

TESTING THE DNDC MODEL FOR NITROUS OXIDE EMISSIONS (N₂O) FROM CROPLAND IN SLOVAKIA

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Abstract

The measured data of N₂O emissions were used to test the DNDC model from cropland during the growing season of spring barley (April-July in 2012) in Slovakia. There wasn't found a good agreement with seasonal N₂O emissions. The relative deviation between observed and simulated total seasonal N₂O emissions (kg N ha⁻¹) from two treatments were 91% and 281% for treatment without and with N fertilizer (N0 and N1), respectively. Also some discrepancies were found between observed and simulated emissions when evaluating the daily N₂O emissions, especially when looking at the magnitude of N₂O emissions peaks. The correlation between observed and simulated daily N₂O emissions was $r = 0.72$ ($n = 18$, $P < 0.01$) and $r = 0.56$ ($n = 18$, $P < 0.05$) for N0 and N1 treatment, respectively.

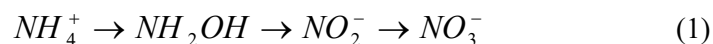
Key words: soil N₂O emission, DNDC model, testing, spring barley

1. INTRODUCTION

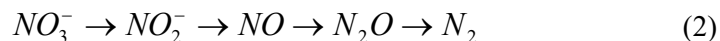
A global climate change caused by anthropogenic emission of greenhouse gases (CO₂, CH₄, N₂O) is one of the most important environmental problems in the latest human history. Nitrous oxide (N₂O) emissions from agriculture reach approximately 70% of annual global N₂O emissions (Mosier, 2001) and approximately 75% of all N₂O emissions in Slovakia (Šiška, Igaz, 2005). Great efforts have been done to measure N₂O from cropland in recent years and lots of field and lab measurements have been collected. However, estimates of N₂O from cropland are still far from being reliable due to large spatial and temporal variability of the N₂O fluxes in response to climatic and soil conditions which make it very difficult to quantify them from cropland or other agricultural sources.

Total N₂O emissions are divided into direct and indirect emissions. Direct N₂O emissions from cultivating have natural source and come into existence in consequence of microbial processes – nitrification and denitrification. They depend on N inputs from: fertilizers, organic fertilizers from livestock production, plant residues and symbiotic fixation of leguminous. Indirect N₂O emissions are a result of processes of atmospheric ammonia and NO_x deposition and transformation of N loosing by soil washing and run off (IPCC 1996).

Nitrification is the aerobic microbial oxidation of ammonium ions to nitrite via NH₂OH, and then to nitrate:



N₂O is also formed in the course of denitrification, the anaerobic microbial (mainly bacterial) reduction of nitrate successively to nitrite and then to the gases NO, N₂O and N₂:



The Slovak Republic as one of the signatory states of the United Nations Framework on Climate Change (UNFCCC) and according to the Kyoto protocol is required to quantify an annual national

inventory of N₂O emission from all anthropogenic sources including soils. Emission of this gas from agricultural soils is regulated by several key properties such as soil moisture, temperature, mineral nitrogen (N), available soil organic carbon (SOC) and pH, and is always varying in space and time (Dobbie et al., 1999). An approach that is currently used in Slovakia to estimate the sources of N₂O emission from agriculture is that provided by IPCC (1997). Emissions factors (EF) for various categories of ecosystems are provided by the guidelines. This methodology includes direct N₂O emission from soils, emissions from animal waste management, and indirect agricultural N₂O emissions. This approach uses the emission factors (EFs), which for direct N₂O emissions from the soil specify the fraction of N input (N-fertiliser, manure, crop residues returned to the field, and N fixed by leguminous crops) that is emitted as N₂O to the atmosphere. The EF is in range of 1.25 ± 1.0 % of total applied N. The IPCC approach requires the national statistics on synthetic fertilizer use, livestock populations, and crop residue management. It doesn't take into an account data on cropland areas, soils, climate, fertilizer types, or other details of farming management. Although the EFs were derived from the field measurements in a variety of countries (not in Slovakia) at sites with various soils, climate and crops, there can be still found the important differences across the country in the interactions between the soil-climate-farming management conditions which may lead to the high spatial differences in N₂O emission, uncertainties in the national and regional estimates and challenge for assessing potential effect of mitigation strategies.

