

MODELING OF NITROUS OXIDE EMISSIONS (N₂O) UNDER DIFFERENT TILLAGE SYSTEMS FOR ORTHIC LUVISOL IN WESTERN SLOVAKIA

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Abstract

The measured data of N₂O emissions from conventional tillage (CT) and reduced tillage (RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1) were used to verify the DNDC model from cropland during February – November in 2013 in Slovakia (covering also the growing season of red clover). Generally, the DNDC model underestimated the total N₂O emissions with relative deviation between observed and simulated total seasonal N₂O emissions (kg N₂O-N ha⁻¹) ranging from 83-98 % for all treatments (CTN0, CTN1, RTN0 and RTN1) as compared to measured data.

Key words: *conventional tillage, reduced tillage, soil N₂O emission, DNDC model, model verification*

1. INTRODUCTION

N₂O is a greenhouse gas whose emission needs to be quantified by Slovakia according to the Kyoto protocol. Nitrous oxide (N₂O) emissions from agriculture reach approximately 70% of annual global N₂O emissions (Mosier, 2001). 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.

There are several ways for evaluation of N₂O emissions. IPCC methodology (1996) is used as the most common. This methodology use emission factors for specifying the fraction of N₂O emitted to the atmosphere from applied amounts of nitrogen with fertilizers and other sources into soils. Since the emission factors were derived from a limited number of measurements in different countries the factors themselves are still uncertain.

Applying process-based models of C and N biogeochemistry is becoming a dominant trend in agro-ecosystem studies. Among the modeling efforts (CASA, CENTURY, Roth-C, N-Expert etc.) the 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 main reason for implementation of conservation tillage systems, including reduced tillage (RT) system is because they have shown potential for soil conservation and potential for saving their properties. They are more water efficient (Lindwall and Anderson 1981), reduce soil erosion (Hussain et al., 1999) and reduce production costs due to lower fuel and labor inputs.

Implementation of conservation systems including reduced tillage and no-till systems is also an indirect measure resulting from ecological standards of the European Union for securing good agricultural and environmental conditions (GAEC) (ecological conditionality for direct payment obtaining also in condition of Slovak Republic). Measures of Slovak Republic for implementation of minimization techniques came in force on 1. January 2009 (Cross-compliance, 2007). Spreading of these techniques in condition of Slovak Republic is limited by large acreage of not suitable compacted soils or partly compacted soils. But there is also an absence of detailed regionalization of suitable soils for this conservation systems as well as absence of long term field research in different ecological conditions. Implementation of conservation systems on agricultural land involves quantification of these effects on biogeochemical cycles of nitrogen (N) and carbon (C) in different soil-climatic conditions and farming managements which defers in time and space. Field experiments are the most

important key for providing the information on these cycles. However, field experiments can't cover all conditions influencing nitrogen and carbon cycles in different agro-ecosystems mostly due to financial resources. Process-based models might be one of the approach or substitution of field experiments over different soil-climatic conditions as well as farming management change in space and time.

The main objective of this study was to test the reliability of the DeNitrification and DeComposition DNDC model to predict N₂O emissions under conventional tillage and reduced tillage combined without and with N-fertilizer application from cropland of the experimental site in Nitra (Slovakia).

2. MATERIAL AND METHODS

Site observed meteorological data (daily maximum and minimum temperature, daily precipitation), soil properties (SOC, bulk density, pH, clay content), and farming management (crop type, planting, harvest dates, tillage, fertilization) 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 Field site and experimental design

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 2013 (February-November). This period covered also the growing season of red clover. 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 experiment consisted of two tillage methods (conventional tillage-CT and reduced tillage-RT) combined with unfertilized control (N0) and addition of N-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 (fig. 1).

