Pol. J. Environ. Stud. Vol. 31, No. 4 (2022), 3767-3778
DOI: *10.15244/pjoes/146465* ONLINE PUBLICATION DATE: 2022-05-05

Original Research

Assessment of Changes in the Total Carbon Content and Carbon Dioxide Emissions in Neris Park Soil Using the Simulating Program DNDC

Mantas Pranskevičius[1], Dainius Paliulis[1]*, Aleksandras Chlebnikovas[2,3], Artūras Kilikevičius[3], Kristina Kilikevičienė[3], Jonas Matijošius[3]

[1]Department of Environmental Protection and water engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania
[2]Institute of Environmental Protection, Vilnius Gediminas Technical University, Vilnius, Lithuania
[3]Institute of Mechanical Science, Vilnius Gediminas Technical University, Vilnius, Lithuania

Received: 1 October 2021
Accepted: 7 February 2022

Abstract

Simulating total carbon changes in soil and carbon dioxide emissions was carried out using the simulating program DNDC. The assessment covered soils of three different types of land-use (arable, meadow and forest). The aim – simulating of carbon dioxide emissions from arable, meadow and forest soil and total carbon quantity in selected soil evaluating climate change. The assessment used the data received from an analysis of the total carbon quantities in soil of the Neris Regional Park. Data for the assessment of carbon dioxide emission were obtained upon carrying out investigations in autumn in the same locations where the total carbon quantity was determined. The value of total carbon simulated in meadow soil was lower by 3.4%, in arable soil was lower by 4.5%, in forest soil was lower by 1.4% comparing to experimental data. The value of CO_2 emission simulated from meadow soil was higher by 24%, from arable soil was higher by 26% and from forest soil was higher by 27% comparing to experimental data.

Keywords: soil, total carbon, carbon dioxide emissions, soil degradation, soil research

Introduction

Carbon stored in soils represents the largest terrestrial organic carbon pool. As a result of mineralization processes carbon is liberated from soil organic matter and can be lost from the soil via the aqueous or the gaseous phase. Carbon occurs in terrestrial ecosystems in several chemical forms and are potentially emitted as greenhouse gases (GHG). The diversity of landscapes and forms of land-use within the EU is large and calls for an international platform of interaction. This will involve an interdisciplinary approach in the collaboration of people with expertise in forest ecology, agriculture, biology, geography and socio-economy. A meaningful proposal for the evaluation of GHG emissions from terrestrial ecosystems is a vital contribution to guidelines for future reporting rules. The challenge is to establish

*e-mail: dainius.paliulis@vilniustech.lt

a dialogue between stakeholders in the scientific, administrative, and political arena. Soils release around 20% of the total CO_2 content to the atmosphere, consequently, forest and agricultural ecosystems have a big influence on CO_2 balance [1]. Because of human activities, the agricultural ecosystem is a critical source of non-carbon dioxide (non-CO_2) greenhouse gases (GHGs), which account for 56 % of anthropogenic emissions of non-CO_2 GHGs [2]. Methane (CH_4) emissions from the global agricultural ecosystems are 3.22×10^6 Gg CO_2-eq yr^{-1} and nitrous oxide (N_2O) emissions are 5.99×10^6 Gg CO_2-eq yr^{-1} [3-5]. It should be noted that land use contributes ~25% of total global anthropogenic GHG emissions: 10-14% directly from agricultural production, mainly via GHG emissions from soils and livestock management, and another 12%-17% from land cover change, including deforestation [6-8]. Scientific and statistical studies state that controlling soil respiration and carbon (C) cycling are of particular interest because soils contain twice as much C as the atmosphere and three times as much as vegetation [9]. Soil respiration is the key factor for understanding responses of terrestrial ecosystems to climate change. Agricultural ecosystems are an integral part of terrestrial ecosystems. Therefore, the agricultural influence on carbon emission and soil carbon sequestration is undoubted. Cropland amounts to about 12% of the earth's surface, and there is a general agreement that many agricultural ecosystems have the potential to sequester large amounts of C and support enhancing C sequestration in the soil [10]. The issue of soils acting as a GHG sink is controversial. Cultivated soils have lost a substantial part of their original C and N as a consequence of anthropogenic use. GHG emissions due to land use change include those by deforestation, biomass burning, conversion to agricultural use of natural ecosystems, drainage of wetlands and soil cultivation. The current sink strength of soils for the retention of C and N is bound to decline, if no specific incentives for adapted forms of land-use are provided.

Crucial topics are the maintenance of the current sink activity of forests soils, agricultural forms of management that turn arable soils into GHG sinks, and the protection of pristine landscapes such as wetlands and old forests, that are currently large reservoirs of C and N.

Agricultural soils are most likely a continuous source of GHGs. Stock changes in soils are difficult to detect because the spatial variability of soil chemical properties is large and blurs the signal of a temporal trend. Soil inventory methods that allow the efficient detection of temporal changes in the C and N stocks are still to be developed. Land-use change (e.g. afforestation of agricultural land), is expected to have a large effect on the GHG sink strength of soils. The main parameters influencing CO_2 emission from the soil are – soil type, vegetation type, temperature, pH, C/N ratio, humidity, air pressure and land use management. Mathematical simulating can be used for simulating of natural and anthropogenic processes. The essence of the contemporary mathematical simulating methodology is the replacement of a real object with its "image" – a mathematical model and later – a virtual object [11]. Simulating results are difficult to verify by field experiments, because the spatial variability often exceeds the temporal trend. Many scientists used DNDC model for simulating of greenhouse gas emissions [12-23], but there is a lack of data about model using for carbon dioxide emissions from arable, meadow and forest soil simulating and its comparing. The aim of simulating – simulating of carbon dioxide emissions from arable, meadow and forest soil and total carbon (TC) quantity in selected soil evaluating climate change.

