

Soil Nitrous Oxide Emissions Following Crop Residues Management in Corn-Wheat Rotation Under Conventional and No-Tillage Systems

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ABSTRACT: Agricultural activity is the major anthropogenic source of nitrous oxide (N₂O) emissions from terrestrial ecosystems. Conservation agriculture including crop residue management can play a key role in enhancing soil resilience to climate change and mitigating N₂O emissions. We investigated the effects of crop residue rates, including 100 % (R₁₀₀), 50 % (R₅₀), and residue removal (R₀), on N₂O emissions in corn-wheat rotation under conventional (CT) and no-tillage (NT) systems. The key factors evaluated affecting N₂O emissions included soil temperature, soil moisture, soil ammonium, and soil nitrate concentrations. Results showed that the N₂O emissions increased with the increasing rate of residue under both CT and NT systems. Both R₁₀₀ and R₅₀ significantly ($p < .05$) increased the N₂O emissions compared to R₀ during the annual rotation cycle. Soil moisture and mineral nitrogen (ammonium and nitrate) were the main driving factors that stimulated N₂O emission in both CT and NT systems. In the NT and CT systems, cumulative N₂O emissions showed a significant increase with R₅₀ (+75.5 % in NT, +36.5 % in CT) and R₁₀₀ (+134 % in NT, +40 % in CT) as compared to R₀. Furthermore, no significant differences were found between R₁₀₀ and R₅₀ in the CT system, while in the NT system significant increases were observed for R₁₀₀ compared to R₅₀. Overall, our study justified as a first approach only during the first year that crop residue removal led to decreased N₂O emissions under semi-arid conditions. However, due to the deteriorating impact of crop residue removal on crop productivity and soil C sequestration, this management method cannot be considered a sustainable agronomic practice. We suggest long-term studies to determine the appropriate rate of postharvest crop residue to achieve less N₂O emissions and climate-friendly agricultural practices.

KEYWORDS: Greenhouse gases, crop residue, soil management, nitrous oxide emission, conventional tillage, no-tillage, global warming

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Introduction

The three major GHGs which contribute to global warming are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) (Mirzaei et al., 2022; Mohammed et al., 2022; Snyder et al., 2009). Especially, nitrous oxide is considered a potent GHGs because of its greater global warming potential (298 more powerful than CO₂) (Collins et al., 2017; IPCC, 2007). The N₂O is a long-lived radiatively active greenhouse gas with an atmospheric lifetime of 114 ± 10 years and the major source of ozone-depleting reactions (Prather & Hsu, 2010; Ussiri & Lal, 2012; Zaman et al., 2021). Soil N₂O emissions are highly heterogeneous in space and time, given their association with both climatic factors and agricultural management practices (Brown et al., 2001; Rodrigo-Comino et al., 2022). Management practices can affect N₂O emissions by altering soil temperature and water content (Dusenbury et al., 2008; Liebig et al., 2010).

Crop residue retention is one of the soil management methods that have significant advantages in improving soil quality, yield production, and mitigating GHGs (Cherubin et al., 2021; Johnson et al., 2017; Stewart et al., 2015). Crop residue can directly affect N₂O emissions by regulating mineral nitrogen (N) substrate availability (Essich et al., 2020; Pelster et al.,

2013; Seiz et al., 2019), and indirectly by changes in the soil environment (Smith et al., 2007). Enhanced N₂O emissions have been reported after the application of high amounts of crop residue (Schmatz et al., 2020). In contrast, some researchers reported recently that the addition of residues intensifies the recovery of microbial C and increases moisture, microbial activity, and thus oxygen consumption, which consequently leads to anaerobic conditions (Baggs et al., 2006; Taghizadeh-Toosi et al., 2021) and thereby the reduction of N₂O to N₂.

Tillage operations can influence the soil's physical properties (structure, aeration, moisture, temperature), C and N availability, microbial activity, and oxygen consumption (Baggs et al., 2006; Monti et al., 2021), which likely affect the N₂O emissions (Badagliacca et al., 2018; Plaza-Bonilla et al., 2014). Baggs et al. (2003) and Rochette et al. (2008) have reported higher N₂O emissions under no-tillage compared to conventional tillage systems. Incremental N₂O emissions under the NT system were attributed to the enhanced denitrification, existence of anaerobic conditions, and availability of readily degradable carbon. While others indicated lower emissions for no-tillage systems (Gregorich et al., 2008; Yoo et al., 2016) due to the better aeration, increased nitrification, and sequential



denitrification, and nitrification by denitrifiers and nitrifiers under favorable soil environmental conditions.

Corn-wheat rotation is one of the major crop rotations in Iran and large amounts of crop residues are obtained from it annually. Plant residues are removed from agricultural lands after harvest to provide various purposes such as livestock fodder, fuel, construction, etc., and the rest is burned, which reduces soil quality and emits GHGs. Therefore, the optimal management of crop residues, such as maintaining an appropriate amount of crop residues in agricultural lands, in addition, to meeting the above objectives, ensures sustainable agricultural goals in such a system. According to a comprehensive review of the relating literature, there is no available information about the effect of crop residue management practices on GHGs emissions, especially N_2O emissions, from agricultural soils.

We hypothesized that soil N_2O emissions increase with the application of a higher amount of crop residue compared to cases without residue. Crop residue decomposition adds more nitrogen and carbon to the soil and retains higher soil moisture which creates favorable conditions for production and emissions of N_2O from the soil. Further, we hypothesized that N_2O emissions would be higher in the no-tillage (NT) system compared to the conventional tillage (CT) system during the first year of application. In the NT system, lack of soil disturbance and retention of crop residue on the soil surface lead to greater soil moisture, increased microbial activity, and oxygen consumption, and, consequently, higher N_2O emissions. The objective of this study was to quantify the effects of different crop residue rates on N_2O emission in corn-wheat rotation under conventional tillage (CT) and no-tillage (NT) systems.

