Nitrous Oxide Emissions from Continuous Winter Wheat in the Southern Great Plains

Tracy M. Wilson,* Blake McGowen, Jeremiah Mullock, D. B. Arnall, and Jason G. Warren

ABSTRACT

Fertilizer-induced N_2O-N emissions (the difference between fertilized and unfertilized soils) are estimated to be 0.01 kg N_2O-N kg^{-1} of applied N. One approach to limiting N_2O-N production in soils is by improving nitrogen use efficiency (NUE) in dryland agricultural systems. However, baseline data on the rate of emissions is needed to determine the potential impact that these efforts might have on N_2O-N concentrations in the atmosphere. A study was established in a long-term continuous winter wheat (*Triticum aestivum* L.) fertility experiment in Stillwater, OK, to determine the effects of N rate on N_2O-N emissions from a dryland winter wheat–summer fallow system in the southern Great Plains of the United States to fill this knowledge gap. Cumulative emissions of N_2O-N varied from year to year and were influenced by environment and N rate. Emissions following N fertilizer application were typically highest following N application, as well as toward the end of the summer fallow period, when summer rainfall and temperatures were conducive for N_2O-N production chambers within plots historically receiving 134 kg N ha^{-1} annually went unfertilized for the 2012–2013 and 2013–2014 crop years and produced N_2O-N emissions equivalent to the 45 and 90 kg N ha^{-1} rate treatments. Annual cumulative emissions ranged from 0.009 to 0.024 kg N_2O-N kg^{-1} N applied with an average of 0.015 kg N_2O-N kg^{-1} N applied, illustrating the variability in N_2O-N emissions.

Nitrous oxide is a naturally occurring greenhouse gas (GHG) that is 310 times more potent than carbon dioxide (CO_2). Therefore, relatively small emissions of N_2O-N into the atmosphere can have a large impact on the atmospheric GHG concentrations. Furthermore, it is estimated that approximately 94% of the total N_2O-N emitted from anthropogenic activities in the United States is from agriculture soil management, specifically application of N fertilizers (USEPA, 2015). The production of N_2O-N in soils is a result of both nitrification and denitrification. The addition of N fertilizer increases the concentration of NO_3–N and/or NH_4–N in the soil thereby increasing the amount of N available to microbes in the soil for nitrification or denitrification and potential loss as N_2O-N (Bremner and Blackmer, 1978). Fertilizer-induced N_2O-N emissions (the difference between fertilized and unfertilized soils) are estimated to be 0.01 kg N_2O-N kg^{-1} of applied N with an uncertainty range of 0.03 to 0.003 kg N_2O-N kg^{-1} (Ravishankara et al., 2009).

In the northern Great Plains region of the United States it was found that four different fertilized cropping systems all exhibited similar trends in N_2O-N emissions. The following crop systems were evaluated for N_2O-N emissions over a 2-yr period: conventional tillage (CT) winter wheat–fallow, no-till (NT) winter wheat–fallow, NT winter wheat–spring wheat, NT winter wheat–spring pea (*Pisum sativum* L.), and alfalfa (*Medicago sativa* L.)–perennial grass (control). All systems except the alfalfa system were fertilized with a moderate (100 kg N ha^{-1}), and a high (200 kg N ha^{-1}) N rate in addition to unfertilized control treatments. Following fertilization all systems had N_2O-N emissions above the corresponding unfertilized control treatments for approximately 10 wk after fertilization. Elevated N_2O-N flux was also measured during freeze–thaw cycles in the winter and spring. The post-fertilization periods and the freeze–thaw cycles accounted for the 84% of the emissions during the 2-yr study. The fertilizer-induced N_2O-N emissions were 0.26% of applied N with significant differences between the moderate and high rates for the CT and NT wheat–fallow and significant differences between all three rates for NT wheat–wheat and NT wheat–pea systems (Dusenbury et al., 2008).

Since the production of N_2O-N in soil occurs naturally there is no method that will eliminate emissions entirely. A meta-analysis by Akiyama et al. (2009) found that urease inhibitors (UIs) did not reduce emissions of N_2O-N. Polymer coated fertilizers (PCFs) and nitrification inhibitors (NIs) have been

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Abbreviations: CT, conventional tillage; DST, days since treatment; GHG, greenhouse gas; IPCC, Intergovernmental Panel on Climate Change; NI, nitrification inhibitor; NT, no-till; NUE, nitrogen use efficiency; PCF, polymer coated fertilizer; UI, urease inhibitor.

shown to reduce N_2O-N emissions by 35 and 38%, respectively, although the reductions from PCFs are less consistent than the reductions from NIs (Akiyama et al., 2009). Decreasing N fertilizer applications will reduce emissions of N_2O-N from the soil; however the reductions in N_2O-N emissions from decreasing N fertilization can come at the expense of lower grain yields. The most reasonable approach to limiting N_2O-N production in soils is by improving NUE in agricultural systems. However, before efforts to assess the impact of management on N_2O-N emissions can be made for a regional production system, baseline data is needed to determine the potential impact that these efforts might have on N_2O-N concentrations in the atmosphere.

