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MEASURED AND MODELED (DNDC) NITROUS OXIDE EMISSIONS (N_2O) UNDER DIFFERENT CROP MANAGEMENT PRACTICES IN THE NITRA REGION, SLOVAKIA

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An important method of investigating N_2O emissions from cropland is model simulation. The measured data of N_2O emissions under conventional tillage (CT) and reduced tillage (RT) with (N1) and without (N0) N fertilizer application were used to test the DNDC model during the year 2012 (April-December) in Slovakia. There was found a good agreement with seasonal N_2O emissions only for CTN0 treatment, but in case of other treatments DNDC overestimated the emissions. The relative deviation between observed and simulated total seasonal N_2O emissions (kg N ha^{-1}) from four treatments were 46%, 164%, 346% and 321% for CTN0, CTN1, RTN0 and RTN1, respectively. Also, some discrepancies were found between observed and simulated emissions when evaluating the daily N_2O emissions, especially when looking at the magnitude of N_2O emissions peaks. The correlation between observed and simulated daily N_2O emissions (N = 38) in case of conventional tillage was quite high and significant with $r = 0.48$ ($P < 0.01$), $r = 0.45$ ($P < 0.01$) for CTN0 and CTN1 treatment, respectively. On the other hand, there was found poor correlation in reduced tillage treatment with $r = 0.22$ ($P > 0.01$) and $r = 0.39$ ($P > 0.01$), for RTN0, RTN1, respectively.

Keywords: soil N_2O emission, DNDC model, testing, cropland

A global climate change caused by anthropogenic emission of greenhouse gases (CO_2, CH_4, N_2O) is one of the most important environmental problems in the latest human history. Nitrous oxide (N_2O) emissions from agriculture reach approximately 70% of annual global N_2O emissions (Mosier, 2001). Great efforts have been done to measure N_2O from cropland in recent years and lots of field and lab measurements have been collected. However, estimates of N_2O from cropland are still far from being reliable due to large spatial and temporal variability of the N_2O fluxes in response to climatic and soil conditions which make it very difficult to quantify them from cropland or other agricultural sources.

Application of models has become popular to estimate N_2O emissions from cropland. A number of models such as DNDC (Li et al., 1992, 2000) Expert-N (Baldioli et al., 1994), CASA (Potter et al., 1993) CENTURY (Parton, et al., 1996), DAYCENT (Del Grosso et al., 2002) have been developed for estimation of greenhouse gases (GHGs) emissions. The process-based DNDC (Denitrification-Decomposition) model demonstrated a distinguished capacity of predicting trace gas emissions and soil organic carbon dynamics in agro-ecosystems (Li et al., 1992; Li, 2000). During the past decade, DNDC has been tested by many researchers worldwide with promising results (Jagadeesh Babu et al., 2006; Smith et al., 2008) but the model has not been tested in conditions of Slovakia.

The main objective of this study was to test the reliability of the DeNitrification and DeComposition DNDC model to predict N_2O emissions from cropland of the experimental site in Nitra (Slovakia).

Material and methods

The DNDC model was tested by comparing the simulated and measured values of seasonal N_2O emissions from the experimental site of SUA Nitra in Nitra region of Slovakia (lat. 48° 19′ 00″; lon. 18° 09′ 00″) for which we had available input parameters. The observed meteorological data (daily maximum and minimum temperature, daily precipitation), soil properties (SOC, bulk density, pH, clay content), and farming management data (crop type, planting, harvest dates, tillage, fertilization) were used as input parameters to run the model. Some assumptions were made wherever primary data was not available. In this case we used model default values. After that the simulated results of N_2O were compared with the field measurements.

Field site and N_2O measurements

The N_2O emissions were measured at the experimental site of the SUA Nitra, in Nitra region of Slovakia (lat. 48° 19′ 00″; lon. 18° 09′ 00″) during 2012 (April – December). This period also covered the growing season of spring barley (March – July in 2012). The soil type was classified as Orthic Luvisol (FAO 1998) containing 360.4 g kg^{-1} of sand, 488.3 g kg^{-1} of silt and 151.3 g kg^{-1} of clay. The average soil carbon content was 12.5 g kg^{-1}, the average soil pH (KCl) was 6.6 and bulk density was 1.25 g cm^{-3}. The average annual air temperature was 11.4°C and annual precipitation was 492 mm.

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The experiment consisted of two tillage methods (conventional tillage-CT and reduced tillage-RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1). The experiment was arranged in a split plot design with tillage as the main plots and the treatments N0 and N1 as the sub-plots with three replicates. CT consisted of tillage to 22–25 cm and RT consisted of disking to 10–12 cm depth both applied each fall, followed by harrow cultivator to 10 cm depth each spring before seeding. The spring barley (Kangoo variety) was seeded on 16 March 2012 at a rate of 4 500 000 seeds ha^{-1}. The doses of fertilizers were calculated by balance method and were applied to the soil twice throughout the season. First application (CT 50 kg N ha^{-1} and RT 40 kg N ha^{-1}) was applied on 11 April and second (CT and RT 7 kg N ha^{-1}) on 23 June 2012. Both CT and RT plots were disked (10–12 cm) after harvest (12 June, 2012) on 24 June 2012.