Material and Methods

Methodological framework

This research took place between July 2018 and July 2019 and was conducted at the University of Tehran, Agriculture Research Station of the College of Agriculture and Natural Resources. Two fields with 15 years of cultivation history of wheat (*Triticum aestivum* L.) - corn (*Zea mays* L.) rotation system were selected for this experiment. The annual average (1980–2019) rainfall and temperature of the area are 245 mm and 13.7 °C respectively. The dimension of each of the two fields was 11 × 16 m. Each of them had different strategies of management. The first one is characterized by the conventional tillage (CT) system and the second one by the no-tillage (NT) system.

Each field had been split into nine plots of 3 × 4 m: a complete randomized block strategy was implemented with three replications. The distance between the sites of replications was 2 m and the distance between plots was 1 m. The physicochemical soil properties of both NT and CT fields have been reported previously (Mirzaei et al., 2021).

The soil texture type was sandy loam in the CT system and clay loam in the NT system. The studied soils in both systems

had a pH value of more than seven at both 0 to 10 and 10 to 20 cm soil depths and there were no salinity problems. In both soil depths, the amount of organic carbon content in the CT system was almost the same and less than 1%, while in the NT system its value for both depths was more than 1%. The amount of total nitrogen was in the range of 0.07% to 0.09% and 0.08% to 0.11% in the CT and NT systems respectively. The amounts of available phosphorus and potassium were higher than the critical levels in the NT system but less than the critical levels in the CT system.

Field research method

The applied research method was based on the treatment of the soils with winter wheat residue. This treatment was implemented through the homogeneous spreading of wheat residue in different concentrations on both soil types, CT and NT, before the sowing of corn in July 2018. The three concentrations used were 3.5 t ha⁻¹ (100%, R_{100}); 1.75 t ha⁻¹ (50%, R_{50}); and no-residue (0%, R_0). These different rates of wheat residue (C:N=66) were applied on the plots in which the two fields were divided.

In the CT system, the crop residue was incorporated into the soil to the depth of 35 cm using a moldboard plow, while in the NT system, crop residue remained on the soil surface. Corn was planted with a seed density of 8 seeds m⁻². The sowing of corn was done in rows with a 75 cm distance between them.

A seeding machine was adapted to both fields (CT and NT) to maintain the original management style. In the CT field, the sowing was achieved through a previous preparation of the soil using a moldboard plow down to 35 cm depth. The NT field was sowed with a single coulter plow to loosen the soil. After disking and leveling the CT soil, basal NPK fertilizers were uniformly distributed on the soil surface in both fields. For this purpose, 23 kg N ha⁻¹ as Urea, 30 kg K ha⁻¹ as Potassium sulfate, and 30 kg P ha⁻¹ as Superphosphate were used. Irrigation was carried out directly after seeding using the sprinkler method. Subsequent irrigation events were performed based on environmental conditions and 7 to 10-day intervals. At eight leaves and ten leaves stages, extra layers of fertilizer including 37 and 125 kg N ha⁻¹ as Urea were used, respectively. Additionally, at the four leaves and eight leaves stages, weeds were removed by hand. The same process was repeated in October 2018, after the corn harvest.

Winter wheat was planted in November 2018 with a seed density of 350 seeds m⁻². The row spacing for wheat was 13.5 cm. Before the planting, we applied basal fertilizer treatment, furthermore, corn residue (C:N=58) was spread in three different concentrations on both fields. 1.8 t ha⁻¹ (100%, R_{100}) and 0.9 t ha⁻¹ (50%, R_{50}) corn residue was applied; and there was a plot to study the case of no-residue (0%, R_0). The fertilization contained 23 kg N ha⁻¹ as Urea, 67 kg K ha⁻¹ as Potassium sulfate, and 40 kg P ha⁻¹ as Superphosphate. Finally, another dose of N was provided for stem elongation, late

tillering, and spiking (51, 51, and 23 kg N ha⁻¹ as Urea, respectively) (Supplemental Table S1).

N₂O emissions measurement

The N₂O emissions were measured using the sampling protocol of GRACEnet Chamber-based Trace Gas Flux Measurement (Parkin & Venterea, 2010). The samples were collected in both fields (CT and NT) for 7 to 10 days intervals and every 2 weeks (during wintertime) using the static closed chamber method (Oertel et al., 2012). The chamber was 12.5 cm high and had a diameter of 15 cm constructed on polyvinyl chloride (PVC). It has ports (rubber septum) for gas sampling placed on the top. Collars were only removed during management practices. When plants exceeded the chamber height, they were shortened. Gas sampling was performed during the day from 9 to 10 am at 0, 30, and 60 minutes by inserting a needle attached to a 20 ml syringe in the sampling port and transferring in 12-mL evacuated glass vials sealed with butyl rubber septa (Labco Exetainer, UK). The concentration of N₂O in gas samples inside the vials was determined with a gas chromatograph (Teif Gostar Faraz, TG 2552, Iran; Brucker, Germany) equipped with an electron capture detector (ECD) in the lab. Temperatures of the column, injector, and detector were set at 65, 100, and 280 °C, respectively. Nitrous oxide flux was calculated as changes in linear concentration gradient over time and from the ratio between chamber volume and soil surface area (Liebig et al., 2010). The flux rate of N₂O was calculated based on µg m⁻² h⁻¹. Cumulative amounts of N₂O fluxes (kg N ha⁻¹ year⁻¹) were calculated using linearly interpolating data points and integrating the underlying area (Sainju et al., 2012; Wegner et al., 2018). Before interpolation and integration, the flux rates were converted to daily emissions.