There are few studies examining the basic effects of N fertilization rate on N_2O-N emissions from dryland winter wheat in semiarid environments. In Germany, Kaiser and Heinemeyer (1996) found large seasonal variability in measured N_2O-N emissions from a sugar beet (*Beta vulgaris* L.)–winter wheat–winter barley rotation. The high N_2O-N flux rates found were measured within a week of N fertilizer application and also after rainfall events that were sufficient to fill 50% of the soil pore volume with water. Variability between years was also found to be high. Barton et al. (2008) found that over half of the annual emission of N_2O-N from dryland winter wheat in Australia occurred while the field was fallow during summer and was not affected by N fertilization. The annual emissions for the single year measured were 0.02% of applied N, which is considerably lower than the Intergovernmental Panel on Climate Change (IPCC) estimate of 1.25%. The authors suggest that the IPCC value may not accurately reflect the N_2O-N emissions from soils in a semiarid environment as there is limited data available regarding N_2O-N emissions from rain-fed cropping systems in semiarid regions. More site-years of measurements would be required to determine the accuracy of the IPCC estimate for rain-fed winter wheat in semiarid regions. The southern Great Plains of the United States has no data evaluating the impact of N application rate on N_2O-N emission from winter wheat. Thus, this winter wheat production area, representing 8.5 million ha is not represented within global N_2O-N emission estimates used by the IPCC (USDA-NASS, 2014). Therefore, the objective of this study was to determine the effects of N rate on N_2O-N emissions from dryland winter wheat in the southern Great Plains of the United States to provide this needed data. In addition, the impact of residual soil profile N on N_2O-N emissions was also evaluated.

MATERIALS AND METHODS

In the fall of 2011, gas flux chambers were installed in an existing long-term continuous winter wheat (wheat followed by summer fallow) fertility trial located at the Oklahoma State University, Agronomy Research Station in Stillwater, OK, on a Kirkland silt loam (fine, mixed, superactive, thermic Udertic Paleustoll). This long-term trial was established in 1968 to evaluate the impact of long-term application of N, P, and K on grain yield in continuous winter wheat. This location was previously managed with conventional tillage; in 2011 the location was converted to no-till. The long-term trial is designed as a randomized complete block with four replications; four treatments from three replications were selected to be sampled. The treatments selected were the N rate treatments with 30.8 kg ha^{-1} P applied as triple superphosphate (0–46–0) and 26.9 kg ha^{-1} K applied as potassium chloride (0–0–60) applied annually before planting. Nitrogen was broadcast applied as urea (46–0–0) at rates of 0, 45, 90, and 134 kg N ha^{-1}; the 134 kg ha^{-1} N rate was split applied so that half of the N was applied before planting and the remaining half was applied in the spring at GS 30 (Zadoks et al., 1974)(Table 1). The remaining treatments were applied before planting. Wheat was harvested using a Massey Ferguson combine with a 2 m wide cutting table. Wheat grain yields were adjusted to 12.5% moisture. Table 1 shows the dates on which the study was fertilized, planted, and harvested during the 3-yr measurement period.

Nitrous oxide emissions were measured using the vented chamber method as described by Mosier et al. (1991) with base anchors measuring 38.1 by 12.7 cm (inner dimensions). Chamber lids were constructed of steel and painted silver to reflect solar radiation and minimize temperature fluxes within the chamber. Base anchors were forced into the soil so as to minimize soil disturbance within and around the anchor. Base anchors were installed within wheat rows after planting and remained in place until the planting of the following year's crop. Wheat plants were kept clipped to the soil surface within the chambers and the clipped material removed from the plot area for the duration of the growing season. At fertilization for the 2012–2013 and 2013–2014 crop years, a 61 by 42 cm area was covered to exclude fertilizer from the chambers designated as residual chambers such that the impact of residual N on N_2O-N emissions could be assessed in these long-term fertility treatments. Fertilized and residual chambers were place in different locations within the plots each year of the study. This was done so that residual measurements represented the long-term N management of the plot area. For the 2011–2012 crop year, one chamber per plot was installed. The 2012–2013 crop year all plots had one chamber, with the exception of the 134 kg N ha^{-1} rate plots which had two (one fertilized and one residual). The 2013–2014 crop year had two chambers in all plots (one fertilized and one residual), with the exception of the 0 kg N ha^{-1} rate plots, which contained only one chamber.

