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N_2O fluxes from agricultural soils in Slovakia and Russia – direct measurements and prediction using the DNDC model

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Abstract

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Direct measurements of N_2O emissions were made on a loamy sand Spodosol (Russia) on agricultural plots with spring barley (*Hordeum vulgare* L.), potato (*Solanum tuberosum* L.), and white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) during the growing seasons of 2004 and 2006. A closed chamber method was used for measurements of N_2O fluxes from the soil. The DNDC model was applied to predict N_2O emissions from agricultural soils in the Danubian Lowland in Slovakia and in a northwestern region of Russia. Comparison of the modeled against the observed data demonstrated that the DNDC model adequately predicted the N_2O fluxes from soils in Russia and was sensitive to precipitation, soil water-filled pore space and rates of N fertilizers. A comparison of the modeled N_2O cumulative fluxes from soils in Slovakia and Russia showed that the DNDC model could be applied for the prediction of their seasonal dynamics in the selected agricultural sites.

Key words

agricultural soils, DNDC model, N_2O emission

Introduction

N_2O is a greenhouse gas whose emission needs to be quantified by Slovakia and Russia according to the Kyoto protocol. 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). N_2O is produced by microorganisms through nitrification and denitrification. Addition of N with mineral fertilizers and manure increases the N_2O emission from soils (Smith et al., 1998; Buchkina et al., 2006).

Nitrous oxide (N_2O) emissions from agriculture reach approximately 70% of annual global N_2O emissions (Mosier, 2001). Among the environmental and anthropogenic pressures, which account for the increased N_2O emissions from agriculture, it is necessary to distinguish precipitation, temperature, fertilisers, soil compaction, animal grazing and erosion processes. In the recent years scientists have already undertaken successful attempts to estimate the N_2O emissions from agricultural soils and to establish a validate basis for national agricultural policies on a reasonable application of mineral and organic fertilisers.

Process-based models of C and N biogeochemical cycling are powerful tools in agro-ecosystem studies. Among these models, the DNDC (Denitrification-

Decomposition) model showed a distinguished capacity for predicting soil organic C dynamics and N_2O, NO, NH_3, CO_2 and CH_4 emissions from soils (Li et al., 1992; Li, 2000). In Slovakia and Russia, the DNDC model is at present used for assessing the environmental and anthropogenic impacts on N_2O emissions from agricultural soils. The DNDC model can simulate the trace gas emissions from agriculture at a site level and at a regional level. At the site level, the model predicts the N_2O emissions from selected locations and, therefore, can be validated against measured N_2O emissions from a cropping system in an agricultural region. Using the validation records, the DNDC model's sensitivity and capacity of predicting trace gas emissions can be assessed for other similar cropping systems in regions with similar climatic conditions. The objectives of the present studies were to:

1. Compare between the modeled and measured N_2O fluxes from an agricultural soil in Russia
2. Compare the modeled N_2O fluxes from soils on selected agricultural sites in Slovakia and in Russia.

Material and methods

The study sites were located on a loamy sand Spodosol in a northwestern region of Russia and on a sandy loam Cambisol in the Danubian Lowland in Slovakia. Our studies were carried out on agricultural sites with different crop types and nutrient conditions. These sites represented agro-ecosystems typical for these regions of both countries.

Soil properties, weather conditions, and soil management in the Danubian Lowland have been well documented by Horák and Šiška (2006). A rate of nitrogen fertilizers was 37.5 kg N ha^{-1} for sugar beet (*Beta vulgaris* var. *saccharifera* L. cv. Intera) and spring barley (*Hordeum vulgare* L. cv. Ebson) for the growing seasons of 2000 and 2001, respectively. The total amount of precipitation was equal to 132 mm and 267 mm for growing periods of spring barley and sugar beet, respectively. A dynamics of precipitation during the growing seasons of sugar beet (2000) and spring barley (2001) in Slovakia is presented in Fig. 1.