Complementary measurements

For measuring the elemental composition of plant residue, the wheat and corn residues were sampled after the respective harvests. Then, samples were dried and finely powdered to assess them under laboratory conditions (Mirzaei et al., 2021). We analyzed organic carbon (OC) applying the Walkley and Black (1934) method, total nitrogen (TN) in plant residue using the Kjeldahl method (Jones, 2001), and P and K concentrations on dried-ash samples using spectrophotometric and flame photometric methods (Jones, 2001).

Additionally, an analysis of the correlation between gas emission and soil quality was conducted. Soil quality was determined by such properties as water content, temperature, and mineral N, including ammonium (NH₄⁺) and nitrate (NO₃⁻). Soil temperature was measured simultaneously with gas sampling with a thermometer placed at 10 cm depth next to the collars to avoid disturbance. Three soil samples (0–10 cm) were taken from each plot and mixed and homogenized into one pooled soil sample. Volumetric soil moisture of samples was

determined using dried soil samples at 105 °C multiplied by soil bulk density. The rest of the soil samples was stored at -4 °C for further analyses. Mineral N (NH₄⁺-N and NO₃⁻-N) of soil samples were determined by the KCl extraction method (Page et al., 1982).

Statistical analysis

The statistical analysis was conducted using the Analysis of Repeated Measures procedure in general linear models (GLM). The SAS software version 9.4 (SAS Institute, Cary, NC, USA) was used. Duncan's method allowed us to compare measurements and analyze them at a 0.05 probability level. Pearson linear correlation analysis was used to determine the relationships between measured soil parameters and N₂O emission.

Results and Discussion

Nitrous oxide emissions during the corn–wheat crop rotation under the tillage systems

During corn–wheat crop rotation, N₂O emissions ranged from 0 to 375 and from 0 to 44 µg m⁻² h⁻¹ in residue treatments under NT and CT systems, respectively (Figures 1A and 2A). Large variability in N₂O emissions has also been reported since production and emission of N₂O occur through the activity of numerous groups of soil microbiota, various microbial processes (denitrification, nitrification, and chemodenitrification), agricultural practices, and soil conditions (Grant & Pattey, 2003; Hénault et al., 2012; Ma, Sun et al., 2013; Ussiri et al., 2009; Zaman et al., 2021). Also, successive periods of drying and wetting cycles as a result of irrigation and rainfall events were among the other causes of fluctuations in N₂O emissions. Brentrup et al. (2000) reported that the presence of wetting and drying sequences can increase N₂O emissions due to their role in oxygen availability in determining the contribution of nitrification and denitrification to N₂O production. Irrigation also can increase N₂O emissions by increasing soil water availability, microbial activity, C and N mineralization, and respiration (Sainju et al., 2010).

N₂O emissions were observed in summer during the corn growing season as well as in late winter and at the beginning of spring during the wheat growing season in both tillage systems. In the NT system, the highest recorded emissions were observed at two sampling times: 16/08/2018 (during the corn growing season), and 11/5/2019 (during the wheat growing season) (Figure 1A). Also, in this system, zero emissions of N₂O were observed in late winter 2019. In the CT system, two peak sampling dates (23/3/2019, and 12/4/2019) were observed during the wheat growing season with the highest N₂O emission (Figure 2A). In addition, at several sampling times, mainly from early autumn 2018 to late winter 2019, the emission rates were zero in this system. The lack of N₂O emissions at the mentioned times is probably due to decreasing fertilizer effect as well as low temperature for nitrification and denitrification

