EFFECT OF COVER CROP DIVERSITY ON NITROUS OXIDE EMISSIONS FROM CORN–SOYBEAN ROTATIONS IN CENTRAL ILLINOIS

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ABSTRACT

Nitrous oxide (N_2O) is a potent greenhouse gas primarily emitted from agricultural soils, where nitrogen (N) inputs and soil conditions interact to drive microbial processes. Cover crops are widely promoted as a climate-smart strategy to improve soil health and nutrient cycling, yet their effectiveness in mitigating N_2O emissions may vary depending on species composition and functional diversity. This study evaluated the influence of cover crop diversity on N_2O emissions in a corn–soybean rotation system in Central Illinois. Sixteen tile-drained plots were established with four treatments: cereal rye, red clover, a hairy vetch–radish mixture, and a no-cover control. With over 22 sampling dates during the 2024 and 2025 growing season, N_2O fluxes were quantified using static chamber methods, while soil nitrogen availability, moisture, and temperature were monitored to interpret emission patterns. The hypothesis guiding this work was that mixtures containing legumes and brassicas would reduce N_2O emissions more effectively than cereal rye alone by improving nitrogen use efficiency and synchronizing nutrient release with crop demand. Preliminary findings suggest that cover crop mixtures altered soil N dynamics relative to cereal rye monocultures and fallow controls, with differences in temporal emission patterns likely mediated by soil moisture and temperature interactions. Crop yield responses were also assessed, providing a critical link between environmental outcomes and agronomic performance. Collectively, these results advance understanding of how cover crop diversity can influence greenhouse gas emissions and nitrogen cycling, with implications for designing management practices that enhance both environmental sustainability and productivity in Midwestern corn–soybean systems.

INTRODUCTION

Nitrous oxide (N_2O) has a global warming potential approximately three hundred times greater than carbon dioxide over a 100-year period. Chemical reactions for nitrous oxide will take longer than what it would take to destroy and remove carbon dioxide, with the breakdown of N_2O into atmospheric N2 calculated to take approximately 121 years, as explained by the US EPA (2024). According to data from the United States Environmental Protection Agency in 2022, around 75% of nitrous oxide emissions in the United States are attributed to agricultural soils. Which is why it is crucial to explore alternative strategies to mitigate nitrous oxide emissions.

The emission of nitrous oxide from agricultural soil is a significant concern for climate change. N_2O is released primarily during the denitrification process, particularly under conditions of excess nitrogen availability and low oxygen levels in the soil. The conversion of nitrate to N_2O is more likely to occur in waterlogged soils or in fields with high organic matter, where anaerobic conditions prevail (Hanrahan et al., 2021). Factors such as soil temperature, moisture content, and pH can all influence the rate of N_2O production. For example, warmer temperatures and high moisture levels often accelerate denitrification, leading to higher emissions of nitrous oxide. Moreover, the overuse of nitrogen fertilizers increases the amount of available nitrate, thereby amplifying N_2O emissions (Bashir et. al, 2013).

Some studies have compared various agricultural systems and management practices, such as conservation tillage and traditional practices, which can include fertilization after harvest and no use of cover crops. While the benefits of some cover crops species are starting to get more recognition, challenges remain in their widespread adoption. In Central Illinois, factors such as the timing of cover crop planting, potential interference with cash crop planting, and the costs of seeds and labor can deter some farmers (Carver et al., 2021). However, programs offering financial incentives and technical support can help overcome these barriers. Extension services, government initiatives, and research collaborations can play a critical role in educating farmers about the long-term benefits of cover crops and providing resources to support their implementation. As more farmers in Central Illinois recognize the role of cover crops in reducing nitrogen losses, these practices are likely to become an integral part of sustainable agriculture (Johnson et al., 2024).

However, there remains a gap in understanding how different cover crop species, in combination with field management practices, affect nitrogen loss rates. The fluctuating rates of N_2O emissions and, therefore, nitrogen losses tend to occur due to the cover crops taking up the nitrogen in the soils (Charteris et al., 2020), which later becomes a source of nitrogen through the decomposition process. That is why this paper had the main objective to evaluate the effect of diverse cover crop species, including legumes and brassicas, compared to no cover on nitrous oxide emissions in a corn–soybean rotation system.

MATERIALS AND METHODS

This study was conducted at the University of Illinois Dudley Smith Farm located in Christian County, Illinois. The region has a temperate climate with a 30-year (1991–2020) average annual rainfall of 1083 mm. The predominant soil is a Virden silty clay loam (fine, smectitic, mesic Vertic Argiaquolls), classified as poorly drained, with 0–2% slopes. Weather data was recorded using an on-site meteorological station. Detailed descriptions of the experimental site and instrumentation were previously reported by (Preza Fontes et al., 2019; Preza-Fontes et al., 2021)) with the site's layout and instrumentation following standard procedures for tile-drained plot research.

The research site, established in 2016, contains 16 subsurface drainage plots, each measuring approximately 0.85 ha. Between 2018 and 2021, the site was in a continuous corn, strip-tillage system evaluating nitrogen management and cover cropping strategies (Preza-Fontes et al., 2021).