In the NW Russia, experimental studies were carried out at the Menkovo experimental station (59°34' N, 30°08' E) of the Agrophysical Research Institute in the St. Petersburg region of Russia during the growing seasons of 2004 and 2006. The study sites were agricultural plots planted with spring barley (*Hordeum vulgare* L. cv. Suzdalets), potato (*Solanum tuberosum* L. cv. Nevsky), and white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L. cv. Kolobok). Rates of N fertilizers were: 0; 65 and 110 kg N ha^{-1} for spring barley and 120 kg N ha^{-1} for potato in 2004, and 0; 70; 110 kg N ha^{-1} for white head cabbage in 2006. The dynamics of precipitation during the growing seasons of spring barley (2004), potato (2004) and white head cabbage (2006) in the NW Russia is presented in Fig. 1.

In our field studies, a closed chamber method was used for measurements of direct N_2O emission from soils two-three times a week (between noon and 2 pm) through the growing seasons of the crops (Buchkina et al., 2006). We used PVC chambers for each of the plots with the selected crops. Chambers were made of inverted cylindrical plastic buckets, 18.9 cm in diameter and 11 cm high. The chambers were pressed into the soil to a depth about 2 cm. Four chambers were used in each plot with spring barley and eight chambers were used on plots with potato and white head cabbage – four in the furrows and four on the ridges. The chambers were placed in a center of the ridge and the furrow (Fig. 2).

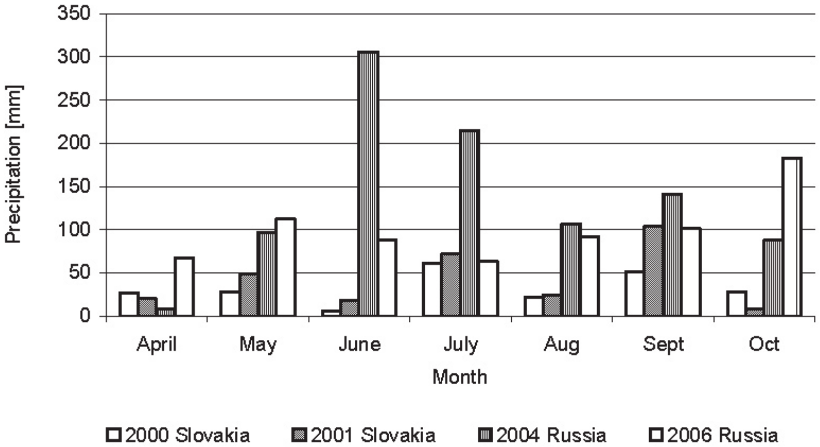

Fig. 1. Dynamics of precipitation during the growing season of sugar beet (*Beta vulgaris* var. *saccharifera* L.) in 2000 (Slovakia), spring barley (*Hordeum vulgare* L.) in 2001 (Slovakia) and 2004 (Russia), potato (*Solanum tuberosum* L.) in 2004 (Russia) and white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) in 2006 (Russia)

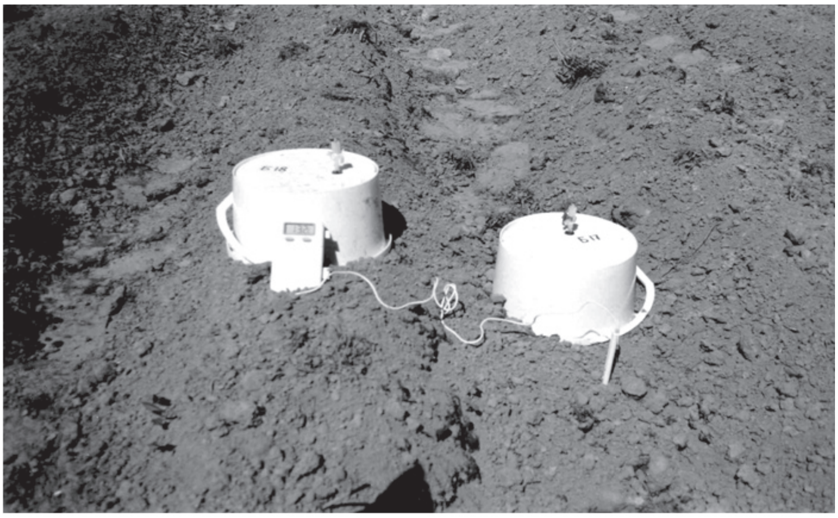

Fig. 2. Chamber placement on the ridges and in the furrows of the potato (*Solanum tuberosum* L.) plots in 2004 at the Menkovo experimental station (Russia)