Methodology of Research

The DNDC model predicts carbon biochemistry in agro-ecosystems. When simulating is performed on a regional scale, the DNDC model reads entered data from the database in which information may be distributed by space. The model predicts crop yield, soil carbon sequestration, nitrate leaching losses and carbon dioxide emissions [24]. The database includes information on soil type, texture, soil pH, SOC, bulk density, etc. An observed area is an upland crop field with sandy loam soils with parameters that are given in Table 1.

For comparing of simulating results with experimental results the ADC BioScientific Limited LCi Leaf Chamber/Soil Respiration analysis system (SRS2000) was used to measure CO_2 flow [25].

Table 1. DNDC model inputs of soil properties.

DNDC model inputs of soil properties	Arable - Silty Clay Loam	Meadow - Sandy clay loam	Forest - Sandy Loam
Initial organic C content at surface soil (kg C/kg)	0.022	0.019	0.027
Bulk density (g/cm^3)	1.236	1.425	1.198
Soil pH	6.0	7.2	5.4
Clay fraction	0.34	0.27	0.09
Moisture (water-filled porosity) (%)	0.477	0.421	0.435

Investigations were carried out in the Neris Regional Park and the localities of Paluknis and Užpaliai (Fig. 1). The investigations were carried out with the aim of setting up a database which could subsequently be used for the modelling and analysis of the change of the total carbon content in soils of different land-use purpose. Soil samples were taken from meadow, arable and forest soils.

The model consists of two components. The first component constitutes the model of soil, climate, crop growth and decomposition. It is used to predict soil temperature, humidity, pH and redox potential (Eh) on the basis of climate, soil, vegetation and human activity drivers. It is possible to perform simulating for a period from 1 to 100 years. Consequently, simulating requires the annual meteorology (air temperature (average, minimum, and maximum), precipitation, solar radiation and the wind speed). One year meteorological data of Vilnius (values of the average daily temperature and precipitation) were used for simulating. The obtained data show the dynamics of carbon dioxide emissions and soil carbon under the worst conditions. Prior to simulating it is necessary to indicate the geographical latitude, i.e. 54°45’ corresponding to the Neris regional park latitude was entered.

The model estimates the dynamics of carbon and carbon dioxide emissions from soil in the current year only. For this purpose, meteorological media were designed taking into account the meteorological forecast according to UTBalt7. The assumption was made that the average ambient annual air temperature will increase by 0.3ºC, while the average annual precipitation will decrease by 0.23% [26]. The forecast was simulated for 1 year and 10 year periods. The second component predicts carbon dioxide, methane, ammonia, nitric oxide, nitric suboxide and nitrogen gas emissions from soils. In addition to soil organic carbon, the analysis covers other sources of carbon, such as plant residues (e.g. litter), microbe biomass, humates (i.e. active humus acids) and passive humus.

The analysis takes into account the rates of decomposition of each carbon source as well as the content of clay and nitrogen in soil. Soil temperature and humidity are also taken into account. The model evaluates oxidation and leaching processes of soil carbon. First, the type of soil was indicated – sand soil. The established soil density up to a depth of 10 cm was indicated. The density of arable soil was – 1.236 g/cm^3, the density of forest soil – 1.198 g/cm^3 and the density of meadow soil – 1.425 g/cm^3. Afterward, soil pH was entered (for arable soil – 6.0, forest soil – 5.4 and meadow soil – 7.2). Pursuant to the analyzed data on the total carbon content, the average carbon concentration in soil at a depth of 0 to 10 cm recalculated from percentage share to kgC/kg in arable soil was 0.022 kg/C/kg, in meadow soil – 0.019 kgC/kg,

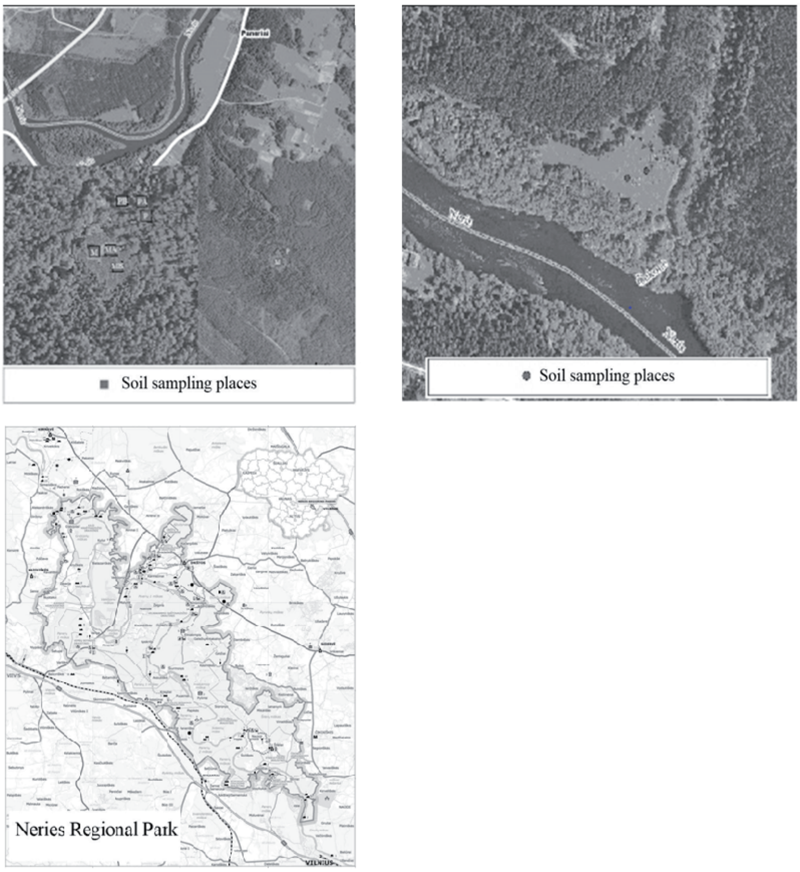

Fig. 1. Places of natural investigations of the total carbon content in the Neris Regional Park.