Application of models has become popular to estimate N₂O 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 GHGs emissions. The process-based model 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). The original purpose of developing the DNDC model was to quantify the impacts of climate change and management on greenhouse gas emissions from agricultural lands in the U.S. The DNDC model can work in site mode or regional model, and hence can be compared against field observations in case of using site mode. During the past decade, DNDC has been tested by many researchers worldwide with promising results (Brown, 1995; Smith et al., 1997; Jagadeesh Babu et al., 2006; Smith et al., 2008) but the model wasn't tested in condition of Slovakia.

The main objective of this study was to test the reliability of the DeNitrification and DeComposition DNDC model to predict N₂O emissions from cropland of the experimental site in Nitra (Slovakia).

2. MATERIAL AND METHODS

The DNDC model was tested by comparing the simulated and measured values of seasonal N₂O emissions from experimental site of SAU-Nitra in Nitra region of Slovakia (lat. 48°19'00''; lon. 18°09'00'') for which we had available input parameters. Site observed meteorological data, soil properties, and crop management were used as input parameters to run the model. Some assumptions were made wherever primary data wasn't available. In this case we used model default values. After that the simulated results of N₂O were compared with the field measurements.

2.1. Measurements of N₂O emissions from the field site

The N₂O emissions were measured at the experimental site of the SAU-Nitra, in Nitra region of Slovakia (lat. 48°19'00''; lon. 18°09'00'') during 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 492mm (tab. 1).

Table 1. 30-year mean and actual (2012) monthly climate data for the nearby automatic weather station (300 m from the field site)

Month	30 - year mean (1961-1990)		2012	
	Precip. (mm)	Mean temp. (°C)	Precip. (mm)	Mean temp. (°C)
January	31.0	-1.7	51.0	1.3
February	32.0	0.7	17.4	-2.5
March	30.0	5.0	5.2	8.1
April	39.0	10.4	39.8	12.1
May	58.0	15.1	15.0	17.6
June	66.0	18.0	47.6	20.4
July	52.0	19.8	109.0	23.0
August	61.0	19.3	15.4	22.9
September	40.0	15.6	31.4	18.0
October	36.0	10.4	80.6	10.8
November	55.0	4.5	29.4	7.3
December	40.0	0.1	50.0	-1.6
Annual (total/average)	539.0	9.8	492.0	11.4

The experiment was cultivated using conventional tillage (CT) combined with unamended control (N0) and addition of 57 kg of nitrogen fertilizers (N1). 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 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 fertilizer application (50 kg N ha⁻¹) was applied on 11 April and the second (7 kg N ha⁻¹) on 23 June 2012. All plots were disked (10-12 cm) after harvest (12 June, 2012) on 24 June 2012. Soil properties as input parameters of DNDC model were 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, soil pH (KCl) was 6.6 and bulk density was 1.25 g cm⁻³.

The soil/crop and the atmosphere N₂O exchange was measured weekly (between 10 am and 2 pm) using closed chamber technique during April-July 2012. The metal collar frame was inserted 10 cm deep into the soil in every plot and left undisturbed until harvest/disking occasion. On every gas sampling, the chamber (30 cm in diameter and 25 cm in height) were 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 N₂O using a gas chromatograph (GC-2010 Plus Shimadzu) equipped with an electron capture detector. The GC was calibrated using 3 certified standard gas mixtures (N₂O, and N₂) in the expected concentration ranges. N₂O fluxes between soil/crop and atmosphere were calculated from the change of concentration during the chamber closure using a linear approach. Cumulative seasonal N₂O emissions were calculated by interpolating the emissions between each sampling day.