The soil/crop and the atmosphere N_2O exchange was measured weekly (between 10 am and 2 pm) using closed chamber technique during April – December 2012. On every gas sampling, the chamber (30 cm in diameter and 25 cm in height) was water sealed onto bottom collars and gas samples (20 mL) were collected through tube fittings (sealed with septum) at 0, 30 and 60 min after chamber deployment using an air-tight syringe (Hamilton) and transferred to pre-evacuated 12 mL glass vials (Labco Exetainer). Gas samples were analyzed for N_2O using a gas chromatograph (GC-2010 Plus Shimadzu) equipped with an electron capture detector. The GC was calibrated using 3 certified standard gas mixtures (N_2O, and N_2) in the expected concentration ranges. N_2O fluxes between soil/crop and atmosphere were calculated from the change of concentration during the chamber closure using a linear approach. Cumulative seasonal N_2O emissions were calculated by interpolating the emissions between each sampling day.

Model DNDC description and validation

DNDC model is a process oriented on computer simulation of soil carbon and nitrogen. The model consists of two components. The first component, consisting of the soil climate, crop growth and decomposition sub-models, predicts soil temperature, moisture, pH, redox potential (*Eh*) and substrate concentration profiles driven by ecological drivers (e.g., climate, soil, vegetation and anthropogenic activity). The second component, consisting of the nitrification, denitrification and fermentation sub-models, predicts NO, N_2O, N_2, CH_4 and NH_3 fluxes based on the modeled soil environmental factors. Input parameters required by the model include daily climate data, soil properties (e.g., texture, pH, bulk density), vegetation (e.g., crop type), and management (e.g., tillage, fertilization, manure amendment, planting, harvest etc.).

DNDC model was validated against field measurements by comparing the simulated and measured N_2O emissions. Field measured emissions of N_2O were summed based on the fluxes observed with a simple interpolation approach and DNDC simulated seasonal emissions were simply the sum of the simulated daily fluxes over the growing season of spring barley. The relative deviation of simulated emission from the observation was calculated, as well as Pearson's correlation coefficient between the measured and simulated results of daily N_2O emissions.

Results and discussion

The seasonal (April–December, 2012) N_2O emissions were simulated well by DNDC model only for the treatment with conventional tillage with no N-fertilizer application (CTN0) (Table 1) and in case of other treatments DNDC overestimated the emissions, especially at the reduced tillage treatments. The seasonal absolute difference between the observed and simulated N_2O emission was 2.94, 11.47, 13.15 and 13.41 kg N ha^{-1} season^{-1} for CTN0, CTN, MTN0 and MTN1 treatments, respectively. Results expressed as relative deviations of simulated emissions from the observed ones showed the difference of 46%, 164%, 346% and 321% for CTN0, CTN, MTN0 and MTN1 treatment, respectively.

Except the overestimation of simulated seasonal N_2O emission by DNDC there were also found discrepancies in daily values of N_2O fluxes (Figs 1a, b and Figs 2a, b).

In case of plots where the conventional treatment was applied combined with unamended control (N0) and addition of nitrogen fertilizers (CTN0 and CTN1) there was measured the very first initial peak of N_2O at the end of June (day 178) which was also simulated by the DNDC model (Figs 1a, b). Since there was not applied any N-fertilizer at CTN0 treatment and for CTN1 there were not applied fertilizers during that period, the only identified reason for these peak was the precipitation and related soil moisture content which got higher after the three precipitation events (total rainfall amount 20 mm) during the last 5 days before the peak occurred (Figure 3). However, the initial simulated peak of N_2O emission appeared right after the rainfall events whereas the measured one appeared a couple of days later.

The second peak was measured and also very well simulated at the beginning of July (day 188) right after the two precipitation events with total rainfall of 12 mm. The

Table 1 Observed and simulated seasonal N_2O emissions under conventional tillage (CT) and reduced tillage (RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1)

Treatment	Seasonal N_2O emissions (kg N ha^{-1} season^{-1})		Absolute difference (kg N ha^{-1} season^{-1})	Relative difference (%)
	observed	modeled		
CTN0	6.42	9.36	2.94	45.9
CTN1	7.02	18.49	11.47	163.5
RTN0	3.80	16.94	13.15	346.4
RTN1	4.18	17.59	13.41	321.2