Gas samples were taken by syringes from a headspace of the chambers via a three-way tap on the top of each chamber. N_2O concentrations in the gas samples, placed into hermetically closed glass vials (10 cm^3), were measured with a gas chromatograph fitted with an electron capture detector. Soil temperature and moisture content was simultaneously determined in each gas sampling. Measurements of soil bulk density, pH (H_2O), content of soil organic carbon (SOC), mineral nitrogen (NO_3^-, NH_4^+), and water were regularly made by conventional methods during the growing seasons. Air temperature and precipitation was measured daily. All of the soil analyses were conducted in three replicates. The means were calculated for selected parameters within each of the plots based on results of analytical measurements. Significance of differences between the means was tested by analysis of variance (one-way ANOVA) at $p \leq 0.05$. Relationships between soil parameters were assessed with a linear regression analysis using a computer statistical package at $p \leq 0.05$. The DNDC model (version 9.1) was used in our studies.

Results and discussion

There were several key factors affecting direct N_2O fluxes from the loamy sand Spodosol during the growing seasons of selected crops in years 2004 and 2006. The first factor was the amount of precipitation. The total amount of precipitation reached 690 mm and 769 mm during the growing seasons of spring barley and potato in 2004, and it was equal to 467 mm during the growing season of white head cabbage in 2006. A high amount of precipitation can cause a formation of soil anaerobic conditions favorable for microbial process of denitrification. Therefore, N_2O fluxes from soil can drastically increase if a water-filled pore space (WFPS) exceeds 60% (i.e. anaerobic conditions) after heavy rainfall events (DOBBIE et al., 1999).

During the growing seasons in 2004, the precipitation-induced WFPS varied in the soil of plots with spring barley from 20.9% to 70.4%, while the WFPS in the soil of ridges and furrows on plots with potato ranged from 21.0% to 45.9% and from 21.0% to 85.7%, respectively. In our studies, strong positive correlations were observed between N_2O emission (Fig. 3a) and WFPS in the soil with spring barley without N fertilizers ($r = 0.71$, $p < 0.05$), and with the rates of N fertilizers applied in amounts of 65 kg N ha^{-1} ($r = 0.81$, $p < 0.01$) and 110 kg N ha^{-1} ($r = 0.78$, $p < 0.05$) during the growing season. On the plots with potato, there were observed weak correlations between N_2O emission (Fig. 3b) and WFPS in the ridges ($r = 0.28$), as aerobic conditions dominated in this soil zone. In the furrows of potato plots, anaerobic conditions were dominant, especially after rainfall events. Therefore, correlations between N_2O emission and WFPS were stronger in the furrows ($r = 0.59$, $p > 0.10$) than in the ridges, as WFPS played a more important role ($r = -0.81$, $p < 0.01$) in a decrease of NO_3^- concentration from 24.8 mg N kg^{-1} soil to 5.0 mg N kg^{-1} soil due to higher denitrification.

In the field experiments with white head cabbage, we studied the seasonal dynamics of N_2O emission in soils differing in fertility. In the soil with poor and rich fertilities, values of pH, SOC and total mineral N (as NO_3^--N + NH_4^+-N) content were equal to 5.6, 17.0 g C kg^{-1} soil, 19.8 mg N kg^{-1} soil and 6.1, 21.0 g C kg^{-1} soil, 30.4 mg N kg^{-1} soil, respectively.

Our results demonstrated that the seasonal N_2O emission also adequately responded to the precipitation events during the growing season of white head cabbage grown on the loamy sand Spodosol with low and high fertility, without and with application of N fertilizers in rates of 70 and 110 kg N ha^{-1} (Fig. 4a, b).