On each sample date a vented chamber lid (7 cm by 39.4 cm by 15.2 cm) was placed into a water-filled trough on the base anchor to form a gas tight seal with air exchange allowed through the vent tube on the lid to maintain ambient air pressure within the chamber. Gas samples of 20 mL were collected from a rubber septum in the chamber lid at 0, 20,

Table 1. Fertilization, planting, and harvest dates of winter wheat for the 2012, 2013, and 2014 cropping years.

Year	Fertilization	Planting	Harvest
2012	15 Sept. 2011 (7 Mar. 2012)†	13 Oct. 2011	8 June 2012
2013	26 Sept. 2012 (11 Mar. 2013)	16 Nov. 2012	28 June 2013
2014	10 Oct. 2013 (21 Mar. 2014)	22 Oct. 2013	18 June 2014

† Date in parentheses indicates date for split application of 134 kg N ha^{-1} rate.

Table 2. Mean wheat grain yield (kg ha^{-1}) for each year and N rate.

N rate	Year		
	2012	2013	2014
kg N ha^{-1}	kg ha^{-1}		
0	1166c†	952a	2074a
45	2238ab	618a	2363a
90	2533a	634a	2458a
134	2040b	606a	2389a

† Within columns, values followed by the same letter are not significantly different (LSD, α = 0.05).

Table 3. Average, maximum, and minimum wheat grain yield (kg ha^{-1}) over 40 yr (1969–2009) of the long-term fertility trial by N rates.

N Rate	40-yr average	Maximum	Minimum
kg N ha^{-1}	kg ha^{-1}		
0	1230	3477	79
45	1590	3851	111
90	1827	3437	206
134	1960	3577	450

Table 4. Post-harvest mean soil nitrate concentration (mg NO_3–N kg^{-1}) in 0 to 15 cm for each year and N rate with yearly mean and N rate mean.

N rate	Year			3-yr average
	2012	2013	2014	
kg N ha^{-1}	mg NO_3–N kg^{-1}			
0	26.72	22.30	10.42	19.81
45	30.48	29.02	12.09	23.86
90	27.15	23.32	12.03	20.83
134	21.59	19.40	10.29	17.09
Average	26.48a†	23.51a	11.21b	

† In last row, values followed by the same letters are not significantly different (LSD, α = 0.05).

40, and 60 min following the lid being placed over the base anchor, beginning at 1000 h. Gas samples were stored in 20-mL evacuated glass vials with gray rubber butyl septa until being analyzed by a gas chromatograph (Varian 450-GC) with an electron capture detector (ECD)(standard deviation of ECD = 0.009 μg L^{-1}), thermoconductivity detector (TCD) and a flame ionization detector (FID) to quantify N_2O-N, CO_2, and CH_4, respectively. Flux measurements were taken daily for 7 d following fertilizer application, then every 7 d for the remainder of the growing season. After harvest, sampling decreased to every 14 d. Chambers were left uncovered except during the 60-min sampling period. Nitrous oxide fluxes were calculated using linear regression between concentration in the chamber headspace and time. Total emissions for the growing seasons were estimated with linear extrapolation between sampling periods.

Surface soil samples (0–15 cm) were collected yearly before pre-plant fertilizer applications using hand probes. The soils were air dried, and ground to pass a 2-mm sieve. Soil samples were extracted with 2 mol L^{-1} KCl (1:10 soil/KCl) and analyzed for NO_3–N and NH_4–N using flow injection analysis (QuickChem FIA+, Lachat Instruments, Milwaukee, WI).

A mixed model was used for ANOVA in the mean cumulative N_2O-N emissions, yield, and soil NO_3–N and NH_4–N. The PROC MIXED procedure in SAS (SAS Institute, 2008) was used to test the fixed effect of N rate; mean separations were conducted using LSD. Interactions between N rate, treatment, and year were evaluated and means were evaluated across years when no interaction was found.