In the fall of 2023, a new crop rotation study began, evaluating three levels of cover crops in a corn–soybean rotation: (1) no cover crop (control), (2) cereal rye, and (3) a mixture of daikon radish and hairy vetch, and (4) red clover. The experiment followed a randomized complete block design with four replications.

In the 2023–2024 season, cover crops were planted on October 16, 2023, at seeding rates of 70 kg ha^{-1} for cereal rye, 11 kg ha^{-1} for red clover, and a mixture of 5.6 kg ha^{-1} of daikon radish with 22.4 kg ha^{-1} of hairy vetch. Cover crops were terminated on April 4, 2024, using glyphosate at 1.29 kg ha^{-1}, and soybean was planted on May 15, 2024. In the 2024–2025 season, cover crops were planted on September 19, 2024, following the same seeding rates and species composition. Termination was carried out on May 7, 2025, with glyphosate at 1.29 kg ha^{-1}, and the subsequent corn crop was planted on May 5, 2025.

Nitrous oxide emissions

N_2O emissions were measured following the USDA-ARS GraceNET project protocol. A static chamber was installed at least 48 hours before the first measurement to allow the soil to settle. The chamber remained in the field for the season and was only removed during key field operations such as planting. Chambers were accompanied by sensors measuring soil temperature and moisture at two and five inches. Nitrous oxide emissions were measured using a Gasmet GT5000 Terra Portable Gas Analyzer. Measurements were taken at increased frequency depending on the stage of the growing season, with sampling conducted twice per week after planting. A total of 24 sampling dates were collected during 2024 and 28 sampling dates during 2025.

In season soil sampling

Soil samples were collected at least once a month since before planting until harvest. Composite soil samples consisting of five cores total, divided in row and between rows to analyze for nitrate (NO3) and ammonium (NH4). All cores were collected at a depth of eight inches to be transported to the laboratory where 7 grams of soil were weighed and dried in an oven at 105°C. as the following step, 2 duplicates were weighed between 12.0 – 12.060 g and 100 ml of a solution of KCl was added to each to later shake for an hour. Samples were allowed to sit for 45 minutes after shaking and after that time had elapsed, they were filtered with 0.1mg filter paper. After going through the extraction process, samples were analyzed for ammonium and nitrate with Automated Discrete Analyzer SmartChem® 200.

Statistical Analysis

Data was analyzed using R software (version 4.5.1). A randomized complete block design was applied, with cover crop treatments considered as fixed effects. Mean differences among treatments were compared using the LSD test at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Nitrous oxide emissions

In 2024, cumulative N_2O–N fluxes showed clear differences among cover crop treatments throughout the growing season as showed in figure 1. Emissions increased steadily from April to October, with the cereal rye treatment consistently exhibiting the highest cumulative N_2O–N flux, reaching approximately 1.4 kg N ha^{-1} by October. The red clover treatment followed closely, while the no cover and hairy vetch + radish treatments produced comparatively lower emissions, both remaining below 1.0 kg N ha⁻¹. The early rise in emissions under cereal rye suggests that its residue decomposition and associated N immobilization processes stimulated denitrification, particularly under warm and moist conditions during late spring and early summer.

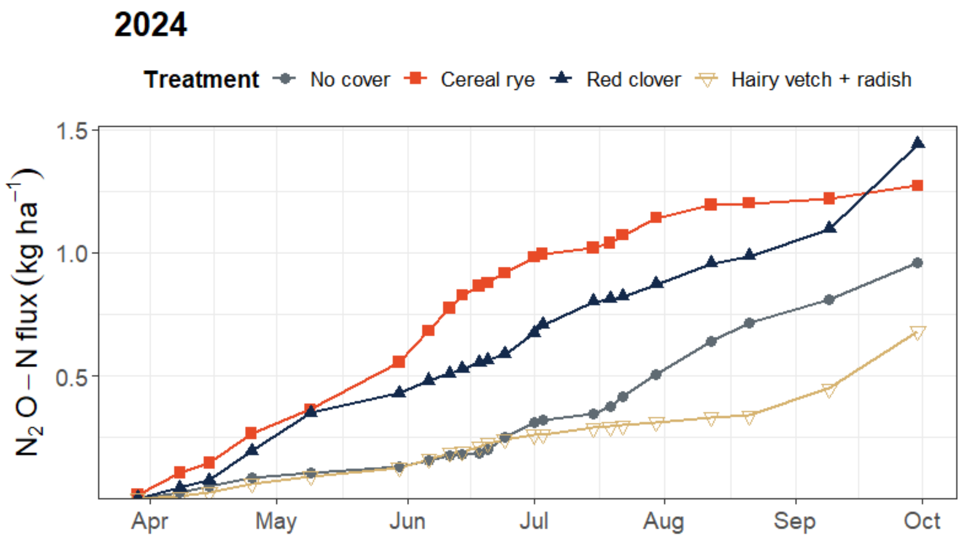

Figure 1. 2024 Cumulative fluxes

In 2025, cumulative N_2O–N fluxes were notably higher overall compared to the previous year, with pronounced differences between treatments as seen in figure 2. Emissions remained low during early spring but began to rise steadily in June, reaching a sharp increase from July to August. The cereal rye treatment showed a rapid escalation in fluxes during this period, exceeding 3.0 kg N ha^{-1} by October, while the no cover treatment reached about 2.0 kg N ha^{-1}. This sharp increase in the cereal rye plots coincided with the fertilizer application period, suggesting strong interactions between cover crop residue decomposition, available nitrogen, and favorable moisture and temperature conditions that promoted denitrification.