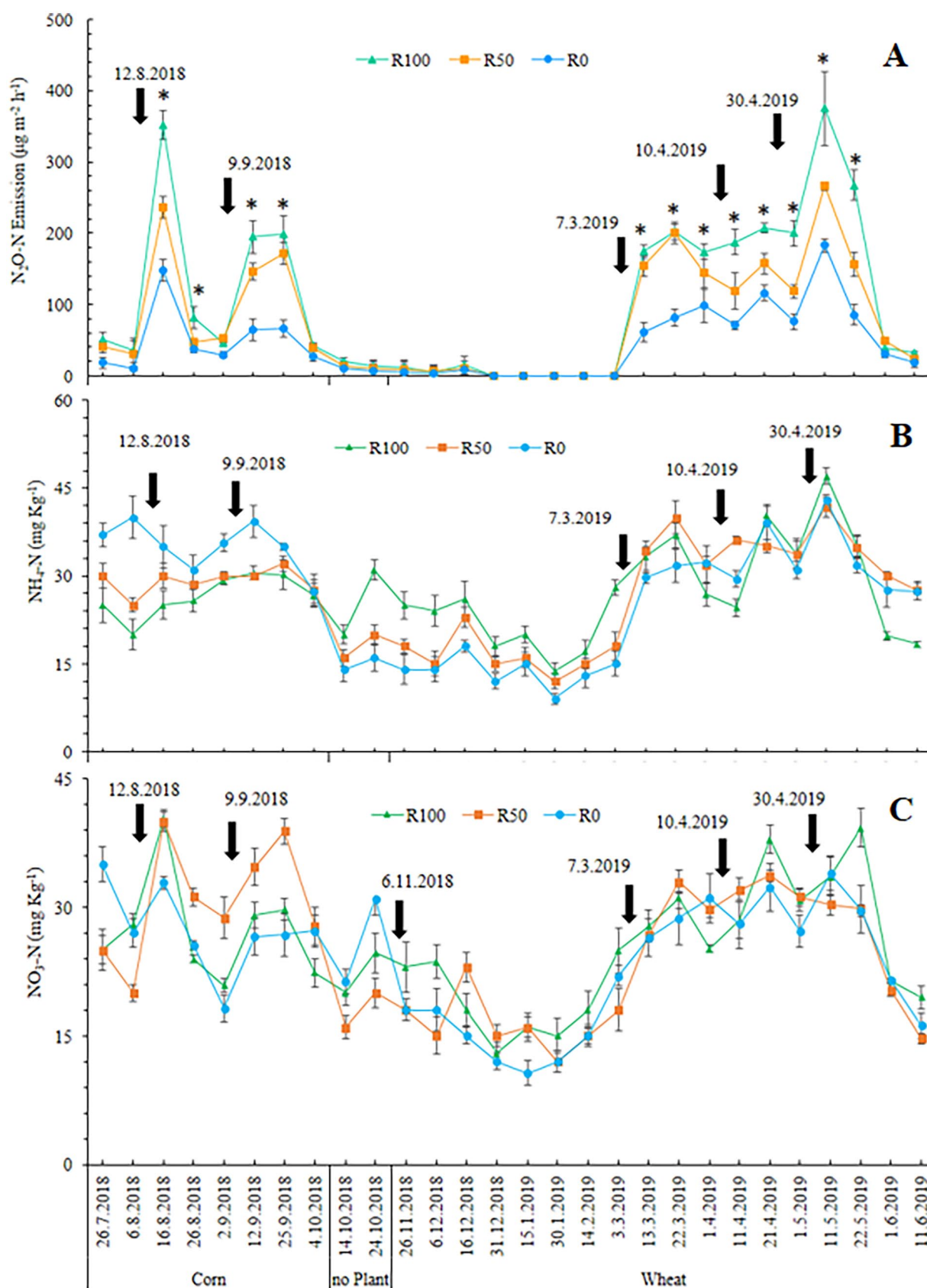


Figure 1. Residue rate effect on daily soil N₂O-N emission (A), NH₄ (B), and NO₃ (C) at the time of greenhouse gas measurement in corn-wheat rotation under the no-tillage (NT) system. Bars represent standard error. The bold black arrows indicate fertilization events. Asterisk (*) shows a significant difference between residue levels within a day at $p < .05$. Zero values are from measurements.

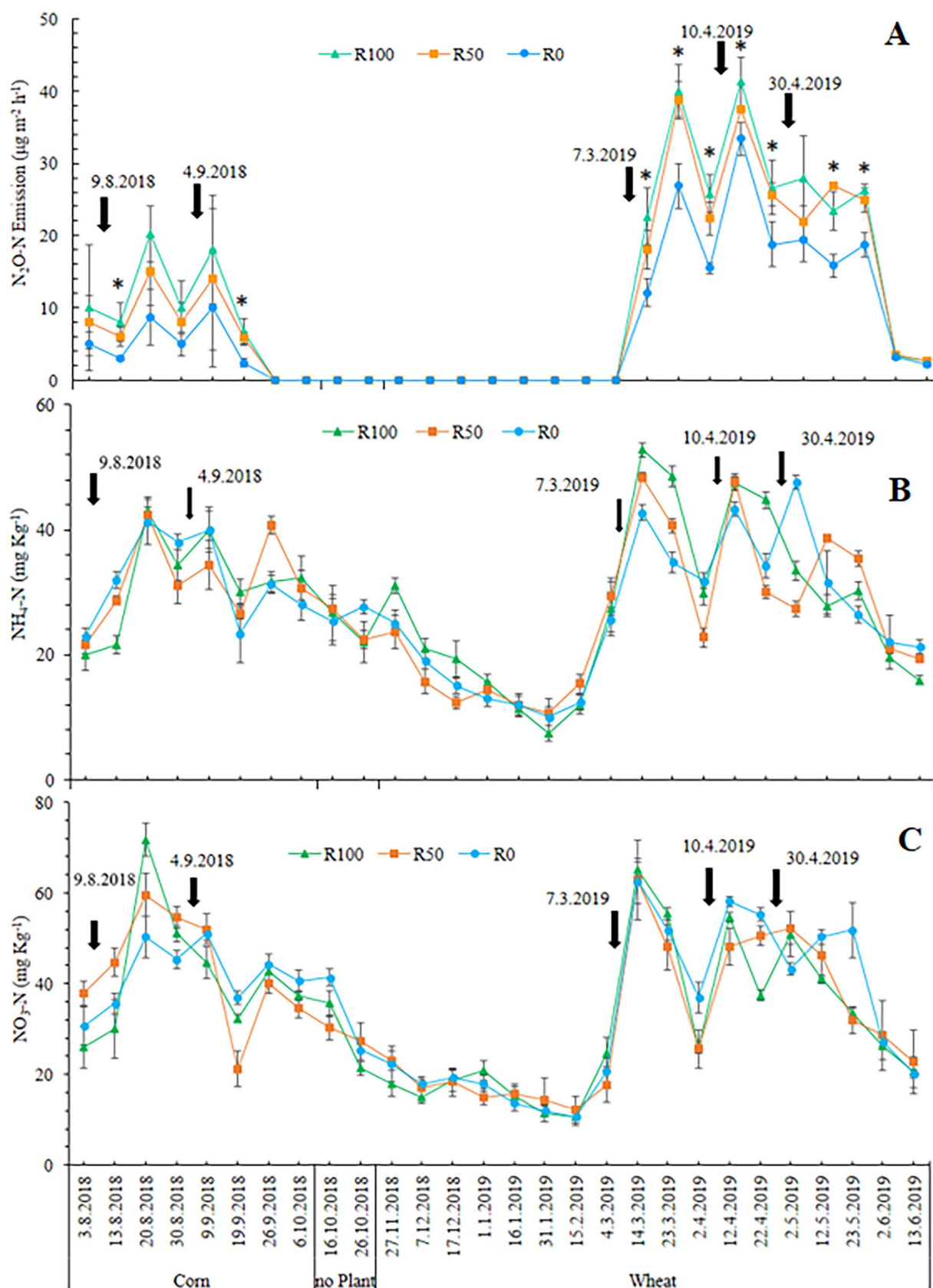


Figure 2. Residue rate effect on daily soil N₂O-N emission (A), NH₄ (B), and NO₃ (C) at the time of greenhouse gas measurement in corn-wheat rotation under conventional tillage (CT) system. Bars represent standard error. The bold black arrows indicate fertilization events. Asterisk (*) shows a significant difference between residue levels within a day at $p < .05$. Zero values are from measurements.