2.2. Model DNDC description

DNDC model is 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 driver (e.g., climate, soil, vegetation and anthropogenic activity). The soil climate submodel calculates vertical profiles of soil temperature, moisture and soil redox potential driven by meteorological data and soil properties. The crop growth submodel calculates crop growth and its influence on soil environmental factors such as soil moisture, dissolved organic carbon (DOC), and available nitrogen concentrations. The decomposition submodel then generates vertical concentration profiles of substrates (e.g., DOC, NH_4^+ , NO_3^-). 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.

2.3. Model validation

DNDC model was validated against field measurements by comparing the simulated and measured N_2O emissions. Field measured emissions of N_2O emissions 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.

3. RESULTS AND DISCUSSION

The seasonal N_2O emissions during growing season of spring barley were not simulated well by DNDC model for both treatments (N0, N1) (tab. 1). The seasonal absolute difference between the observed and simulated seasonal N_2O emission was 1.76 and 6.42 $\text{kg N ha}^{-1} \text{ season}^{-1}$ for N0 and N1 treatment, respectively. Results expressed as relative deviations of simulated emissions from the observed ones showed the difference of 91% and 281% for N0 and N1 treatment, respectively.

Table 2. Observed and simulated seasonal N_2O emissions for spring barley growing season under two fertilization treatments in Slovakia.

Treatment	Seasonal N_2O emissions ($\text{kg N ha}^{-1} \text{ season}^{-1}$)		Absolute difference ($\text{kg N ha}^{-1} \text{ season}^{-1}$)	Relative difference (%)
	Observation	Model DNDC		
not fertilized (N0)	1.94	3.69	1.76	90.7
fertilized (N1)	2.29	8.71	6.42	280.9

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

In case of not fertilized treatment (N0) the very first initial peak of N_2O was measured at the end of June (day 178) which was also simulated by the DNDC model (fig. 1). Since there wasn't applied any N-fertilizer during the growing season, the only reason for these peak were identified 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 (fig. 3). However, the initial simulated peak of N_2O emission appeared right after the rainfall events whereas the measured one appeared couple days later. However, it has to be noted that DNDC simulated also three small peaks of N_2O fluxes before the initial measured peak. 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 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 last peak was observed at the end of July (day 206) just after the second fertilizer application (23 June 2012) combined with three precipitation events (total rainfall

amount 18 mm) during the last 5 days. However, DNDC failed to capture the peak pattern of measured daily N_2O emissions.

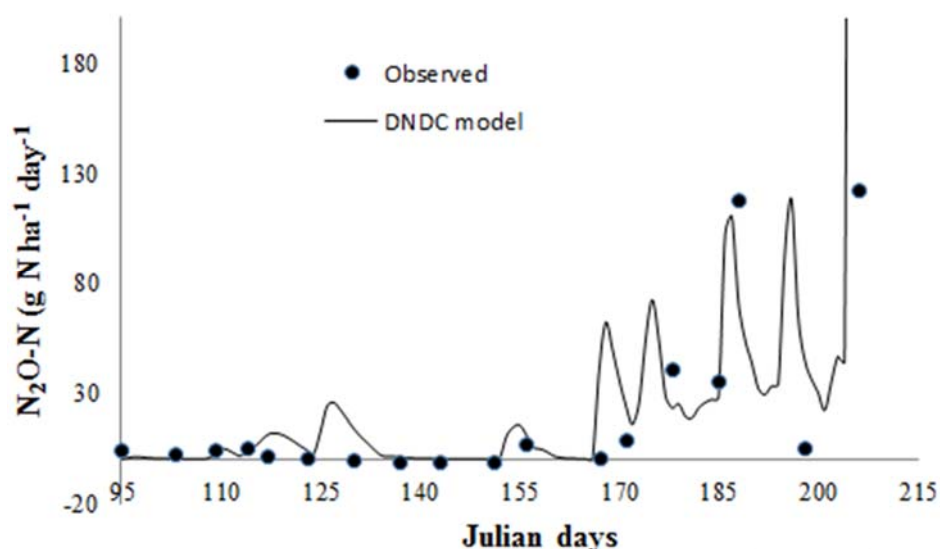


Figure 1. Comparison between observed and simulated daily N_2O emissions during spring barley growing season without N-fertilizer application (N_0).