Although no statistically significant differences were observed, a noticeable shift in the emission dynamics was evident in 2025. Nitrogen fertilizer was applied in mid-May, which coincided with a divergence in the seasonal emission trends. Additionally, data from the weather station indicated higher rainfall accumulation in July, during which a 51.6% increase in emissions was observed for cereal rye

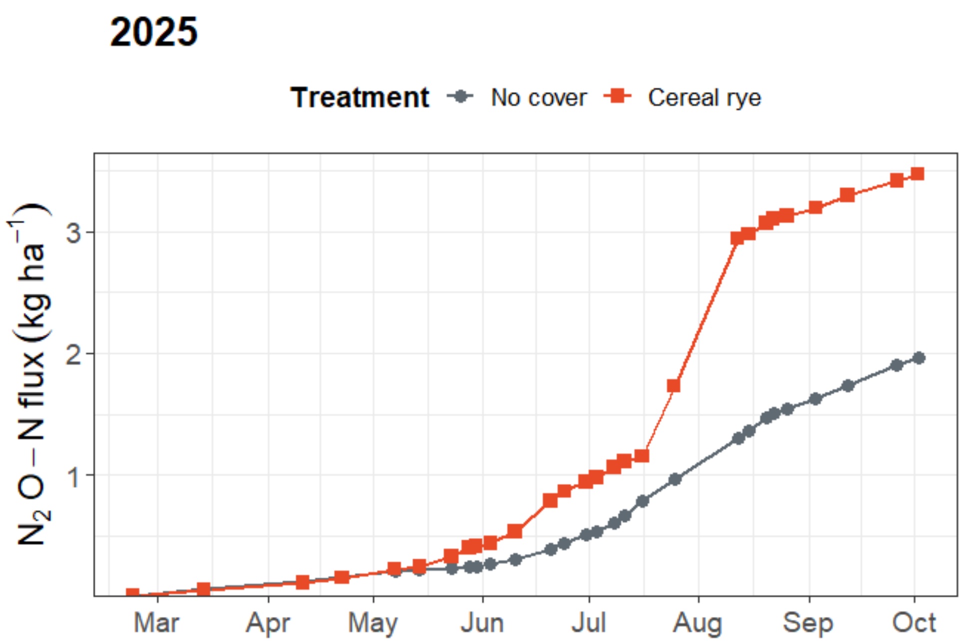

Figure 2. 2025 Cumulative fluxes

Table 1. Yield and yield scale losses summary

CC Treatment	Soybean Yield Mg/ha	cN2O_kgha	Yield-scaled N2O emissions (kg N_2O^- Mg^{-1} grain)	Corn Yield Mg/ha	cN2O_kgha	Yield-scaled N2O emissions (kg N_2O^- Mg^{-1} grain)
Cereal rye	4.4 b	1.25	0.28	13.95	3.46	0.248
No cover	5.0 a	0.958	0.19	14.78	1.11	0.075
Red clover	4.8 a	1.44	0.30			
Vetch & Radish	4.9 a	0.68	0.14			
P-value	0.012	0.59		0.21	0.49	

Soybean yield differed significantly among cover crop treatments ($P = 0.012$), with the no cover, red clover, and vetch & radish treatments producing higher yields (4.8–5.0 Mg ha^{-1}) compared to cereal rye (4.4 Mg ha^{-1}) (Table 1). Despite these differences in yield, cumulative N_2O emissions during the soybean phase were not significantly affected by cover crops ($P = 0.59$). However, yield-scaled N_2O emissions tended to be higher under red clover (0.30 kg N_2O–N Mg^{-1} grain) and cereal rye (0.28 kg N_2O–N Mg^{-1} grain) than under no cover or vetch & radish, indicating that legume-based and high-residue covers may slightly increase N_2O losses relative to grain yield efficiency.

In contrast, no significant differences were found among treatments for corn yield or N_2O emissions in the 2025 season ($P = 0.21$ and $P = 0.49$, respectively). Corn yields ranged from 13.9 to 14.8 Mg ha^{-1} across treatments, while cumulative N_2O emissions varied from 1.11 to 3.46 kg N_2O–N ha^{-1}. The cereal rye treatment exhibited higher cumulative and yield-scaled N_2O emissions compared to the no cover treatment, suggesting that the decomposition of high C:N rye residues and subsequent nitrogen fertilizer application may have stimulated denitrification. Overall, results indicate that while cover crops had limited effects on corn yield, species with contrasting residue quality influenced N_2O emissions and their efficiency relative to grain production.

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