometer was used to measure the leaf area index (LAI). This device measured the above and below photosynthetically active radiation (PAR) in the crop canopy in each treatment plot.

N_2O emissions measurement

According to Sistani et al. (2011), vented chambers with lids were built. The closed vented chambers were installed between the soybean rows (2.5 feet wide and 30 feet long) immediately after planting. During the sampling time, a 30 mL syringe and needle were used to obtain air samples from the closed vented chamber at 0, 15, 30, and 45-minute intervals (Sadeghpour et al. 2018). The air sample was immediately dispensed into an exetainer vial of 12 mL obtained from Labco Ltd., Lampeter, United Kingdom. Air samples obtained were 16 times in WW 2021-2022 however, in soybeans, it was 18 times for a single season and 12 times for a double crop in 2022, respectively. Air sampling was carried out intensively two times per week following fertilizer application in the winter wheat phase and during intensive rainfall occurrence.
The concentration of N_2O emissions in air samples stored in the exetainers was quantified using a Shimadzu Gas Chromatograph (GC-2014; Shimadzu Scientific Instruments, Inc., Columbia, MD). Air samples were automatically transferred from the exetainer vials to the GC machine by a Multifunctional AOC-6000 autosampler (Shimadzu Scientific). A 1 mL air sample was withdrawn from the exetainer vials with a N_2-purged glass syringe and injected into the GC machine for analyses.

Table 1: N Application Rates for WW Growth Stages in Fall and Spring 2021-2022.

	FALL lbs ac^{-1}	SPRING lbs ac^{-1}				TOTAL lbs ac^{-1}
		Tillering		Jointing		
	DAP	DAP	UAN	DAP	UAN	
Low	-	27	40	-	40	107
Medium	-	27	70	-	70	167
High	27	-	70	-	70	167

Soil N_2O emission rates were calculated by linearly regressing N_2O concentrations against time after chamber closure. If a non-linear response was observed for N_2O concentrations across the sampling time, linear regressions were derived by randomly selecting three measurements. Sampling dates where high N_2O emissions were recorded typically demonstrated a strong linear regression fit ($R^2 > 0.90$), which was used to calculate N_2O fluxes. Total and monthly cumulative N_2O emissions were calculated through interpolating between sampling periods and according to the USDA-ARS GraceNet protocol (Parkin and Venterea, 2010). Data on dry biomass, grain yield, and total cumulative of N_2O were analyzed using the mixed model in SAS (SAS Institute, 9.4, 2024). However, data on sampling dates and monthly cumulative for N_2O were analyzed as repeated measures using mixed models in SAS. Mean separation was done using Tukey's Honestly Significant Difference (HSD) test at .05 level of significance.

RESULTS AND DISCUSSION

The WW biomass and grain yield were similar among all treatments at both research sites (Figure 1). The soybean grain yield showed statistically significant differences across all treatments. Grain yields were higher in the single-season soybean compared to the double-season system. (Figure 2). The low yield in the double-cropped soybeans were probably due to the smaller plant size, shorter flowering period, pod set, and seed filling caused by delayed planting.

Soil N_2O fluxes were affected by date of sampling during the WW growing season. High N_2O fluxes were observed during the periods of freeze–thaw cycles and following N fertilizer application due to the response of nitrifying and denitrifying microbial activities to shifts in environmental conditions and N addition. Nevertheless, soil N_2O fluxes were similar among treatments across the different sampling dates (Figure 3).

Calculated monthly cumulative N_2O fluxes were affected by sampling months and treatment effects but not their interaction. The N_2O fluxes were higher in the high-input fertilizer treatment plots when compared to those that received low-input fertilizer. This increase suggests that surplus nitrogen in the high-input plots served as an additional substrate, thereby enhancing N_2O production through microbial nitrification and denitrification pathways. Furthermore, N_2O fluxes peaked in February and March, likely attributable to warming temperatures and increased soil moisture, which stimulated microbial activity and accelerated nitrification and denitrification processes.

Soil N_2O emissions during the soybean season were affected by sampling dates, treatments, and their interactions (Figure 4). The observed N_2O fluxes were due to temperature and soil moisture increase, which enhanced activities of microorganisms and accelerated the nitrification and denitrification processes. The monthly cumulative of N_2O fluxes showed that month and treatments were statistically significant. However, the interaction between month and treatment was not statistically significant. The HW treatment had the highest N_2O fluxes when compared to the single season soybean approach. The MW and LW treatments were similar to the single season soybean treatment and HW (Figure 4). The total cumulative analysis was not statistically significant.

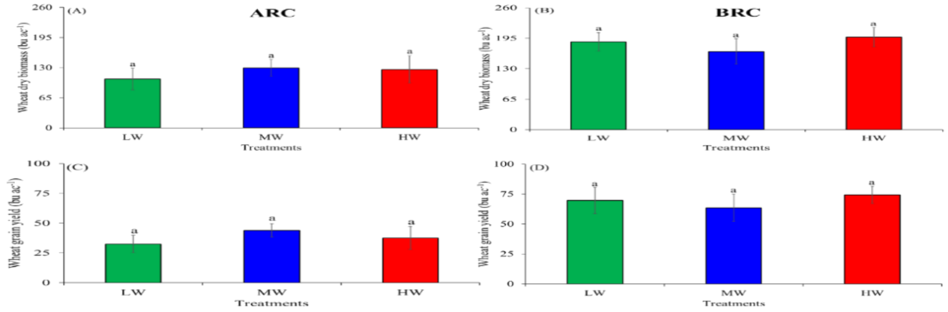

Fig. 1. Response of WW biomass (A-B) and grain yield (C-D) to varying N fertility management intensities. Identical letters indicate no significant difference (Tukey *p* ≤ .05 level). Abbreviation: NOCC = No cover crop, LW = low fertilizer rate, MW = medium fertilizer rate, and HW = high fertilizer rate for WW.