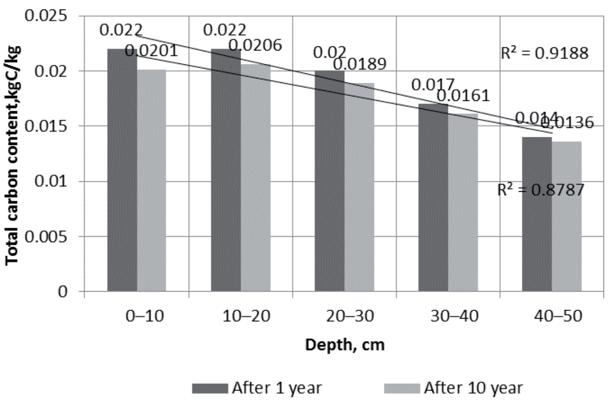

Fig. 2. Change in the total carbon content in arable soil at a depth of 0 to 50 cm after 1 and 10 years.

and in forest soil – 0.027 kgC/kg. The DNDC model has no allowable computational error. The typical permissible error for various models is in range from 20 to 50 percent.

Results and Discussion

Arable Soil

The period of simulating with regard to arable soil was ten years. Data are presented for the first year and a period after ten years. The first-year simulating results showed that the total carbon content in soil at a depth of 0 to 10 cm would decrease by 8.22% (Fig. 2).

The total carbon content in soil at a depth from 10 to 50 cm will, on average, decrease by 5.57% for every 10 cm. Compared to research results the obtained values should decrease by up to 10.7 % after ten years. A discrepancy between research data and simulated data in the first year is 2.7%.

During the first year the total carbon content in 1 hectare of arable soil falls from 87394 kgC/ha to 86564 kgC/ha, i.e. by 830 kgC/ha (Fig. 3). After ten years the total carbon content in this soil will decrease from 82339 kgC/ha to 81887 kgC/ha (an annual difference is 452 kgC/ha). After ten years the total

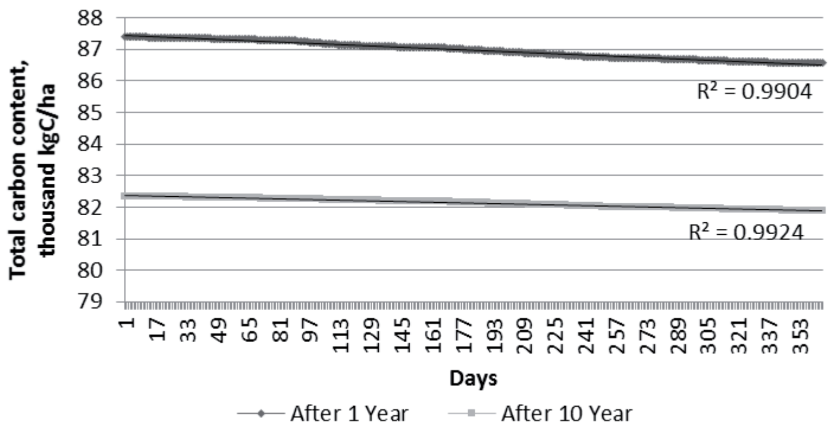

Fig. 3. Change in the total carbon content in arable soil after 1 and 10 years.

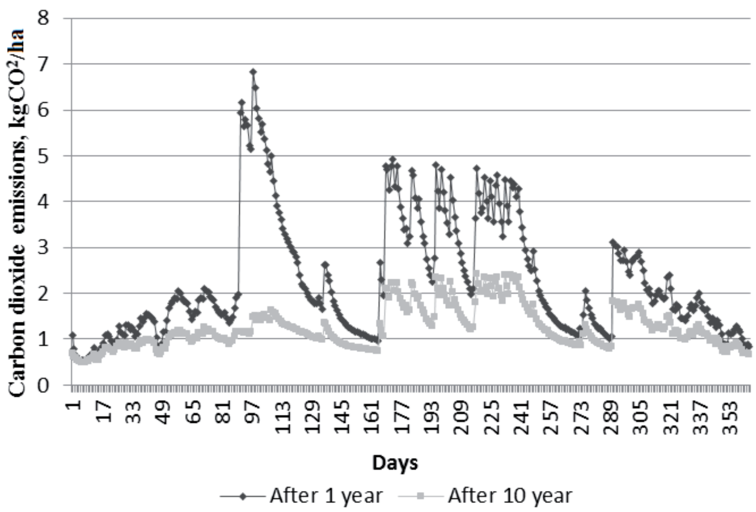

Fig. 4. Change in carbon dioxide emissions per day in arable soil after 1 and 10 years.

carbon content in arable soil will decrease from 830 to 452 kgC/ha, i.e. by 378 kgC/ha.

During the first year the average carbon dioxide emissions from arable soil (from hectare per day) amounted to 2.28 $kgCO_2$/ha per day. The biggest emissions per day were established at the beginning of spring – 6.84 $kgCO_2$/ha. During the period of vegetation carbon dioxide emissions reached up to 4.89 $kgCO_2$/ha per day. At that time the dynamics of carbon dioxide emissions was for the most part influenced by precipitation (Fig. 4).

Humidity is required for maintaining mineralisation processes. Decreasing of soil humidity is a reason of reduced microbiological activity. In autumn, when the content of humidity in soil increases, carbon dioxide emissions also increase. The coefficient of correlation between precipitation and carbon dioxide emissions was 0.3.