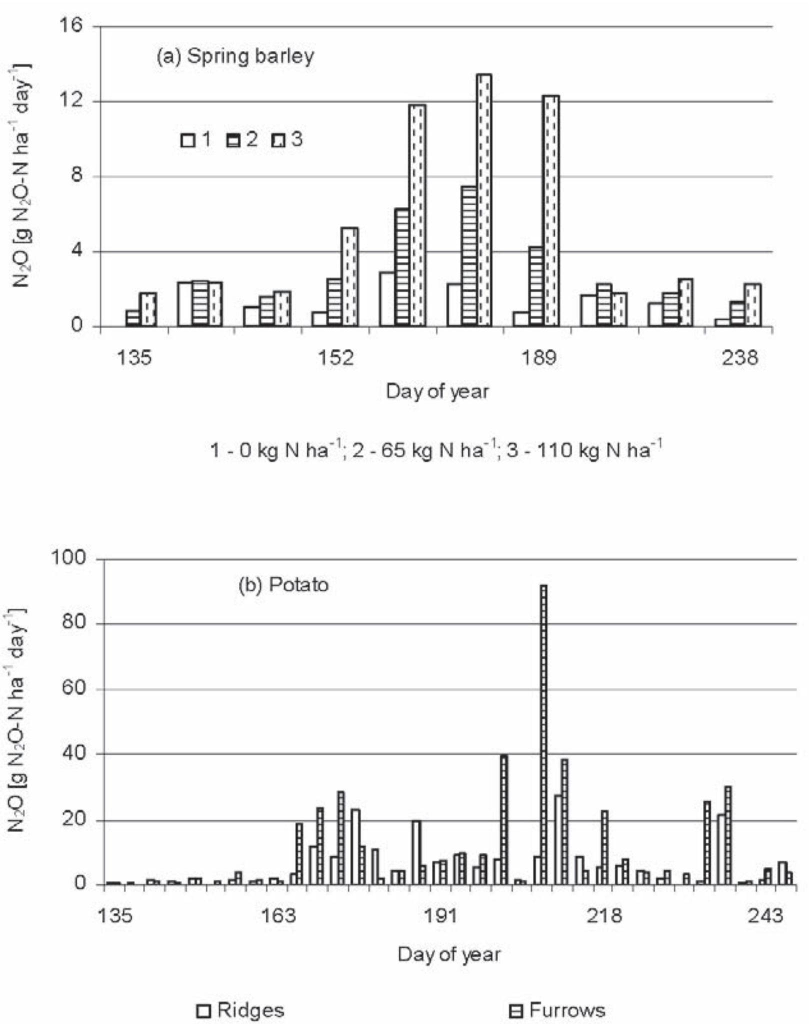

Fig. 3a, b. Dynamics of N_2O emission from loamy sand Spodosol under (a) spring barley (*Hordeum vulgare* L.) and (b) potato (*Solanum tuberosum* L.) at the Menkovo experimental station in 2004 (Russia)

The second factor of influence on N_2O emission was N fertilizers. The N_2O fluxes from the soil with spring barley increased with increasing rates (0–110 kg N ha^{-1}) of N fertilizers (Fig. 4a, b). The increasing rates of N fertilizers additively affected a total amount of soil mineral N (as NO_3^--N + NH_4^+-N), which varied from 7.9 to 76.1 mg N kg^{-1} soil (spring barley, 0 kg N ha^{-1}), from 10.5 to 139.3 mg N kg^{-1} soil (spring barley, 65 kg N ha^{-1}), and from 7.4 to 306.2 mg N kg^{-1} soil (spring barley, 110 kg N ha^{-1}) during the growing season of spring barley. Therefore, the soil with higher amount of available mineral N had more favorable conditions for microbial processes of nitrification and denitrification (Dobbie et al., 1999; Smith et al., 1998).

Our results showed that the DNDC adequately predicted the seasonal dynamics of N_2O cumulative fluxes from soil under spring barley with rates of N fertilizers of 65 and 110 kg N ha^{-1}, and under potato in the ridges. The differences (y, %) between the modeled (mod) and measured (meas) N_2O cumulative fluxes (F) were calculated according to the equation: $y = (Fmod - Fmeas)/Fmeas \times 100$. The differences between the modeled and measured N_2O cumulative fluxes, in terms of their final absolute values, changed from negative (at the rates of 0 and 65 kg N ha^{-1}) to positive ones (at the rate of 110 kg N ha^{-1}) for spring barley. In the case of potato, the differences between the modeled and measured records were higher for the furrows than for the ridges (Fig. 5).

The DNDC model was not able to adequately detect the formation of the above-mentioned anaerobic conditions in the furrows of potato plots.