In case of fertilized treatment (N_1) it was a bit complicated to compare the daily measured and simulated N_2O emissions (fig. 2). Measured data also showed 3 relevant high N_2O peaks (days: 178, 188, 206) as it was found in the treatment without fertilizer application. These three N_2O peaks were also simulated by DNDC model and also the peaks were simulated just after the rainfall events and not couple days later as it was measured. In the fertilized treatment the DNDC completely failed to capture the peak pattern of measured daily N_2O emissions. DNDC simulated a lot of peaks when no peaks were observed at the beginning of experiment and mostly during the June-July, 2012. This lots of simulated peaks were clearly identified to be due to the precipitation events (fig. 3) and related soil moisture content which got higher after the three precipitation events.

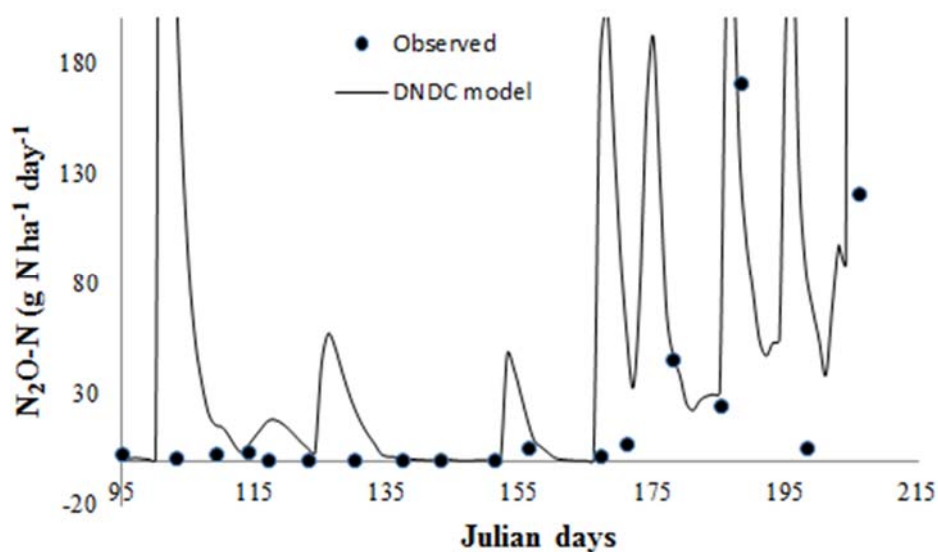


Figure 2. Comparison between observed and simulated daily N_2O emissions during spring barley growing season with N-fertilizer application (N1).

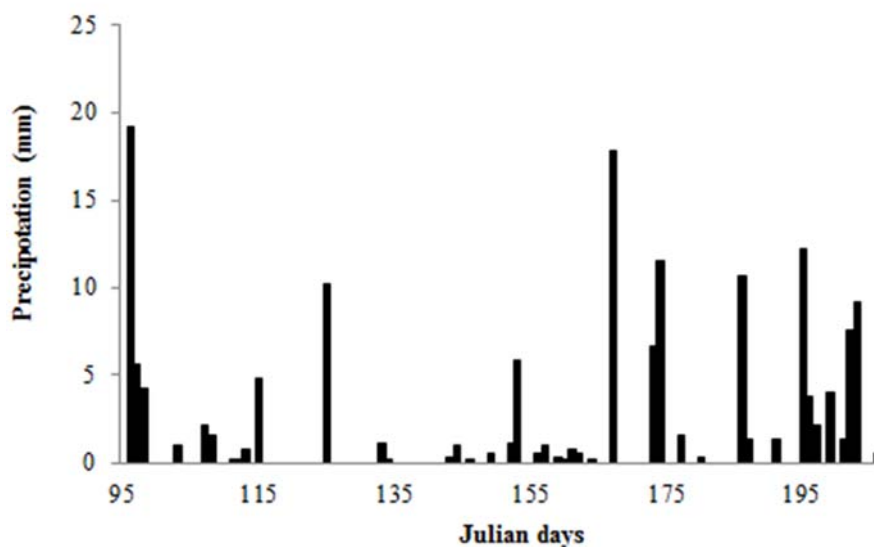


Figure 3. Precipitation during spring barley growing season from nearby automatic met. station