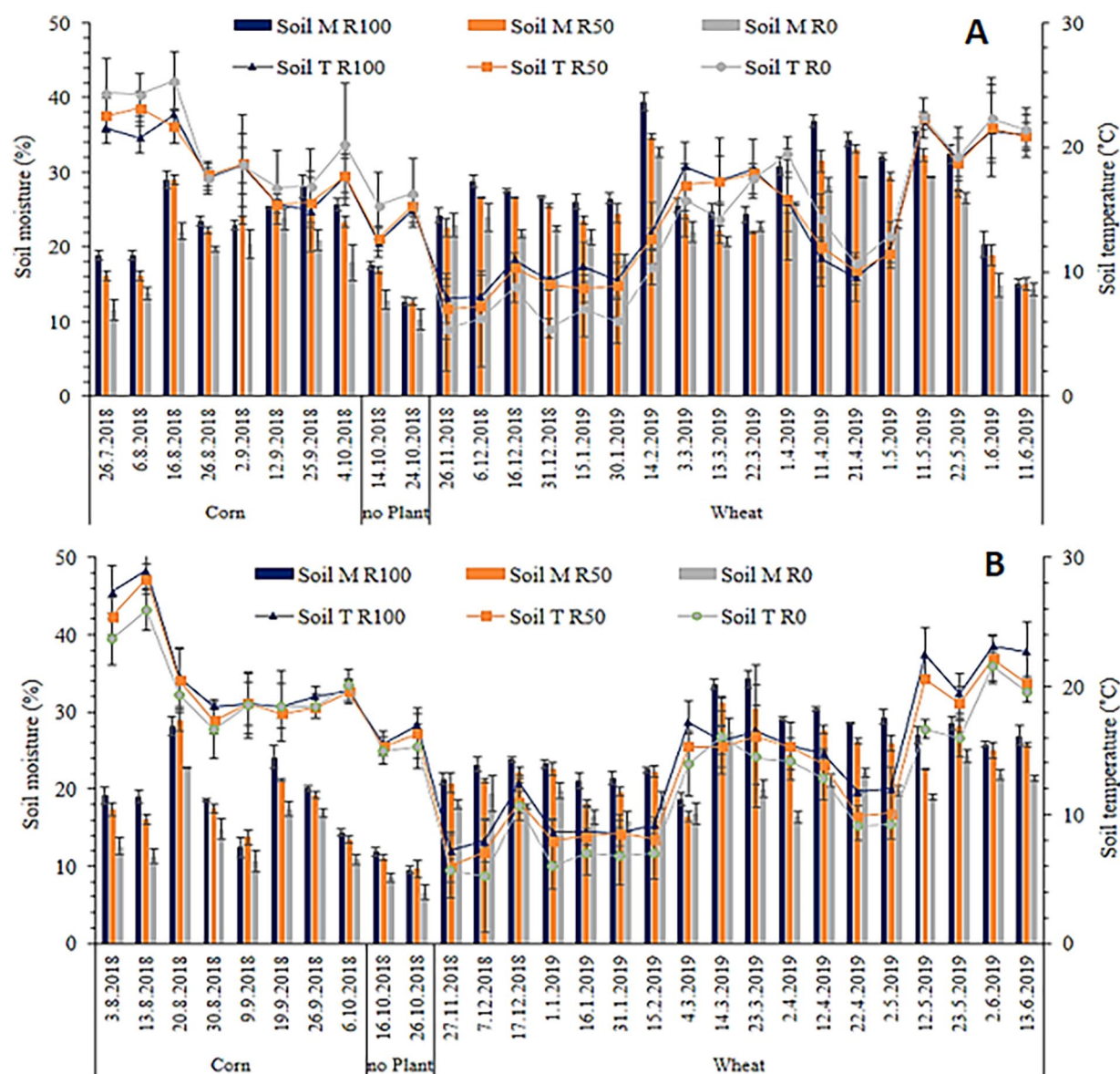


Figure 3. Residue rate effect on daily soil moisture (M) and temperature (T) at the time of greenhouse gas measurement in corn-wheat rotation under a no-tillage (NT) (A) and conventional tillage (CT) (B) systems. Bars represent standard error.

processes (Ussiri et al., 2009; Wang et al., 2011). Increased emissions in spring can be the consequence of reduced biological activity due to temperature restrictions (Supplemental Figure S1, Figure 3) for microbial activity in winter, which leads to accumulation of available substrate, changing the season to spring and favorable conditions increases microbial activity and production and emissions of gas (Christensen & Tiedje, 1990). Previous studies have also reported the increase in N_2O emissions due to the change of seasons from winter to spring mainly due to the increase in air and soil temperature (Jacinthe & Lal, 2004; Ussiri et al., 2009). The rate of N_2O emissions was increased after fertilization events (Figures 1 and 2) due to the abundant availability of substrate for nitrification and denitrification. The reason for the increase in N_2O emissions after fertilization is the provision of N as one of the essential components for the production and release of N_2O

(Zaman et al., 2021), and it was justified by the positive and strong correlation of N_2O emissions with the ammonium and nitrate (Table 1, Figures 1 and 2).