RESULTS AND DISCUSSION

Yield

Wheat grain yields for the 2012 to 2014 harvests are presented in Table 2. For comparison, the historical yields from 1969 to 2009 are presented in Table 3. Yield measured during the measurement period (2012–2014) was found to have a significant interaction between year and treatment using ANOVA (α = 0.05, p < 0.0001) therefore years were analyzed separately. Analysis of variance found mean grain yield in 2012 to be highest in the 45 and 90 kg N ha^{-1} rates, with the 45 and 134 kg N ha^{-1} rates not significantly different (Table 2). The lack of significant difference between the 45 and 134 kg N ha^{-1} rates is not unexpected as the 134 kg N ha^{-1} rate is split applied (50% in the fall, 50% in the spring) and a lack of spring rainfall likely prevented the spring N application from being utilized. The lowest yield for 2012 was from the 0 kg N ha^{-1} rate. Grain yields were low in 2013 due poor stand establishment and growth resulting from drought conditions. This low yield environment resulted in no significant differences in yield between treatments that received fertilizer additions. The 0 kg N ha^{-1} rate had significantly higher yields than all other treatments. Yields in 2014 followed similar trends to those found in 2012 with maximum yields observed at the 90 kg ha^{-1} rate. In fact, maximum yields were similar between the 2 yr with 2533 and 2458 kg ha^{-1} produced at the 90 kg N ha^{-1} treatment in 2012 and 2014, respectively. However, observed differences were not significantly different in 2014. The 0 kg N ha^{-1} treatment produced a yield of 2074 kg ha^{-1}, which was 384 kg ha^{-1} lower than the maximum yield in 2014. In contrast, the 0 kg N ha^{-1} treatment produced 1166 kg ha^{-1} which was 1367 less wheat grain than the maximum yield in 2012. The lack of yield response in 2014 may be due to a freeze event that occurred 15 April which could have reduced yield in the fertilized treatments compared to the 0 kg N ha^{-1} treatment.

Soil Nitrate–Nitrogen and Ammonium–Nitrogen

Analysis of variance found no significant interaction between year and N rate in the post-harvest surface (0–15 cm) soil samples for either NO_3–N concentration or NH_4–N concentration in the soil. Furthermore, N rate did not significantly influence NO_3–N or NH_4–N, however there was a significant difference among years for both NO_3–N and NH_4–N (Tables 4 and 5). The low concentration of soil NH_4–N after harvest in 2014 and 2012 when compared to the 2013 post-harvest soil data can be explained by the fact that yields were suppressed in 2013. In fact, the 2014 yields were three times those achieved in 2013. The low yields harvested in 2013 were primarily the result of poor stand establishment followed by limited growth in the winter months which negated the above average rainfall experienced in April and May (Table 6). In contrast, soil moisture at planting of the 2011–2012 and 2013–2014 crops was sufficient to provide stand establishment and above average yields as compared to

Table 5. Post-harvest mean soil ammonium concentration (mg NH_4–N kg^{-1}) in 0 to 15 cm for each year and N rate with yearly mean and N rate mean.

N rate	Year			3-yr average
	2012	2013	2014	
kg N ha^{-1}	mg NH_4–N kg^{-1}			
0	17.18	26.01	16.59	19.93
45	22.29	31.25	18.25	23.93
90	17.39	28.95	15.38	20.57
134	14.79	22.05	14.87	17.23
Average	17.91b†	27.06a	16.27b	

† In last row, values followed by the same letters are not significantly different (LSD, $\alpha = 0.05$).

the 40-yr average (Table 3). The soil NO_3–N concentrations were significantly lower in 2014 as compared to the remaining years. The difference in soil NO_3–N between 2014 and 2013 can be explained by the differences in yield. However, the fact that the soil NO_3–N concentration in 2012 were similar to those found after the low yielding 2013 crop can only be explained by the limited rainfall in June and July in 2012. Because soil N dynamics were not the focus of this study the data does not provide for full explanation of these temporal changes however, the lack of rainfall in 2012 could be responsible for allowing for the movement of subsoil NO_3–N as a result of evaporation from the soil surface, it may have also resulted in less immobilization of inorganic N than what occurred in 2014.

Nitrous Oxide–Nitrogen Emissions

Figures 1 to 3 illustrate the distribution of N_2O-N flux events resulting from fertilization of continuous no-till wheat in the southern Plains of the United States. In each year the primary flux periods occurred directly after fertilizer application and again during the summer and early fall months. The duration of the initial flux event after N application ranges from 40 d during the 2011–2012 and 2012–2013 crop years to 70 d during the 2013–2014 crop year. This is consistent with data collected from studies of summer crops showing that N_2O-N emissions is most pronounced directly after N fertilizer application (Venterea et al., 2005). This initial flux period was followed by a period during the winter months where fluxes were low.