In the case of white head cabbage, the lowest difference (–3%) between the modeled and measured N_2O cumulative fluxes was observed for the plot with rich soil without supplying N fertilizers. The modeled N_2O emission, compared to the measured ones, was much more sensitive to some precipitation events during the growing season of white head cabbage on the poor and rich soils amended with mineral N fertilizers (Fig. 6).

Therefore, the differences between the predicted and measured N_2O cumulative fluxes from the soil under white head cabbage could reach very high values (Fig. 7).

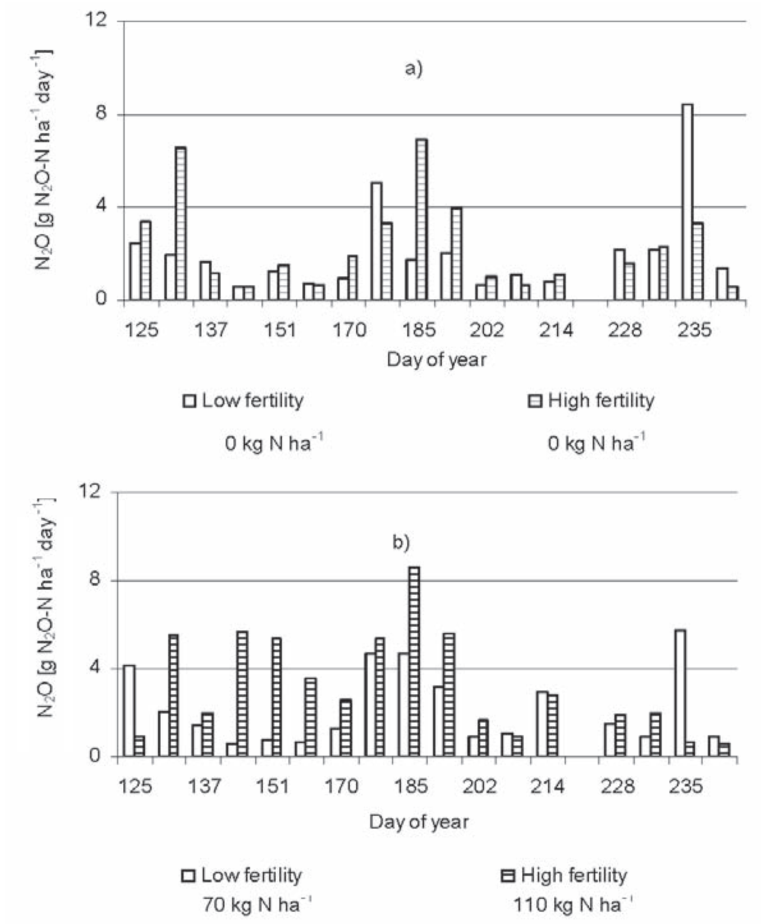

Fig. 4a, b. Dynamics of N_2O emission from loamy sand Spodosol with low and high fertility without (a) and with (b) application of N fertilizers for white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) at the Menkovo experimental station in 2006 (Russia)