The effect of crop residue on nitrous oxide emissions under the tillage systems

In general, N_2O emissions increased with the increasing residue retention at all sampling times in both tillage systems. Complete residue retention treatment (R_{100}) and 50% residue retention (R_{50}) resulted in a significant increase ($p \leq .05$) compared to the residue removal treatment (R_0). Differences were not significant between R_{100} and R_{50} treatments at several sampling times. Also, N_2O emissions increased with the increasing residue rate, and R_{100} and R_{50} resulted in significant increases ($p \leq .05$) in N_2O emissions compared to residue removal treatment (R_0) at

Table 1. Correlations of N₂O Emission With Selected Soil Properties for Different Rates of Plant Residues Under a No-Tillage (NT) and Conventional Tillage (CT) Systems.

TILLAGE SYSTEM	RESIDUE RATE	SOIL PARAMETERS	N ₂ O EMISSION	
			PEARSON CORRELATION (R)	P VALUE
NT	R ₁₀₀	Temperature	0.336	.081
		Moisture	0.513**	.005
		NH ₄ -N	0.818**	.000
		NO ₃ -N	0.837**	.000
	R ₅₀	Temperature	0.348	.070
		Moisture	0.464*	.013
		NH ₄ -N	0.880**	.000
		NO ₃ -N	0.828**	.000
	R ₀	Temperature	0.410*	.030
		Moisture	0.509**	.006
		NH ₄ -N	0.847**	.000
		NO ₃ -N	0.668**	.000
CT	R ₁₀₀	Temperature	0.049	.806
		Moisture	0.752**	.000
		NH ₄ -N	0.752**	.000
		NO ₃ -N	0.768**	.000
	R ₅₀	Temperature	0.078	.692
		Moisture	0.756**	.000
		NH ₄ -N	0.739**	.000
		NO ₃ -N	0.676**	.000
	R ₀	Temperature	0.027	.890
		Moisture	0.645**	.000
		NH ₄ -N	0.655**	.000
		NO ₃ -N	0.728**	.000

**Correlation is significant at the .01 level.

*Correlation is significant at the .05 level.

most sampling times. Furthermore, the difference between R₁₀₀ and R₅₀ treatments was not significant at any sampling times.

Considering the whole crop rotation period, under both CT and NT systems, significant increases in N₂O emission were observed in treatments R₁₀₀ and R₅₀ compared to R₀. In the NT system, significant differences in the average amount of N₂O emission were observed among residue treatments where R₁₀₀ and R₅₀ resulted in significant increases of 132 and 74.5 % in N₂O emissions compared to the residue removal treatment (R₀), respectively (Figure 4A). Also, in this system, significant increases ($p \leq .05$) in N₂O emission were observed in R₁₀₀ compared to R₅₀. In the CT system, R₁₀₀ and R₅₀ led to significant increases of 41 and 37.5 % compared to R₀, respectively

(Figure 4B), but the differences between R₁₀₀ and R₅₀ were not significant.

Accelerated crop residue decomposition in the CT system due to tillage, reduced their effects on moisture retention as one of the main drivers of N₂O emissions, which consequently led to no significant differences between R₁₀₀ and R₅₀. A significant increase in N₂O emissions in R₁₀₀ compared to R₅₀ under the NT system could be attributed to higher soil moisture in higher residue rates (R₁₀₀) and a more pronounced effect on nitrous oxide emissions. Higher N₂O emissions, as a result of increased crop residue, were in line with previous research findings in the United States, Australia, and Germany (Barton et al., 2016; Jin et al., 2014;