Emissions of N_2O-N in winter wheat in Canada followed a similar temporal pattern as was seen in this study, with increased emissions following fertilization, low emissions during the winter, then an increase in emissions during the late summer/early fall (Dusenbury et al., 2008). In 2012, the post-winter flux events from the fertilized treatments were first observed in May and were sporadically observed through the remainder of the fallow period with the largest events occurring at 48 wk after fertilizer application (October 2012) (Fig. 1). In 2013, post-winter N_2O-N fluxes became consistently observed in April and remained elevated for the 134 kg N ha^{-1} treatment during the remainder of the fallow period but were less consistent for the other treatments (Fig. 2). Barton et al. (2008) found that the largest N_2O-N fluxes followed the first summer rains, not the largest rainfall event which differs from the N_2O-N fluxes measured in this study (Fig. 1–3). In 2013, the greatest fluxes of N_2O-N were found at 315 days since treatment (DST) (Fig. 2) just after the largest rainfall event (2.9 cm) of the year, which occurred on 8 August. In 2014, the onset of consistent N_2O-N fluxes was delayed until June after which it was consistently elevated (Fig. 3). In each year the maximum flux was observed in the 134 kg N ha^{-1} and occurred 10 to 12 mo after N fertilizer applications. This illustrates the importance of not only residual N on N_2O-N fluxes despite the fact that significant differences in inorganic soil N were not observed after harvest but also the importance of variables beyond residual soil N such as rainfall, temperature, and residue cover.

Analysis of variance found a significant year × N rate interaction for cumulative N_2O-N emissions ($\alpha = 0.05$, $p = 0.0254$). Table 7 contains cumulative N_2O-N emissions means for each year and N rate. Comparison of N rates found that the

Table 6. Average monthly rainfall (mm) and average monthly temperature (temp) (°C) for each year of the study and the 15-yr averages for Stillwater, OK.

Month	Year						15-yr average	
	2011–2012		2012–2013		2013–2014			
	Temp	Rainfall	Temp	Rainfall	Temp	Rainfall	Temp	Rainfall
	°C	mm	°C	mm	°C	mm	°C	mm
Sept.	21.1	58.2†	23.5	9.31	23.9	14.31	22.3	23.26
Oct.	16.2	3.21	15.5	5.00	15.5	15.40	15.5	20.53
Nov.	9.7	8.45	11.0	3.81	7.9	13.63	9.9	13.62
Dec.	4.2	6.94	5.3	3.52	0.8	5.24	3.8	11.37
Jan.	5.3	7.87	3.9	8.19	1.9	0.74	2.9	9.40
Feb.	6.2	25.66	4.6	28.21	1.9	3.63	4.6	14.68
Mar.	15.7	32.12	8.6	9.18	7.6	9.91	10.7	20.99
Apr.	18.3	52.15	12.5	45.13	15.6	7.11	16.0	28.64
May	23.0	9.18	19.1	50.96	21.4	5.33	20.7	36.02
June	26.2	18.29	25.6	33.44	25.4	53.26	25.4	43.42
July	30.9	0.57	26.5	45.64	25.4	32.61	27.9	28.71
Aug.	27.1	22.66	26.6	20.81	27.5	16.47	27.5	24.45
Total rainfall		245.3		263.21		177.64		275.09

† Rainfall data was not available from the Stillwater location in September 2011 therefore, rainfall reported was collected from the Marena mesonet station approximately 16 km from the study location.