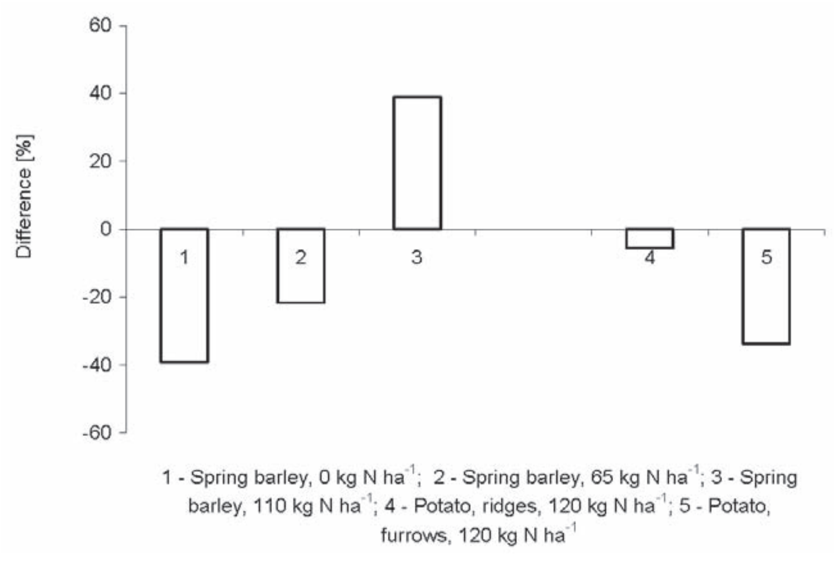

Fig. 5. Differences between the modeled and the measured N_2O cumulative fluxes from loamy sand Spodosol under spring barley (*Hordeum vulgare* L.) and potato (*Solanum tuberosum* L.) in ridges and furrows at the Menkovo experimental station in 2004 (Russia)

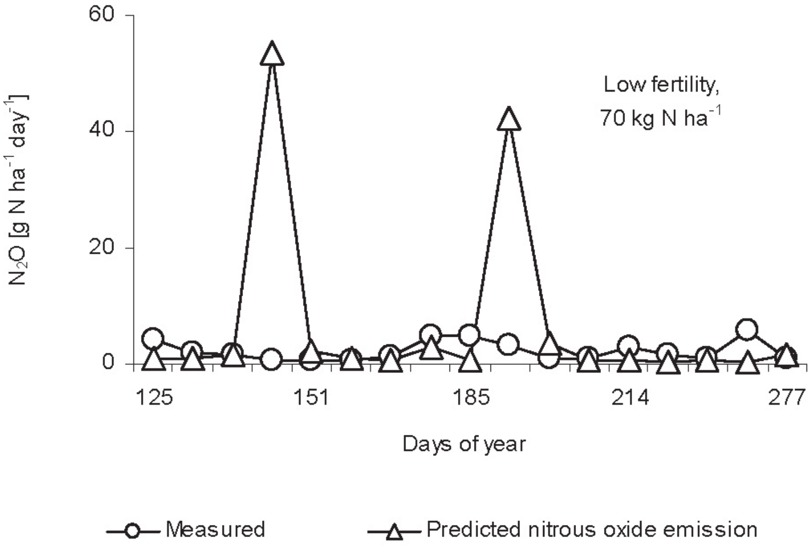

Fig. 6. Dynamics of the measured and predicted N_2O fluxes from loamy sand Spodosol under white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) in 2006 at the Menkovo experimental station (Russia)

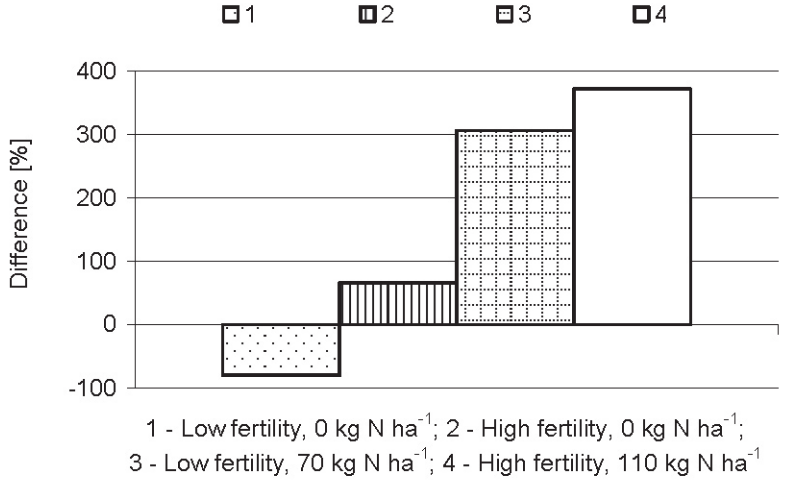

Fig. 7. Differences between the modeled and measured N_2O cumulative fluxes from loamy sand Spodosol with low and high fertility under white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) at the Menkovo experimental station in 2006 (Russia)

There were observed high negative differences between the modeled N_2O cumulative fluxes from the sandy loam Cambisol (Slovakia) and loamy sand Spodosol (Russia) with sugar beet and potato (–78 to –84%) as well as with spring barley (as shown in Fig. 8). The differences in precipitation and soil moisture content could result in the observed discrepancies in the modeled data for the selected sites in both countries.