Source: Authors' original work

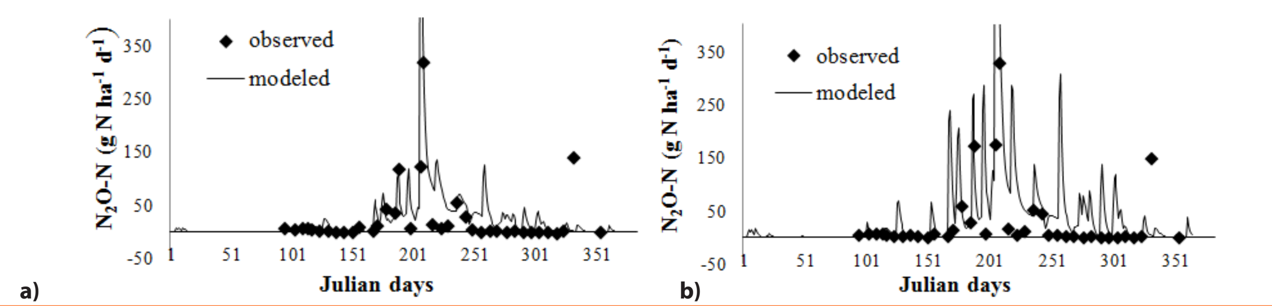

Figure 1 Comparison between observed and simulated daily N_2O emissions for CTN0 (a) and CTN1 (b) treatment during the studied period
Source: Authors' original work

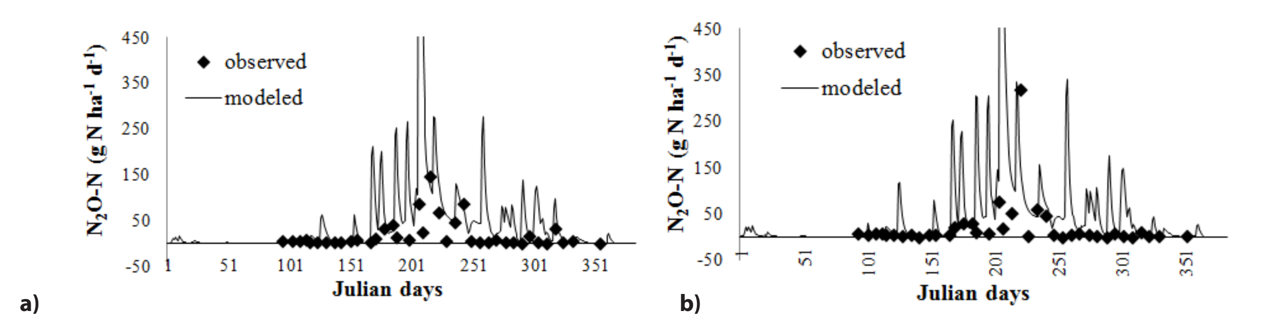

Figure 2 Comparison between observed and simulated daily N_2O emissions for RTN0 (a) and RTN1 (b) treatment during the studied period
Source: Authors' original work

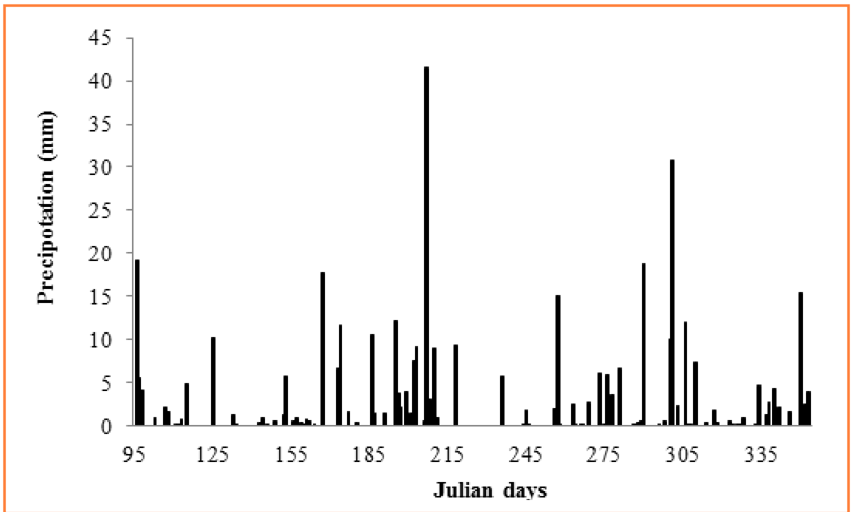

Figure 3 Precipitation during the studied period from nearby automatic meteorological station
Source: Authors' original work

study of Lessard et al (1996) found that rainfall had a large impact on N_2O emissions, particularly between days 150 and 208. Higher denitrification can occur due to higher moisture contents as a result of precipitation. The third and the biggest peak of all peaks was observed at the end of July (day 209) for both CTN, as well as for CTN1. It has to be noted that the second fertilizer application (23 June 2012) wasn't the main cause of the biggest peak, because the CTN0 treatment did not receive any N-fertilizer during the whole season and the N_2O peak was even higher (318.18 g N ha^{-1} day^{-1}) as compared to N_2O peak at CTN1 treatment (261.55 g N ha^{-1} day^{-1}). There were measured the three precipitation events (total rainfall amount 18 mm) during the last 5 days before the peaks were measured.