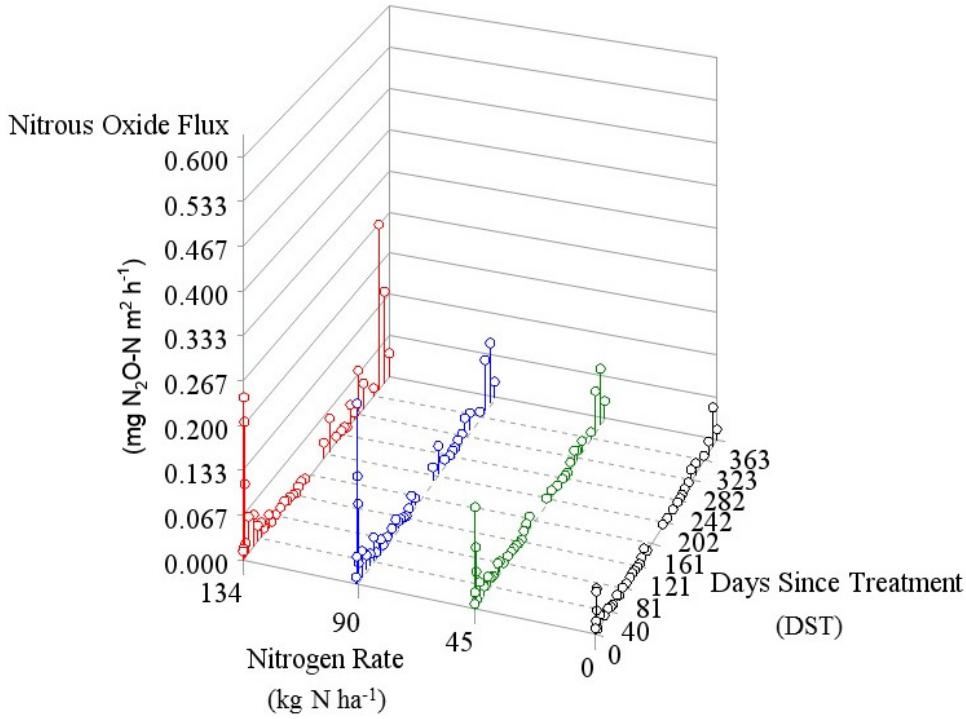

Fig. 1. Mean N_2O-N flux for crop year 2011–2012 for each N rate by days since N fertilization. Pre-plant N applied 15 Sept. 2011 (days since treatment, DST = 0) and split application of 134 kg N ha^{-1} rate applied 17 Mar. 2012 (DST = 193). Harvest 8 June 2012 (DST = 276).

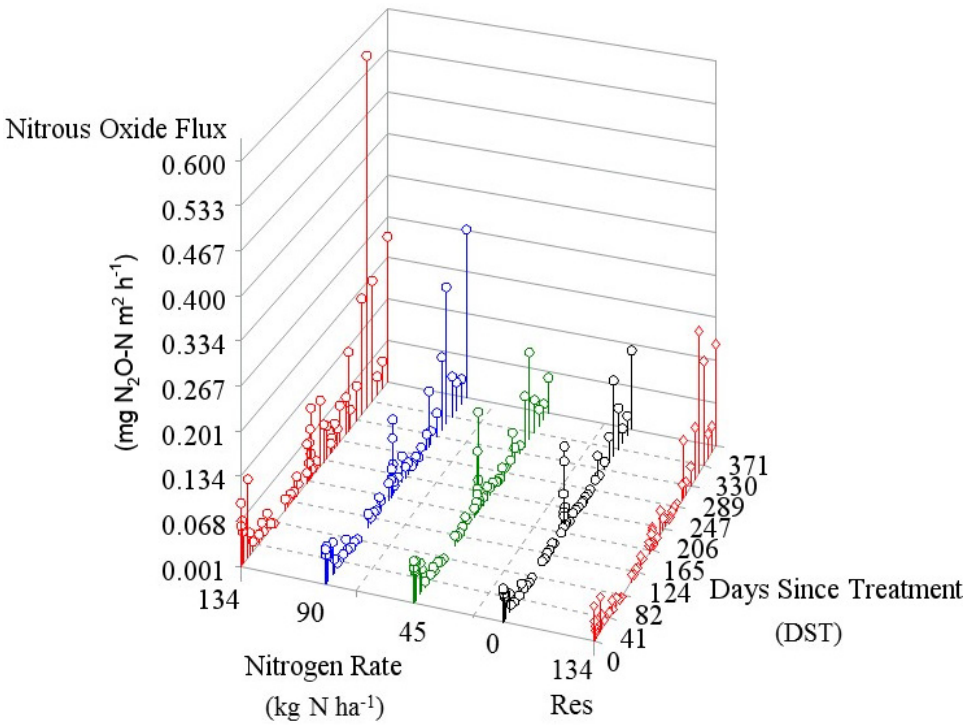

Fig. 2. Mean N_2O-N flux for crop year 2012–2013 for each N rate by days since N fertilization, including residual N treatments (Res). Pre-plant N applied 26 Sept. 2012 (days since treatment, DST = 0) and split application of 134 kg N ha^{-1} rate applied 11 Mar. 2013 (DST = 165). Harvest 28 June 2013 (DST = 274).