The average carbon dioxide emission after ten years reached 1.24 $kgCO_2$/ha. A decreasing amount of the total carbon predetermined smaller emissions of carbon dioxide. The dependence of carbon dioxide on precipitation remained unchanged. The correlation coefficient was 0.35. The most reliable carbon dioxide correlation occurs when emissions was in the range from 0.5 to 2.0 $kgCO_2$/ha per day. With regard to temperature, the coefficient of correlation reached 0.51.

Based on the data of other authors' research, it can be seen where the data on the initial organic carbon content is 0,032 kg C kg^{-1}. DNDC model predicts cumulative CO_2 emissions of 920 and 1303 kgC/ha, respectively, than 699 kg/ha from the field measures data [27]. By comparison, the measured carbon dioxide emissions from rice cultivation in South Korea can range from 1,1 to 159,1 kgC/ha per day, with a daily average of 37,4 kgC/ha per day. Modeling results show carbon dioxide emissions was between 3,9 and 5,6 t CO2 ha^{-1} $year^{-1}$ [28]. Simulating also took into account a linkage between the total carbon content in soil and carbon dioxide emissions. Data on arable soil showed reverse correlation r = -0.74 (Fig. 4). The average values of the total carbon and carbon dioxide during a period of ten years were used for statistical analysis. It was also identified that the relationship displays some tendency. Tendentious irregularities in relationship were identified in the chart from 8429 kgC/ha to 84347 kgC/ha, from 84347 kgC/ha to 84618 kgC/ha and from 84618 kgC/ha to 84883 kgC/ha. When the carbon content in soil was the biggest the maximum carbon dioxide emissions were established, which corresponds to the processes of mineralisation occurring in spring. While the ambient air temperature is not high, carbon dioxide emissions rise gradually, however, later, under the influence of climatic parameters carbon dioxide emissions start falling. The central part of the chart reflects the processes of metabolism occurring during the period of vegetation. Decreasing metabolism in soil at the end of the year is displayed when carbon dioxide emissions decrease with the decreasing carbon amounts.

As regards climate change, the total carbon content in arable soil insignificantly increased. Increased ambient air temperature and precipitation predetermined a 0.9% increase in the total carbon content at a depth of 0 to 10 cm in the first year. After 10 years, this increase at a depth of 0 to 10 cm will account for 6.1%. Considering these forecasts, a biomass increment should grow due to shifting climatic zones in Lithuania's territory. The model evaluated the influence of the increased average annual temperature as well as change in precipitation. However, this model does not estimate the adverse consequences of climatic conditions, such as floods or lengthy droughts.

The total carbon content at other depths increased, on average by 1% during the first year. As data for the period after ten years shows, the total carbon content at a depth of 10 to 50 cm should grow, on average by 7.2% (Fig. 5). The impact of climate change on arable soil manifests itself by an increased content of the total carbon. It is, however, assumed that soils located closer to the equator will see a decrease in the total carbon content due to decreasing precipitation in the climatic zone of the equator.

In accordance with the data obtained from simulating, carbon dioxide emissions in arable soil in the current situation will decrease by 379 $kgCO_2$/ha/year after 10 years of use. This decrease results from exhausted soil in which the total carbon decreased by 378 kgC/ha after 10 years of use. In the prognosticated situation, carbon dioxide emissions will increase by up to 57 $kgCO_2$/ha/year during the second year as a result of favourable climatic conditions for plant growth. However, already after 3 years of use carbon dioxide emissions will fall.

Other researchers see the same. For the pasture, DNDC predicted a cumulative annual CO_2–C efflux of 9.6 t C ha^{-1} compared with the observed efflux of 11 t C ha^{-1}.

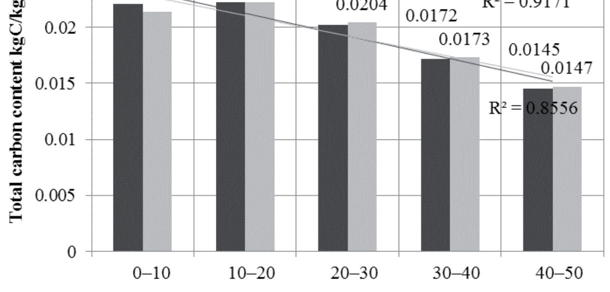

Fig. 5. Change in the total carbon content at a depth from 0 to 50 cm in arable soil after 1 and 10 years taking into account climate influence.

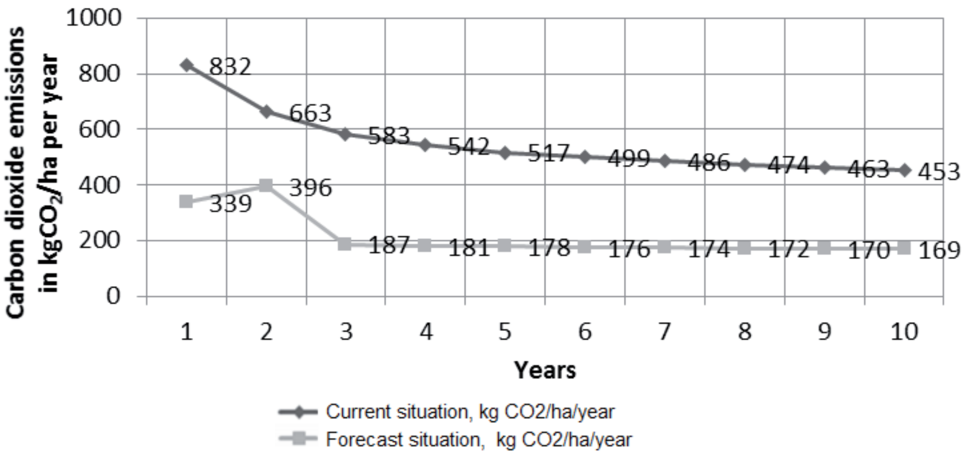

Fig. 6. Change in carbon dioxide emissions in arable soil in period of 10 years taking into account climate change.