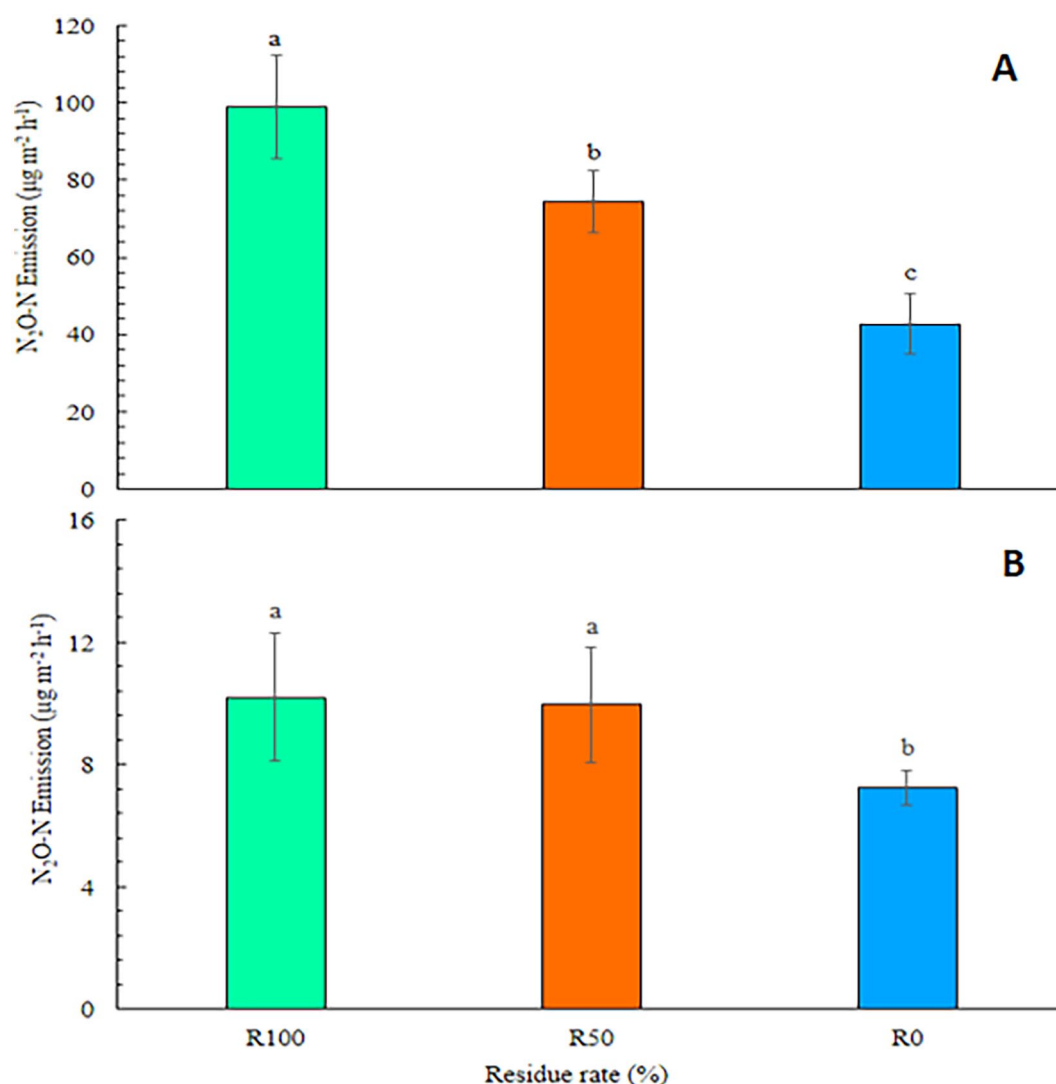


Figure 4. The effect of crop residue rates on mean N₂O-N emission during corn-wheat rotation under a no-tillage (NT) (A) and conventional tillage (CT) (B) systems. Means with the same letter are not significantly different. Bars represent standard error ($n=3$).

Seiz et al., 2019). In this study, the increase in N₂O emissions with increasing residue could be attributed to various factors, including the direct effect of plant residues in providing C and N for microorganisms responsible for N₂O production processes (nitrification and denitrification) (Schmatz et al., 2020; Weiler et al., 2018).

Crop residues directly stimulate the emission of N₂O through the input of N content from the plant residue, which was confirmed by a positive and significant correlation between N₂O emission and moisture content in both CT and NT systems (Table 1). In residue removal treatment (R₀), due to factors such as reduced moisture and reduced availability of substrate due to lack of proper soil cover, N₂O emissions are reduced. Jin et al. (2014) attributed lower greenhouse gas emissions in plant residue removal treatment to reduced C and N uptake into the soil, as well as microclimatic differences related to changes in soil cover. However, other studies reported different findings when removing crop residues from agricultural land increased the N₂O emissions.

Tenesaca and Al-Kaisi (2015) found that the complete removal of crop residue from the soil increases the emission of N₂O gas compared to the maintenance of large amounts of crop residue, which is contrary to the findings of the current study. Also, the research of Johnson and Barbour (2010) showed that removing corn residues compared to their preservation did not change the amount of N₂O emissions. In addition, studies by Zhang et al. (2015) on the integrative effects of soil tillage and straw management on crop yields and greenhouse gas emissions in a rice-wheat cropping system showed that in comparison with the control, returning residue to the soil had no significant effect on N₂O emissions during the wheat season and the entire rice-wheat cycle.

Cumulative N₂O emissions

In the corn-wheat rotation under the tillage systems, with an increasing amount of residues, the cumulative N₂O emission also increased (Figure 5). Significant increases ($p < .05$) in