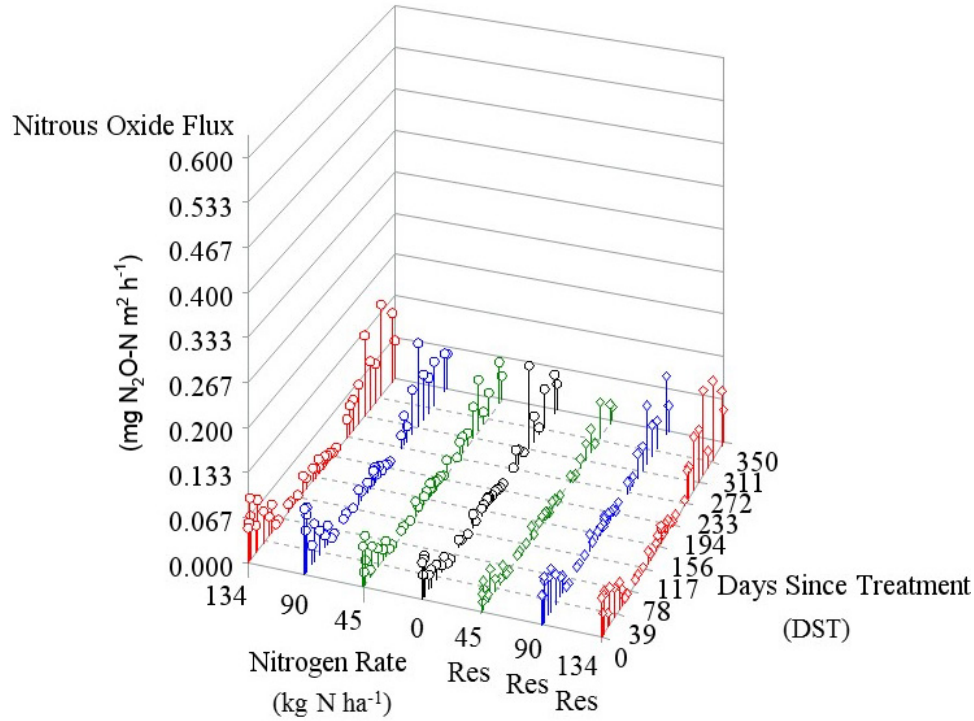

Fig. 3. Mean N_2O-N flux for crop year 2013–2014 for each N rate by days since N fertilization, including residual N treatments (Res). Pre-plant N applied 10 Oct. 2013 (days since treatment, DST = 0) and split application of 134 kg N ha^{-1} rate applied 21 Mar. 2014 (DST = 161). Harvest 18 June 2014 (DST = 250).

cumulative N_2O-N emissions from the 0 and 45 kg N ha^{-1} N rates were significantly lower than the 134 kg N ha^{-1} N rate in 2012, with no difference between the 90 kg N ha^{-1} treatment and remaining treatments. The cumulative N_2O-N emissions in 2013 followed a similar pattern where the 134 kg N ha^{-1} rate was significantly higher than all other N rates. The residual chamber (134 kg N ha^{-1} residual) cumulative N_2O-N emissions were significantly lower than the 134 kg N ha^{-1} rate, however the emissions were not different from any of the other N rates. In 2014, the treatments receiving 90, 134 kg N ha^{-1}, and the 134 kg N ha^{-1} residual treatments had significantly higher cumulative N_2O-N emissions than the other fertilized treatments. The 134 kg N ha^{-1} residual treatment was not significantly different from the 90 kg N ha^{-1} residual treatment, and neither were different from the 90 kg N ha^{-1} application treatment. This data from the residual chambers