The DNDC model generally captured the trend of daily N_2O emissions for not fertilized treatment but failed the trend in the fertilized treatment. DNDC failed to capture the magnitude of daily N_2O emissions for both treatments (N0, N1). In case of unfertilized treatment (N0) the measured daily N_2O emission during spring barley growing season ranged from -1.1 (uptake) to 122.3 g N ha⁻¹ day⁻¹ while the simulated emissions ranged from 0 to 953.4 g N ha⁻¹ day⁻¹ (fig. 1). The measured average daily N_2O were 19.6 and 22.3 g N ha⁻¹ day⁻¹ for N0 and N1 treatment, respectively (tab. 3).

The DNDC average daily N_2O emissions were 68.3 and 136.6 g N ha⁻¹ day⁻¹ for N0 and N1 treatment, respectively. Fertilized treatment (N1) showed that the measured daily N_2O emission ranged from 0.34 to 170.8 g N ha⁻¹ day⁻¹ while the simulated emissions ranged from 0 to 1594.0 g N ha⁻¹ day⁻¹ (fig. 2).

The overall correlation between observed and simulated daily N_2O emissions was $r = 0.72$ ($n = 18$, $P < 0.01$) and $r = 0.56$ ($n = 18$, $P < 0.05$) for N0 and N1 treatment, respectively. DNDC model thus

successfully simulated the site-specific N₂O variability. The wrong simulated magnitude of daily N₂O emissions was driven by the disagreement in the height of the N₂O peaks.

Table 3. Observed and simulated average daily N₂O emissions (for days only when measurements were taken) including Pearson's correlation coefficient (r) for spring barley growing season under two fertilization treatments in Slovakia.

Treatment	Average daily N ₂ O emissions (g N ha ⁻¹ day ⁻¹)		r	p-value for r
	Observed average	Modeled average		
N0	19.57	68.32	0.72	0.0008
N1	22.32	136.55	0.56	0.0148

Trace gas fluxes are highly variable, both spatially and temporally (Bouwman 1999), due to a wide range of chemical, physical, and biological controlling factor. DNDC simulates in process-based detail dynamics of only a few of the dominant controlling factors such as temperature, soil redox potential, and substrate availability. It doesn't simulate in detail factors that control gas transport, which will have a significant effect on the temporal dynamics of gas fluxes.

Nitrous oxide (N₂O) 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 then daily emission values. DNDC simulation of seasonal results at the experimental site in Nitra region of Slovakia indicates that the DNDC model overestimated the total growing season N₂O emissions. The discrepancies between simulated and observed temporal dynamics of N₂O during the spring barley growing season indicate that the DNDC doesn't incorporate all processes that might influence N₂O fluxes.

4. CONCLUSIONS

This study showed the result of testing of the DNDC (DeNitrification-DeComposition model) at the experimental site in Nitra region of Slovakia during growing season of spring barley under two fertilization treatments. The results indicate that the model DNDC didn't simulated well the seasonal N₂O emissions during growing season of spring barley under both treatments (N0, N1) and overestimated the seasonal N₂O emissions. Except the overestimation of simulated seasonal N₂O emission by DNDC were also found discrepancies in daily values of N₂O fluxes. Firstly, the DNDC model generally captured the trend of daily N₂O emissions for not fertilized treatment but failed the trend in the fertilized treatment. Secondly, DNDC failed to capture the magnitude of daily N₂O emissions for both treatments (N0, N1). The wrong simulated magnitude of daily N₂O emissions was driven by the disagreement in the height of the N₂O peaks with some N₂O peaks being 8 and 13 times higher as compared to measured ones for N0 and N1 treatment, respectively.

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