Meadow Soil

The simulated quantities of the total carbon in meadow soil, compared to related field measurements, were smaller by 1.6% (0 to 10 cm deep) (Fig. 6). During the first year the total carbon content in meadow profile (0 to 50 cm deep) will decrease by 1.1 times. After ten years, the total carbon content in meadow soil at a depth of 0 to 10 cm will decrease by up to 7.94%. A decrease in the total carbon at the depths of 10 to 50 cm will reach 5.34%. A comparison of the first and the tenth year at all depths shows an average decrease in the total carbon of up to 1.1 times. A comparison of data obtained from simulating and field research shows a difference of 9.4%.

During the first year, the total carbon in one hectare of meadow soil will decrease up to 740 kgC/ha (Fig. 8). Meanwhile in the tenth year this decrease will reach 542 kgC/ha. Consequently, during ten years the total carbon should fall up to 198 kgC/ha.

According to correlative relations, the total carbon amounts and carbon dioxide emissions in meadow soil are identical to those in arable soil. A similar arrangement of correlative relations was also identified

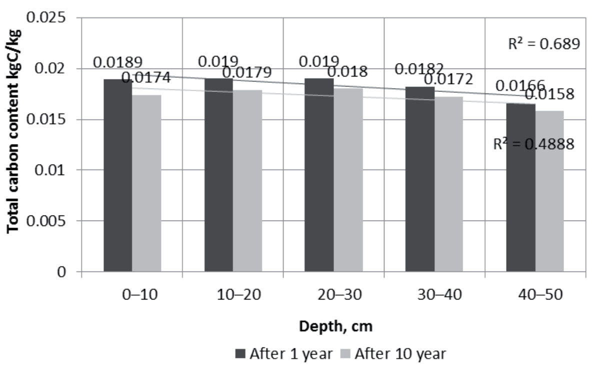

Fig. 7. Change in the total carbon content in meadow soil at a depth of 0 to 50 cm after 1 and 10 years.

in this soil. Carbon dioxide emissions in meadow soil, like in the case of arable soil, start growing only in the springtime. However, carbon dioxide emissions from meadow soil are higher (from arable soil – 1.24 $kgCO_2$/ha, from meadow – 1.53 $kgCO_2$/ha) (Fig. 8). The biggest carbon dioxide emissions in spring amounted to 2.4 $kgCO_2$/ha. During the period of vegetation carbon dioxide emissions reached up to 3.51 $kgCO_2$/ha. In the meantime at the end of the year these emissions decreased to 2.51 $kgCO_2$/ha (Fig. 9). Compared to arable soil, carbon dioxide emissions were similar in the period of vegetation and in autumn. The biggest difference with regard to arable soil was noticed in spring. Such a change is chiefly predetermined by agricultural works on arable field in spring.

The impact of climate change on meadow soil manifested itself in deeper layers. An increase in the total carbon was identified in these layers (10 to 30 cm deep). If during the first year the total carbon content in meadow soil at a depth of 0 to 10 cm amounted to 0.019 kgC/kg, in the tenth year it fell by up to 1.01 times. However, during the first year of analysis the total carbon content in deeper layers increased insignificantly. In the meantime, in the tenth year it increased by 1.1 times at a depth of 10 to 30 cm. A comparison of the obtained data and field measurements at a depth of 0 to 10 cm shows an increase of 1%. As the data from the tenth year analysis shows, the results of the model and field research coincided. As identified by depths, the average total carbon content in the first year data amounted to 0.018 kgC/kg. Compared to the tenth year, a difference accounted for 2.81%.

In the current situation, carbon dioxide emissions increase up to the second year only by 1.2 times (159 $kgCO_2$/ha/year) (Fig. 10). In subsequent periods carbon dioxide emissions decreased. Compared to the first year of the current situation, carbon dioxide emissions will decrease up to 200 $kgCO_2$/ha/year. However, in the prognosticated situation carbon

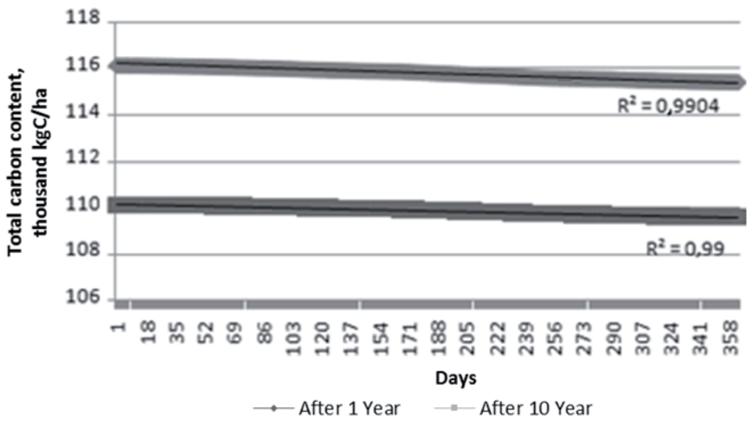

Fig. 8. Change in the total carbon content in meadow soil after 1 and 10 years.