The amount of precipitation in the Danubian Lowland was less than that in the NW Russia (Fig. 1). Therefore, the DNDC model was able to adequately predict the lesser N_2O cumulative fluxes resulted from a lower amount of precipitation and soil water in the soils in the Danubian Lowland.

Conclusions

Our results showed that the direct N_2O emission adequately responded to changes in precipitation, water-filled pore space and mineral N content during the growing seasons of spring barley, potato and white head cabbage on the loamy sand Spodosol. The results of comparison of the modeled against field observations demonstrated a distinguished capacity of the DNDC in

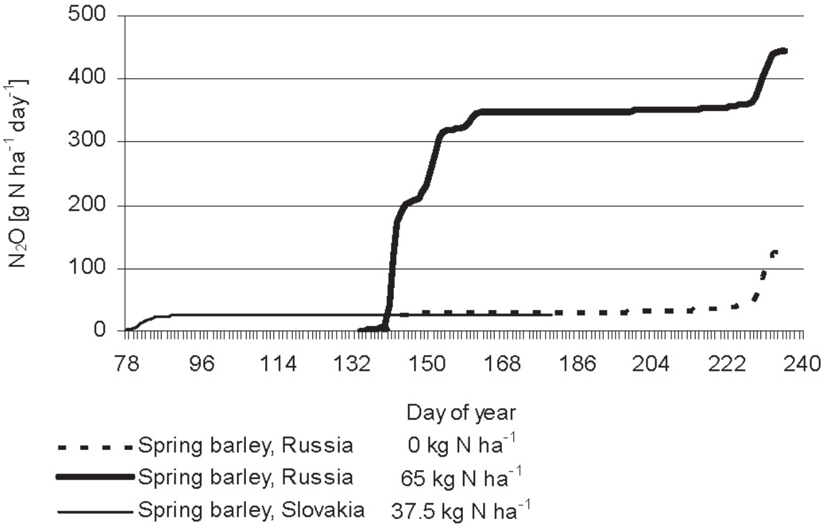

Fig. 8. Dynamics of the predicted N_2O cumulative fluxes from the loamy sand Spodosol and sandy loam Cambisol under spring barley (*Hordeum vulgare* L.)

predicting seasonal dynamics of the N_2O fluxes from this soil in selected treatments. The data on comparison tests of the modeled N_2O cumulative fluxes showed a satisfactory reliability of the DNDC model in the prediction of their seasonal dynamics in the selected agricultural sites of Slovakia and Russia.

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A scholarship of the Ministry of Education of the Slovak Republic and the Slovak Academic Information Agency (SAIA) enabled Dr. E. Balashov to carry out 3-month studies at the Slovak University of Agriculture in Nitra. The study was made also with support of the grant project VEGA 1/0866/10 "Proposal of adaptive measures to reduce negative climate change impacts on agricultural landscape of Danubian lowland".

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Toky N_2O z poľnohospodársky využívaných pôd na Slovensku a v Rusku – priame merania a prognóza využitím modelu DNDC

Súhrn

Priame merania emisií N_2O sa uskutočnili pod porastami jačmeňa siateho (*Hordeum vulgare* L.), zemiakov (*Solanum tuberosum* L.) a hlávkovej kapusty (*Brassica oleracea* var. *capitata* f. *alba* L.) na hlinito-piesočnatých pôdach – spodosoliach v Rusku vo vegetačných obdobiach 2004 a 2006. Meranie emisií N_2O z pôdy sa uskutočnilo metódou uzavretej komory. Predikcia emisií N_2O z poľnohospodárskych pôd na Slovensku (Podunajská nížina) a severovýchodnej oblasti Ruska bola stanovená pomocou modelu DNDC. Porovnaním modelových a meraných emisií na pôdach v severozápadnom Rusku sa zistilo, že model je citlivý na zrážky, vyplnenie pôdnych pórov vodou a úrovne hnojenia vo vzťahu k tokom N_2O z pôdy. Porovnanie celkových tokov N_2O modelovaných pre pôdy Ruska a Slovenska ukázali, že model DNDC je možné použiť pre predikciu sezónnej dynamiky na vybraných poľnohospodárskych plochách.

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