In case of plots where the reduced tillage treatment was applied combined with unamended control (N0) and addition of nitrogen fertilizers (RTN0 and RTN1) it was complicated to compare the daily measured and simulated N_2O emissions (Figs 2a, b). The DNDC model failed to capture the peak pattern of measured daily N_2O emissions for both RTN0 and RTN1 treatments. The DNDC simulated a lot of peaks when no peaks were observed throughout the season and only some of them were measured. This lots of simulated peaks were clearly identified to be due to the precipitation events (Figure 3).

Generaly, the DNDC simulated a lot more N_2O emissions peaks which were closely related to the precipitation events during the whole studied period (Figs1a, b; Figs 2a, b and Figure 3). Overall, the DNDC model generally captured the trend of daily N_2O emissions only for CTN0 and also for CTN1 treatment (Figs 1a, b) but failed the trend in the treatments RTN0 and RTN1 (Figs 2a, b).

The DNDC failed to capture the magnitude of daily N_2O emissions for all treatments (CTN0, CTN1, RTN0 and RTN1). In case of CTN0 treatment the

Table 2 Observed and simulated average daily N_2O emissions during the studied period under conventional tillage (CT) and reduced tillage (RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1)

Treatment	Average daily N_2O emissions (g N ha^{-1} day^{-1})		Pearson's correlation coefficient (*r*)	*p*-value for *r*
	observed average	modeled average		
CTN0	23.78	53.91	0.48	0.0023
CTN1	25.33	101.77	0.45	0.0045
RTN0	15.62	92.55	0.42	0.0080
RTN1	17.38	91.23	0.22	0.1853

Source: Authors' original work

measured daily N_2O emission during the studied period ranged from -3.7 (uptake) to 318.2 g N ha^{-1} day^{-1} while the simulated emissions ranged from 0 to 953.4 g N ha^{-1} day^{-1} (Figure 1a). Measured daily N_2O emissions of CTN1 treatment ranged from -3.7 to 261.5 g N ha^{-1} day^{-1} while the simulated emissions ranged from 0 to 1,594.0 g N ha^{-1} day^{-1} (Figure 1b). Measurements of daily N_2O emission for RTN0 treatment ranged from -3.1 to 143.7 g N ha^{-1} day^{-1} while the simulated emissions ranged from 0 to 1,415.8 g N ha^{-1} day^{-1} (Figure 2a). In case of RTN1 treatment the measured values ranged from -4.2 to 317.2 g N ha^{-1} day^{-1} while the simulated emissions ranged from 0 to 1,331.9 g N ha^{-1} day^{-1} (Figure 2b).

The Table 2 shows average daily N_2O emissions, as well as Pearson's correlation coefficient between observed and simulated daily N_2O emissions for all treatments. The correlation between observed and simulated daily N_2O emissions (N = 38) in case of conventional tillage was quite high and significant with $r = 0.48$ ($P < 0.01$), $r = 0.45$ ($P < 0.01$) for CTN0 and CTN1 treatment, respectively. On the other hand, there was found poor correlation in reduced tillage treatment with $r = 0.22$ ($P > 0.01$) and $r = 0.39$ ($P > 0.01$), for RTN0, RTN1, respectively.

Nitrous oxide (N_2O) has a relatively long atmospheric lifetime (around 150 years) and is well mixed in the atmosphere, so from an environmental point of view it is more important for a model to match seasonal emission values than daily emission values. DNDC simulation of seasonal results at the experimental site in Nitra region of Slovakia indicates that the DNDC model worked well for treatment with conventional tillage with no N-fertilizer application (CTN0) and in all other treatments overestimated the total seasonal N_2O emissions.

Conclusion

From the point of view of seasonal results it can be concluded that the DNDC model worked well for treatment with conventional tillage with no N-fertilizer application (CTN0) and in all other treatments, it overestimated the total seasonal N_2O emissions. Except the overestimation of simulated seasonal N_2O emission by DNDC there were also found discrepancies in daily values of N_2O fluxes. Overall, the DNDC model generally captured the trend of daily N_2O emissions only for CTN0 and also for CTN1 treatment but the trend in the treatments RTN0 and RTN1. The DNDC failed to capture the magnitude of daily N_2O emissions for all treatments. The wrongly simulated magnitude of daily N_2O emissions was driven by the disagreement in the height of the N_2O peaks.

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