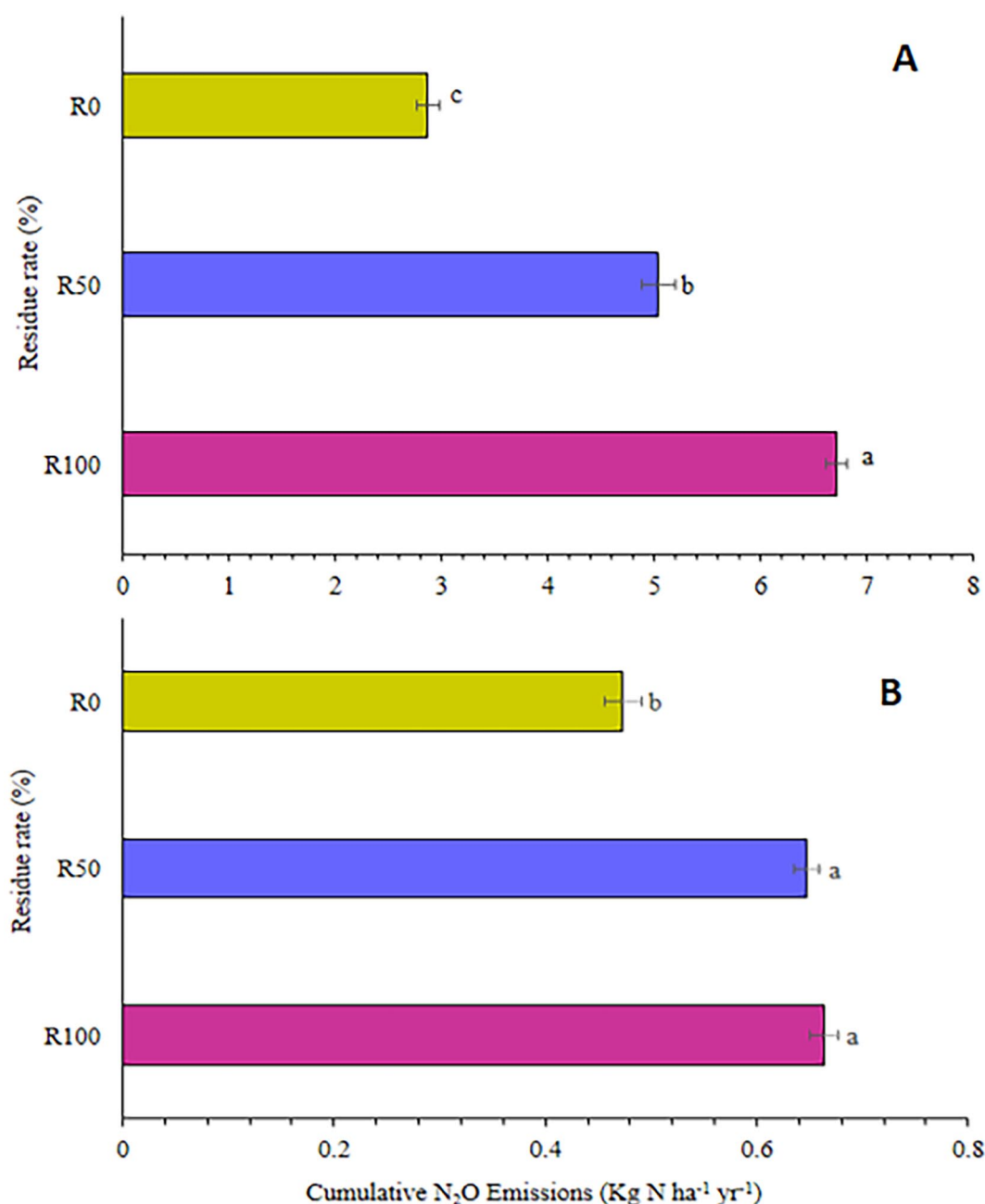


Figure 5. Residue rate effect on annual cumulative N₂O-N (kg N ha⁻¹ year⁻¹) under a no-tillage (NT) (A) and conventional tillage (CT) (B) systems. Means with the same letter are not significantly different. Bars represent standard error ($n=3$).

cumulative N₂O emission were observed for R₁₀₀ and R₅₀ compared to R₀. The annual cumulative N₂O emissions in R₁₀₀ (6.7 kg N ha⁻¹ year⁻¹) and R₅₀ (5 kg N ha⁻¹ year⁻¹) were respectively 134% and 75.5% higher than R₀ (2.87 kg N ha⁻¹ year⁻¹) under NT system (Figure 5A). In the CT system, compared to R₀ (0.47 kg N ha⁻¹ year⁻¹), R₁₀₀ (0.66 kg N ha⁻¹ year⁻¹) and R₅₀ (0.64 kg N ha⁻¹ year⁻¹) resulted in 40 and 36.5% increases for cumulative N₂O-N emissions (Figure 5B). Also, cumulative N₂O emissions were significantly ($p < .05$) higher in the NT system than in the CT system (Supplemental Figure S2).

Increased cumulative N₂O emissions in R₁₀₀ and R₅₀ treatments compared to R₀ treatment could be due to high soil

moisture and N from residue decomposition in these treatments, all of which ultimately create favorable conditions to increase production and emissions. Whereas, low soil moisture content and mineral N are the reasons for decreased emission in residue removal (Sainju et al., 2012; Toma & Hatano, 2007). Previous studies have also reported that the differences in cumulative emissions of GHGs are due to differences in soil moisture and temperature (Lu et al., 2015; Sainju et al., 2010). The findings of this study are consistent with the results of Vasconcelos et al. (2018). They reported the lowest cumulative emission of N₂O in residue removal compared to other treatments.

Drury et al. (2021) reported that reducing residue rate increased the cumulative emissions of N_2O under both conventional and no-tillage systems and the highest emissions were related to the complete removal of residue. They attributed the reduction of N_2O emissions in residue conservation treatments to N immobilization, which reduced the N required to produce N_2O . Also, higher amounts of available C under residue treatments that lead to the conversion of N_2O to N_2 were other reasons given by these researchers for reduced N_2O emissions. Guzman et al. (2015) found no significant differences in the cumulative emissions of N_2O among the 100% and 50% residue, and the residue removal due to the reason that the soil moisture status under these treatments was not a limiting factor for N_2O emissions.

Higher cumulative N_2O emissions in the NT system compared to the CT system have also been reported in previous studies (Ma, Sun et al., 2013; Pelster et al., 2011; Rochette et al., 2008; van Kessel et al., 2013). Higher oxygen concentration in the soil due to soil disturbance under the CT system could be mentioned for lower cumulative N_2O emissions (Baggs et al., 2003, 2006). In the NT system, higher soil density and water content provide favorable anaerobic conditions for the production and emission of N_2O emissions. Previous studies have also reported the strong effect of soil moisture content on the magnitude of N_2O emissions under no-tillage and tillage systems (Almaraz et al., 2009; Boeckx et al., 2011; Ma, Sun et al., 2013). Furthermore, in the current study, soil texture type in the NT system (clay loam) could also be another reason for higher N_2O emissions compared to that in the CT system (soil texture: sandy loam). The existence of more capillary pores in finer textured soils than in light-textured soil helps them to retain soil water more strongly and create and maintain long-term anaerobic conditions which consequently led to higher emissions of N_2O than in sandy soils (Bouwman et al., 2002; Lesschen et al., 2011; Parton et al., 1996; Stehfest & Bouwman, 2006; Weier et al., 1993; Zaman et al., 2021). Soil texture influences N_2O emissions due to its effect on aerobic or anaerobic conditions, microbial population, and availability of nitrogen and soil organic carbon (Charles et al., 2017; Lesschen et al., 2011; Meurer et al., 2016; Wang et al., 2021; Xu et al., 2013).

Conclusions

The N_2O emissions during corn-wheat rotation were highly variable which is mainly attributed to the nature of N_2O gas production and release as well as environmental and soil factors. Regardless of tillage systems, crop residue significantly increased N_2O emissions compared to residue removal. Greater N_2O emissions coincided with the application of higher residue rates, where full retention of crop residue induced the highest N_2O emissions in both tillage systems. Furthermore, cumulative N_2O emissions were higher in no-tillage systems than in conventional tillage systems. We conclude that to

develop more efficient management strategies in agricultural systems, long-term field studies are needed to better assess the GHGs emissions, better soil quality, and crop performance following crop residue management.

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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