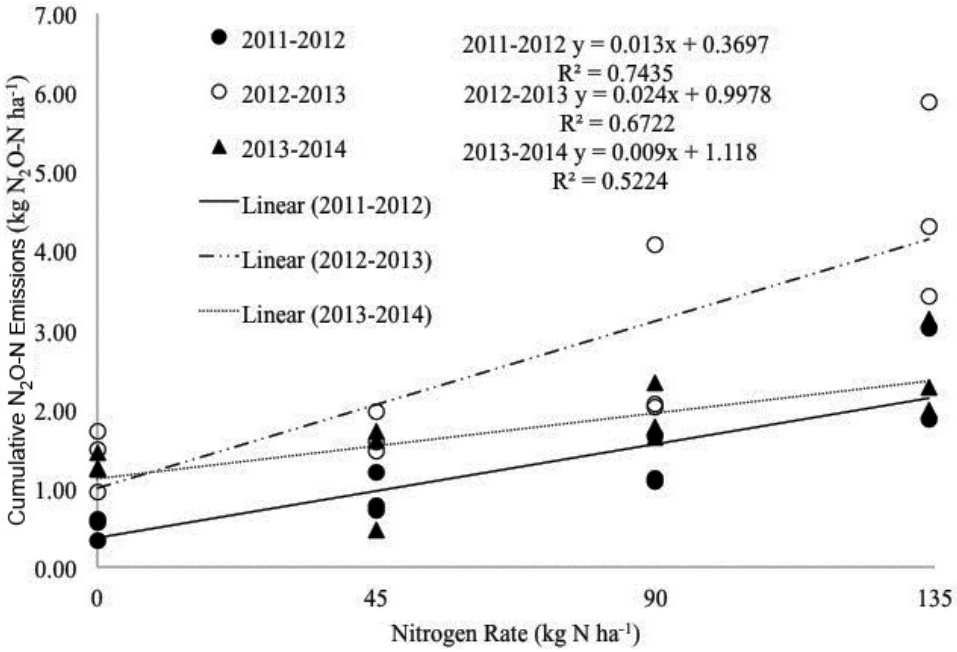

Fig. 4. Linear relationship between N rate and cumulative N_2O-N emissions (kg N_2O-N ha^{-1}) in winter wheat in Stillwater, OK, for crop years 2011–2012, 2012–2013, and 2013–2014.

Table 7. Mean cumulative N_2O-N emissions (kg N_2O-N ha^{-1}) in winter wheat for each N rate and year combination.

N rate	Year		
	2011–2012	2012–2013	2013–2014
kg N ha^{-1}	kg N_2O–N ha^{-1}		
0	0.50b†	1.38c	1.35cd
45	0.90b	1.67bc	1.26cd
90	1.28ab	2.72b	1.91ab
134	2.04a	4.54a	2.46a
45 Residual	–	–	0.81d
90 Residual	–	–	1.67bc
134 Residual	–	2.36bc	2.07ab

† Within columns, values with the same lowercase letters are not significantly different (LSD, $\alpha = 0.05$).

suggest that previous N fertilizer history can influence N_2O-N emissions and that removing N fertilizer applications in a single year may not reduce N_2O-N emissions to background levels as was the case in 2014 for the 134 kg N ha^{-1} residual treatment.

Figure 4 shows the linear relationship between N rate and the cumulative annual N_2O-N emissions. The average slope of these regression equations suggests that on average 0.015 kg N_2O-N will be emitted per kg N applied; the IPCC estimate is 0.01 kg N_2O-N. Assessment of regression analysis resulting from each year shows that in 2012 and 2014 the slope is 0.013 and 0.009 kg N_2O-N per kg N applied, respectively. In contrast, the slope for 2013 was 0.024 kg N_2O-N per kg N applied. The low yields can, in part, explain why N_2O-N emissions were largest for the 2013. As mentioned, yields were low in 2013 due to below normal rainfall during the fall months of 2012 (Table 6) resulting in poor stand establishment (rainfall between 14 September and 31 December was 127 mm below normal). The fall of 2012 was followed by above normal rainfall during the spring and throughout the summer fallow period, which as mentioned above allowed for elevated N_2O-N fluxes to be measured in April and throughout the summer months in 2013 (Fig. 2).

SUMMARY

The 3-yr average losses of 0.015 kg N_2O-N per kg N applied observed in no-till winter wheat production in the southern Great Plains is greater than the current IPCC estimate of 0.01 kg N_2O-N. However, the emissions were variable from year to year ranging from 0.009 to 0.02 kg N_2O-N kg^{-1} for 2014 and 2013, respectively. This variability demonstrates the dynamic nature of N_2O-N emissions. The primary periods of N_2O-N flux were following N fertilization, and again in the late summer and early fall months as the environmental conditions became more favorable to production of N_2O-N in the soil. Cumulative emissions of N_2O-N were highest in 2013 when wheat yields were poor, indicating a lack of crop uptake and therefore more N in soil that was available to be lost as N_2O-N.

Emissions of N_2O-N from the residual chambers containing soil that received no fertilization for one crop year following yearly N applications of 134 kg N ha^{-1} produced as much N_2O-N as the 45 and 90 kg N ha^{-1} treatments. This indicates that when soils have been historically fertilized at high N rates there is still potential to produce emissions of N_2O-N that are comparable to mid-range N fertilization.

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