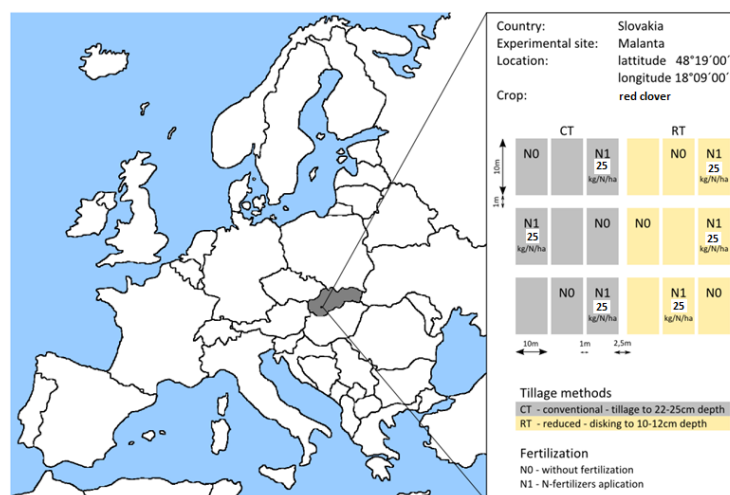


Figure 1 Experimental site and treatments

The red clover was seeded on 15. April 2013 with one cut on 10th of July. The doses of fertilizers were calculated by balance method and were applied in the amount of 25 kg N ha⁻¹ in the form of ammonium nitrate. The CT plots were plowed (depth 25 cm) RT plots were disked (10-12 cm) on 3 September 2013. The other crop (winter wheat) was seeded on 9 October 2013. The N-fertilizers application rate and other information on farming practices for the crop including the timing for tillage, planting day, harvesting day, etc. were set according to the individual needs of crops

recommended in terms of good agricultural practices (Fazekašová et al., 2016; Angelovičová & Fazekašová 2014; Fazekašová et al., 2013; Halaj et al., 2013a; Halaj, et al. 2013b; Halaj et al., 2013c; Bárek et al., 2008; Bárek et al., 2013).

2.2 Nitrous oxide (N_2O) measurements

The soil/crop and the atmosphere N_2O exchange was measured weekly (between 10 am and 2 pm) using closed chamber technique. 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 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.

2.3 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.

Input parameters required by the model include daily climate data (maximum and minimum air temperature, precipitation), soil properties (e.g., texture, pH, bulk density), vegetation (e.g., crop type), and management (e.g., tillage, fertilization, manure amendment, planting, harvest, etc.).

2.4. 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

Table 1 shows seasonal N_2O emission under two tillage combined with two fertilization levels during the studied period in 2013. Generally, the DNDC model underestimated the seasonal N_2O emissions with relative deviation between observed and simulated total seasonal N_2O emissions ($kg\ N_2O-N\ ha^{-1}$) ranging from 83-98 % for all treatments (CTN0, CTN1, RTN0 and RTN1) as compared to measured data. The comparison under conventional tillage showed that the DNDC model values were lower by 5.66 and 7.87 $kg\ N_2O-N.season^{-1}$ for N0 and N1 treatments, respectively as compared to measured values. In case of reduced tillage the DNDC showed even higher differences for both fertilization treatments (N0, N1).

Table 1 Observed and simulated seasonal N₂O emissions under two tillage and two fertilization treatments during the studied period (February – November, 2013).

Treatments Year 2013	N ₂ O emissions (kg N ₂ O-N.season ⁻¹)		Absolute difference (kg N ₂ O-N.season ⁻¹)	Relative difference (%)
	Observed	DNDC		
CT_N0	6.82	1.16	-5.66	-83.0
CT_N1	9.10	1.23	-7.87	-86.5
RT_N0	10.30	0.23	-10.07	-97.8
RT_N1	10.98	0.32	-10.66	-97.1

There were also found differences in daily values of N₂O emissions in both tillage treatments with and without N-fertilizer (fig. 1 and fig. 2). The highest measured N₂O emission peaks appeared in all treatments at the end of April (day 107) and lasted till mid-May (day 127). However these peaks were not simulated at the treatments with no N-fertilizer application (CT_N0, RT_N0) (Fig. 2a; Fig. 3a). These peaks were simulated by the DNDC model when nitrogen fertilizer was applied under the both tillage treatments (CT_N1, RT_N1), but the peaks were postponed and were lower and started three days later (from day 127 till day 129) (Fig. 2b; Fig. 3b).

The measured N₂O emission peaks were attributed to combined effect of environmental conditions (precipitation and related soil moisture) and agricultural management practices (tillage and fertilization). There was a rainfall event 4 days earlier (day 102) with total rainfall amount 11 mm (fig.4). The tillage (preparation of seed bed for red clover) was done 2 days earlier (day 105) and the fertilizers were applied on 7th of May (day 127) which was also the end of N₂O emission peaks period.

The study of Lessard et al (1996) found that rainfall had a large impact on N₂O emissions, particularly between days 150 and 208. Higher denitrification can occur due to higher moisture contents as a result of precipitation. There are also other studies showing that precipitation and drying could increase N₂O emission (Zona et al., 2011). Some results indicated that N₂O production and emission was greatly influenced by tillage because of the breaking of the soil uniformity (Kay and VandenBygaart, 2002). It has to be noted that the fertilizer application wasn't the main cause of the peak emissions, because the CTN0 and RTN0 treatments didn't receive any N-fertilizer during the whole studied period and the measured N₂O peaks appeared, as well reaching similar values as the fertilized treatments.