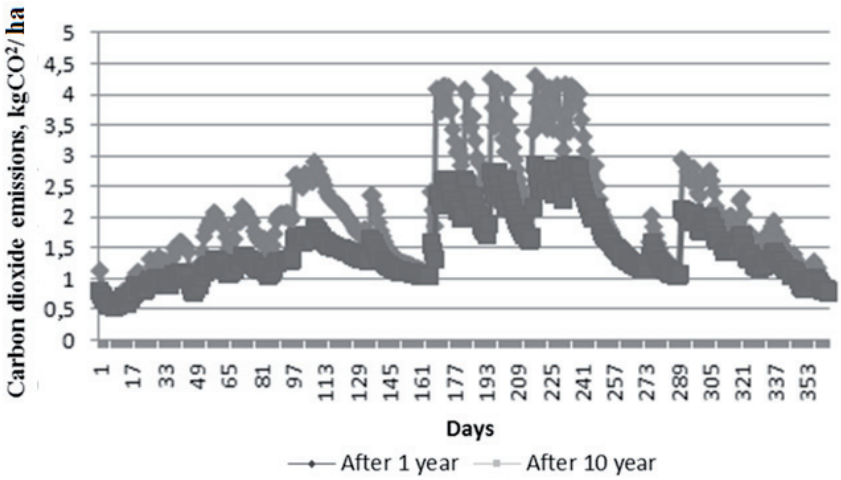

Fig. 9. Change in carbon dioxide emissions per day in meadow soil after 1 and 10 years.

dioxide emissions in meadow soil will increase. The biggest increase will occur during the first four years – 443 kgCO_2/ha/year. Meanwhile in the subsequent years an increasing trend will stabilise.

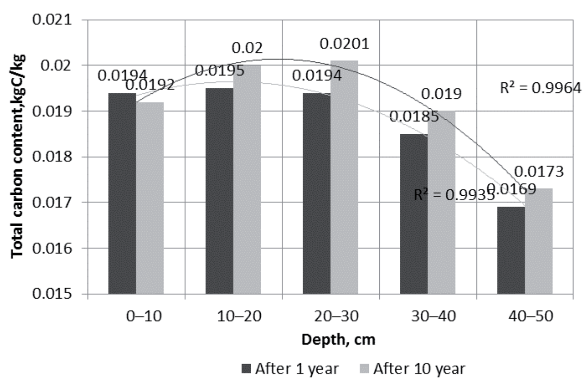

Fig. 10. Change in the total carbon content in meadow soil at a depth of 0 to 50 cm after 1 and 10 years taking into account climate change.

In arable soil both the total carbon content and carbon dioxide emissions will decrease, while in meadow soil a reverse process will occur. This is predetermined by the fact that arable soil is exhausted, while the conditions of simulating meadow soil were adapted for unused meadow. It can be assumed that unused areas of soil will thrive due to more favourable growth conditions. Larger amounts of formed biomass will access soil, which will stimulate the increase of the total carbon in deeper layers as well as carbon dioxide emissions.

Forest Soil

Quantities of the total carbon in forest soil, like in the case of meadow soil, will increase in deeper soil layers. This increase should be reflected best after ten years. During the first year only a minor increase in the total carbon content will occur at a depth of 10 to 30 cm. In the meantime, in the tenth year the amount of the total carbon in meadow soil, compared to data regarding a depth of 0 to 10 cm, will increase by 1.05 times or up to 4.04% (Fig. 11). According to field

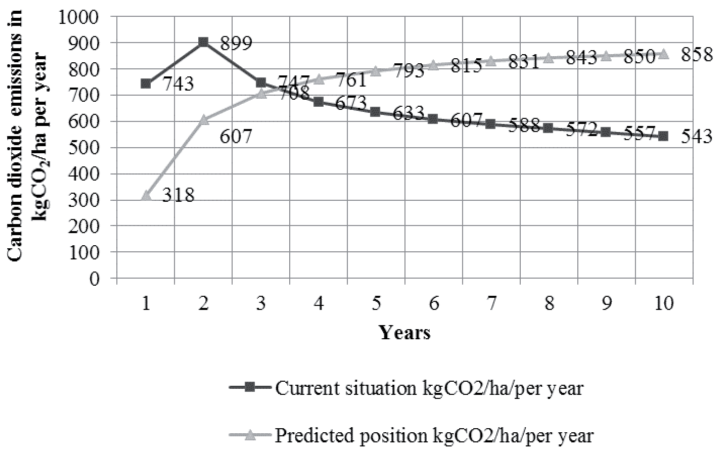

Fig. 11. Change in carbon dioxide emissions in meadow soil after 10 years taking into account climate change.

research findings, values obtained in the first year at a depth of 0 to 10 cm are by 0.4% bigger, while in the tenth year by 0.4% smaller.

In the current situation the total carbon tends to accumulate in forest soil at the end of the year. As the chart shows, from November the total carbon content in soil increases by 812 kgC/ha after a year, while after 10 years this increase reaches up to 4623 kgC/ha (Fig. 12). However, as the annual balance shows, during the first year the total carbon content in forest soil will increase by 937 kgC/ha, while after ten years – 565 kgC/ha every year. However, after ten years forest soil will contain, on average, 144447 kgC/ha, compared to 140955 kgC/ha in the first year. After ten years the total carbon content in forest soil should increase up to 4058 kgC/ha.

During the first year average emissions from forest soil will amount to 2.82 $kgCO_2$/ha per day. Over the period of the tenth year carbon dioxide emissions will decrease up to 2.58 $kgCO_2$/ha per day (Fig. 13). It is obvious from the chart that during the first year carbon dioxide emissions were greatly impacted by environmental drivers. In the tenth year the dynamics of carbon dioxide emissions was more gradual. The biggest carbon dioxide emission identified in the first year by means of simulating reached 6.52 $kgCO_2$/ha per day, while after ten years emissions in meadow soil decreased to 4.71 $kgCO_2$/ha per day.