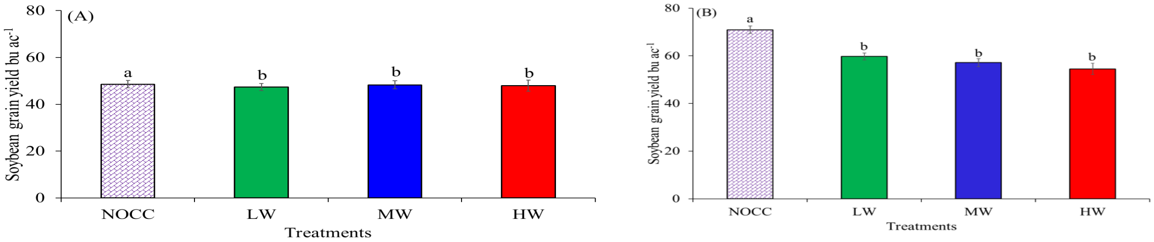

Fig. 2. Soybeans grain yield at ARC (A) and BRC (B) as influenced by WW double crop and different N fertility management intensities in 2022. Identical letters indicatee no significant difference (Tukey *p* ≤ .05 level). Abbreviation: see Table 1.

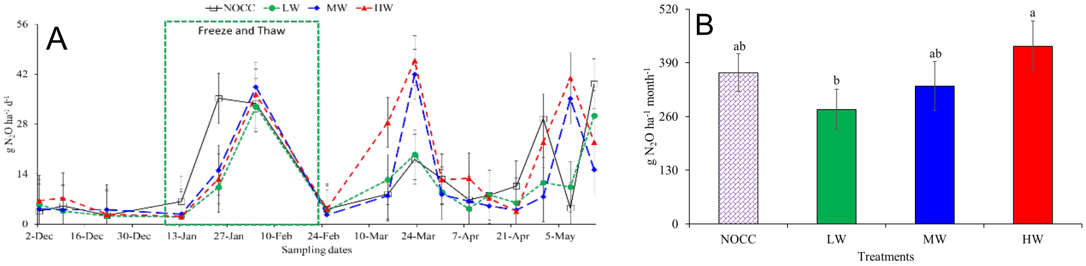

Fig. 3. N$_2$O flux trends (A) and monthly cumulative N$_2$O fluxes (B) across fertilizer treatments during WW growth in 2022. Identical letters indicate no significant difference (Tukey *p* ≤ .05 level). Abbreviation: see Table 1.

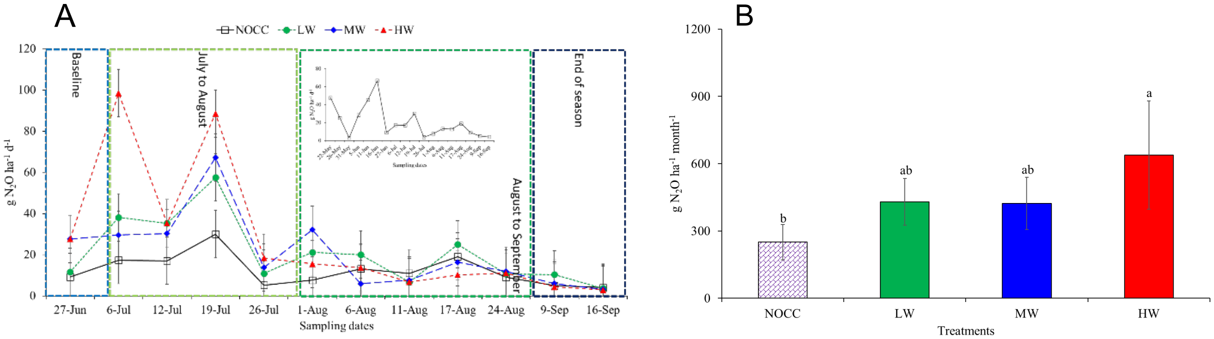

Fig. 4. N_2O flux trends (A) and monthly cumulative N_2O fluxes (B) across fertilizer treatments during soybeans in 2022. Identical letters indicate no significant difference (Tukey $p \leq .05$ level). Abbreviation: see Table 1.

PRELIMINARY CONCLUSION

This study assessed the impact of N fertilizer management on N_2O emissions, biomass, and yield in a wheat-soybean double-cropping system. Our results showed that eliminating the fall nitrogen application in the medium-input treatment does not significantly affect wheat biomass, grain yield, or N_2O emissions when compared to the high-input treatment, which includes fall fertilization. While the total N applied in both treatments remains the same, the absence of fall fertilization presents an opportunity to reduce N_2O fluxes without sacrificing crop productivity. These findings have practical implications for optimizing nitrogen application timing, particularly for farmers looking to improve environmental stewardship. The that fall nitrogen applications might not be essential for attaining high yields or reducing nitrous oxide emissions. However, additional site-years of data are needed to solidify this conclusion, which would support the development of more effective fertilizer management strategies.

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