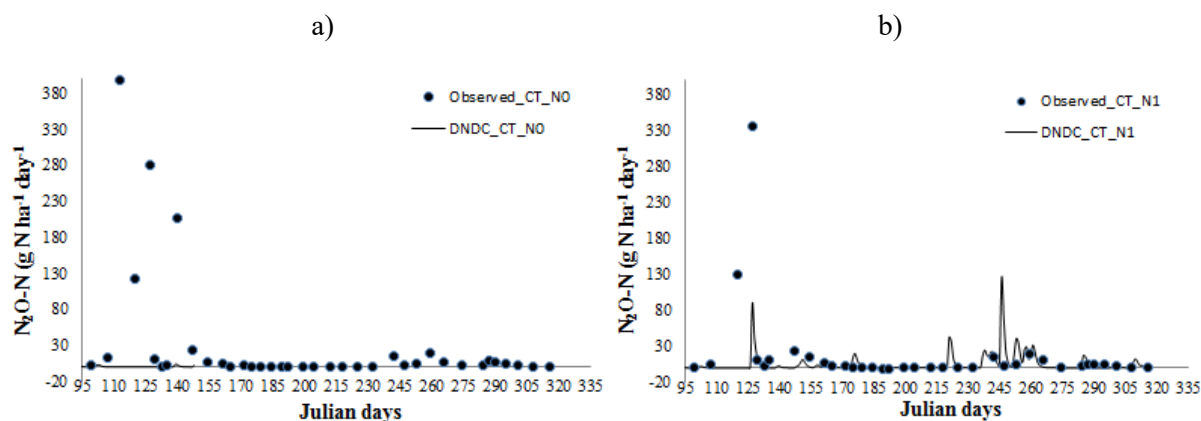


Figure 2 Comparison between observed and simulated daily N₂O emissions under conventional tillage (CT) combined without N-fertilizer (N0) and with application of N-fertilizer (N1).

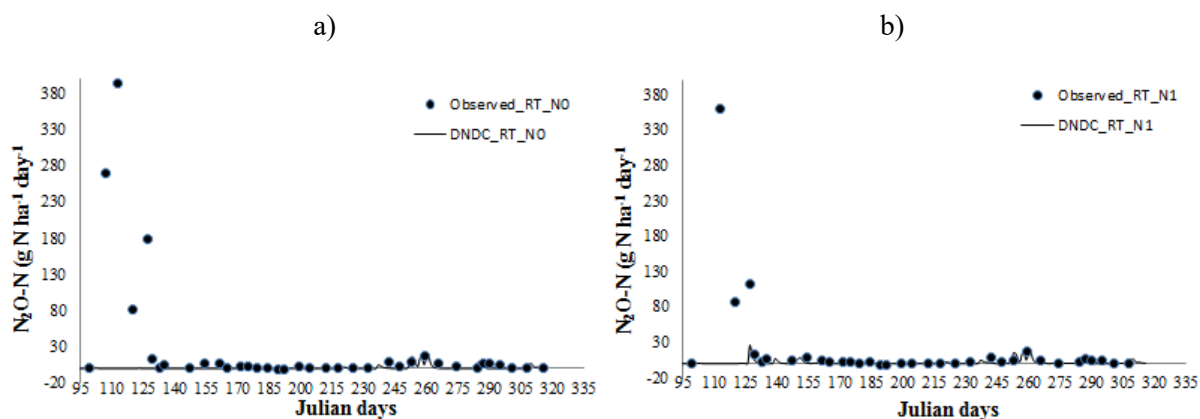


Figure 3 Comparison between observed and simulated daily N_2O emissions under reduced tillage (RT) combined without N-fertilizer (N0) and with application of N-fertilizer (N1).