The performed analysis of the dependence of the total carbon content on carbon dioxide emissions shows that r = -0.58. At the beginning of the year carbon dioxide emissions are quite low. The carbon dioxide emissions identified in arable soil reached up to 1.7 $kgCO_2$/ha per day, while in meadow soil – 1.65 $kgCO_2$/ha per day. In the period of vegetation carbon dioxide emissions in forest soil varied from 0.48 $kgCO_2$/ha per day to 5.08 $kgCO_2$/ha per day.

In the first year, during simulation of climate change the total carbon content in forest soil at a depth of up to 30 cm changed insignificantly. A comparison of the obtained field research data and values obtained from simulating showed a difference of 0.7%. Meanwhile this difference at a depth of 0 to 10 cm after ten years

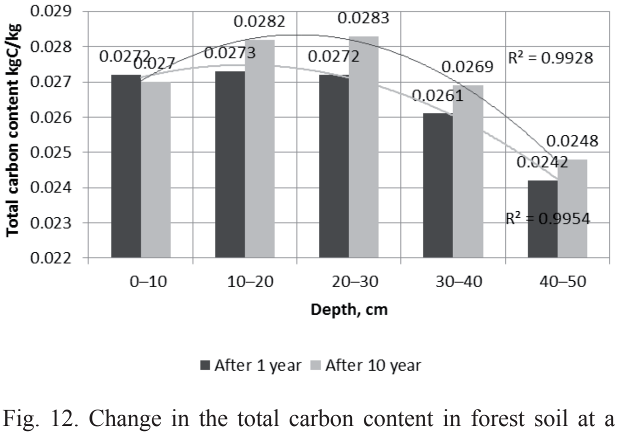

Fig. 12. Change in the total carbon content in forest soil at a depth of 0 to 50 cm after 1 and 10 years.

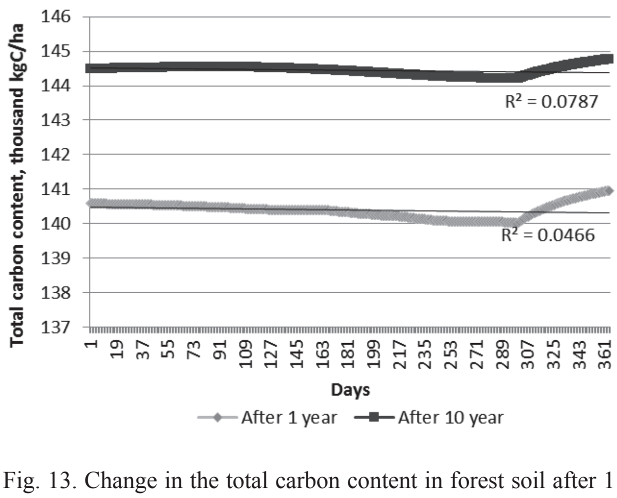

Fig. 13. Change in the total carbon content in forest soil after 1 and 10 years.

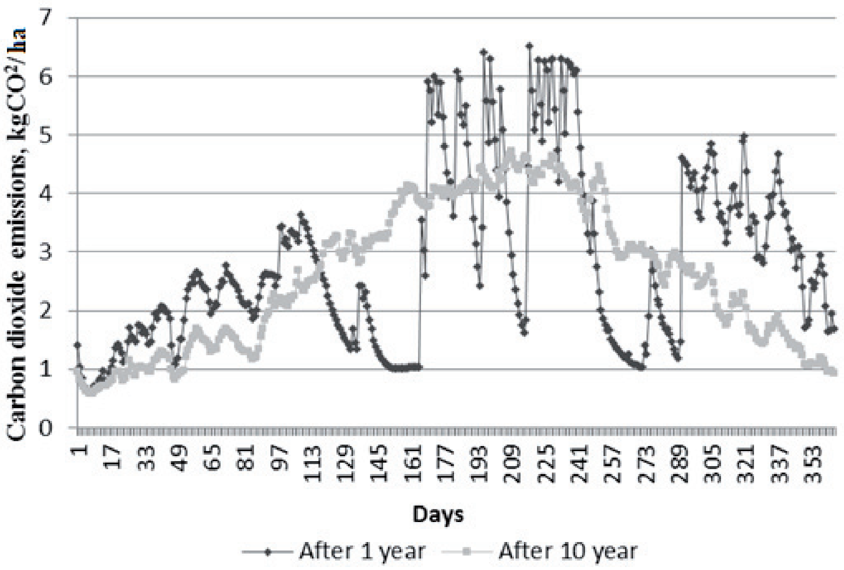

Fig. 14. Change in carbon dioxide emissions per day in forest soil after 1 and 10 years.

accounts for 6.6% (Fig. 14). As regards forest soil, it has been determined the total carbon content at a depth of up to 30 cm will increase (by 1.04 times). However, the prognosticated quantities will be lower than in the first year. As the chart of the total carbon dynamics in the current situation shows, the quantities of carbon are insignificantly bigger. The average decrease of the total carbon content after ten years will account for 2.09% (10 to 50 cm deep).