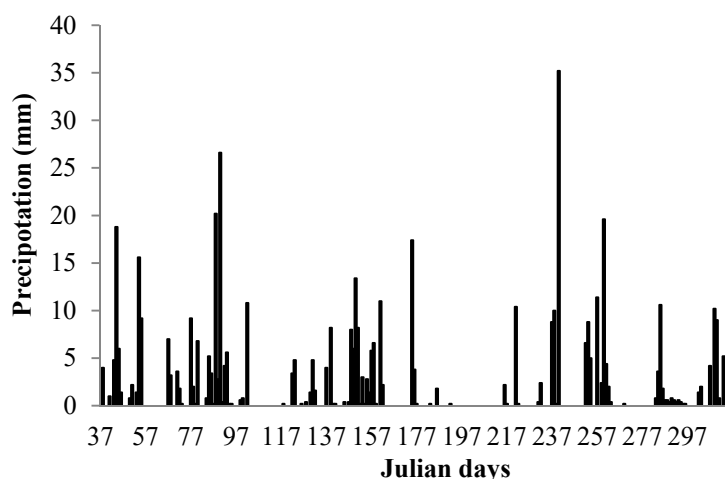


Figure 4 Precipitation during the studied period from nearby automatic meteorological station

The figures (fig.2 and fig.3) show weak visible trend in simulated daily N_2O emissions as compared to measured ones only for CTN1 and RTN1 but completely failed the trend in unfertilized treatments (CTN0, RTN0).

When looking at the magnitude of daily N_2O fluxes, the DNDC didn't capture the magnitude of daily N_2O emissions for all treatments (CTN0, CTN1, RTN0 and RTN1). In case of CTN0 treatment the measured daily N_2O emission during the studied period ranged from -2.5 (uptake) to $398\ g\ N\ ha^{-1}\ day^{-1}$ while the simulated emissions ranged from 0 to $43\ g\ N\ ha^{-1}\ day^{-1}$ (fig. 1a). Measured daily N_2O emissions of CTN1 treatment ranged from -0.7 to $438\ g\ N\ ha^{-1}\ day^{-1}$ while the simulated emissions ranged from 0 to $90\ g\ N\ ha^{-1}\ day^{-1}$ (fig. 2b). Measurements of daily N_2O emission for RTN0 treatment ranged from -1.1 to $394\ g\ N\ ha^{-1}\ day^{-1}$ while the simulated emissions ranged from 0 to $16\ g\ N\ ha^{-1}\ day^{-1}$ (fig. 3a). In case of RTN1 treatment the measured values ranged from -4 to $466\ g\ N\ ha^{-1}\ day^{-1}$ while the simulated emissions ranged from 0 to $26\ g\ N\ ha^{-1}\ day^{-1}$ (fig. 3b).

The Pearson correlation coefficient between observed and simulated daily N_2O emissions ($N=42$) was quite low and insignificant ($P < 0.05$) in all tillage and fertilization treatments (tab. 3). The best correlation between measured and simulated values of N_2O emissions was found in CTN1 treatment ($r=0.26$; $p=0.0925$) and the worst one in RTN0 treatment.

Table 2 Observed and simulated average daily N₂O emissions (for days only when measurements were taken) including Pearson's correlation coefficient (r) under conventional tillage (CT) combined without N-fertilizer (N0) and with application of N-fertilizer (N1).

Treatments	N ₂ O emissions (kg N ₂ O-N.season ⁻¹)		Pearson correlation coefficient [r]	p- value for r
	Observed average	DNDC average		
CT_N0	27.64	4.45	0.10	0.5302
CT_N1	36.65	7.34	0.26	0.0925
RT_N0	39.62	0.72	0.07	0.6568
RT_N1	41.89	1.63	0.14	0.3664

From an environmental point of view it is more important for a model to match seasonal N₂O emission values than daily emission values because the nitrous oxide has a relatively long atmospheric lifetime (around 150 years) and is well mixed in the atmosphere. The DNDC simulations of seasonal N₂O results in 2013 in this study indicate that the DNDC model didn't worked well for all treatments and underestimated the total seasonal N₂O. The study of Horák and Mukhina (2016) showed opposite results with DNDC overestimating the total seasonal emissions of N₂O at the same locality, under the same treatments, but year before in 2012 under the spring barley.

4. CONCLUSIONS

According to the results it can be concluded that the DNDC model didn't work well and underestimated the seasonal N₂O emissions with relative deviation between observed and simulated total seasonal N₂O emissions (kg N₂O-N ha⁻¹) ranging from 83-98 % for all treatments (CTN0, CTN1, RTN0 and RTN1) as compared to measured data. The results showed that there was a weak visible trend in simulated daily N₂O emissions as compared to measured ones only for CTN1 and RTN1 but the DNDC completely failed the trend in unfertilized treatments (CTN0, RTN0). When looking at the magnitude of daily N₂O fluxes, the DNDC didn't capture the magnitude of daily N₂O emissions for all treatments because the height of emission peaks in relevant occasions (precipitation, tillage, fertilization) showed big difference.

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