In the first year, in the current situation carbon dioxide emissions, unlike in the case of forest soil, will decrease from 1027 kgCO_2/ha/year to 565 kgCO_2/ha/year (a decrease of 462 kgCO_2/ha/year) (Fig. 15). But already from the second year carbon dioxide emissions will increase. During the tenth year emissions from forest soil will be lower by 87 kgCO_2/ha/year. In the prognosticated situation no changes are identified. In the period from the first

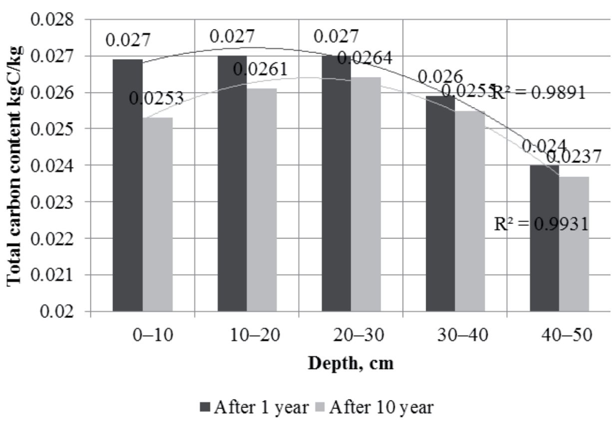

Fig. 15. Change in the total carbon content in forest soil at a depth of 0 to 50 cm after 1 and 10 years taking into account climate change.

to the second year carbon dioxide emissions will increase by 1.2 times (97 kgCO_2/ha/year). However, it is a temporary increase. Forest soil is affected by climate change least. A stable carbon cycle makes it possible to reliably reduce carbon dioxide by converting it into biomass and locking in soil and trees. In the period from the 3rd to the 10th year annual carbon dioxide emissions will amount, on average, to 202 kgCO_2/ha/year.

If we compare the data of other authors in the evaluation Net Ecosystem Exchange (NEE) values from three widespread ecosystems southeast of Ireland (forest, arable and grassland). Although, the field-DNDC version overestimated NEE at temperatures> 5ºC, forest-DNDC under-estimated NEE at temperatures>5ºC. The results suggest that the field/forest DNDC models can successfully estimate changes in seasonal and annual NEE from these ecosystems [29].

Simulating results were compared with experimental data (Tables 2-3). The value of total carbon simulated in meadow soil was lower by 3.4%, in arable soil was lower by 4.5%, in forest soil was lower by 1.4% comparing to experimental data (Table 2).

In arable soil carbon dioxide emissions are also low as a result of a decreasing amount of the total carbon. While, as regards meadow soil in the prognosticated situation, carbon dioxide emissions will significantly increase as this soil is not characteristic of good possibilities of immobilising carbon dioxide.

The value of CO_2 emission simulated from meadow soil was higher by 24%, from arable soil was higher by 26% and from forest soil was higher by 27% comparing to experimental data (Table 3). Differences between the established values could have been impacted by the fact that research results were obtained through

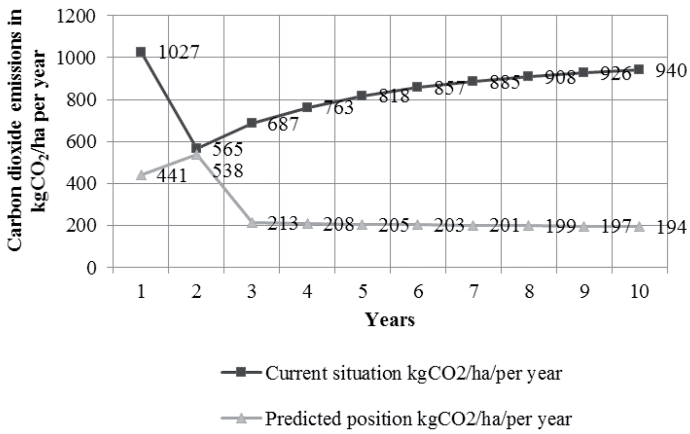

Fig. 16. Change in carbon dioxide emissions in forest soil after 10 years taking into account climate change.

Table 2. Comparing of TC content simulated applying DNDC with experimental data.

Measured total carbon content, kgC/kg	Simulated total carbon content, kgC/kg	Difference, %
Meadow soil		
0.149	0.144	3.4
Arable soil		
0.022	0.021	4.5
Forest soil		
0.139	0.137	1.4

measurements carried out for 11 hours only. In the meantime the model presents the results of 24 hours.

According to other authors, the DNDC model also provides close data. For example, a study by the Net Ecosystem Exchange (NEE) found that Differences in NEE were found to be primarily land cover specific [29].

The average annual NEE, GPP (gross primary productivity) and R_{eco} (ecosystem respiration) values over the measurement period were −904, 2379 and 1475 g C m^{-2} (forest plantations), −189, 906 and 715 g C m^{-2} (arable systems) and −212,1653 and 1444 g C m^{-2} (grasslands), respectively [29].

Table 3. Comparing CO_2 emisision simulated applying DNDC with experimental data.

Measured carbon dioxide emission, $kgCO_2$/ha	Simulated carbon dioxide emission, $kgCO_2$/ha	Difference, %
Meadow soil		
0.149	0.185	24
Arable soil		
0.263	0.331	26
Forest soil		
0.139	0.176	27

Total carbon consists of organic and inorganic carbon, bet the dominant part in topsoil consists of organic carbon. There are no data about content of TC in topsoil of Europe. Content of organic carbon in soil of Europe is in range from less than 1.5 till 20%. The content of organic carbon within the topsoil of Lithuania is in range from 3.5 till 12.5 % [30]. In addition, the assessment used the average value of the field research period but not the annual average. In summary of research results it has been established that the model presents quite close values and therefore the model was applied in further investigations due to reliable compliance of simulating data with research data. The authors using this model also note that the model reliably reflects the dynamics of carbon in soils of different land-use purpose [31].

Conclusions

1. The DNDC model made could evaluate the reliability of data obtained by research and through simulating. Due to minor errors this model is suitable for the estimation of total carbon contents in soil as well as carbon dioxide emissions from soil. A comparison of the obtained simulating data and research data on the total carbon content in soil showed a difference of up to 4.55%. The simulated quantities of carbon dioxide emissions differ from research data by up to 27%.

2. As determined during simulating, carbon dioxide emissions are directly dependent on ambient air temperature. As the data of the performed analyses of correlation between temperature and carbon dioxide emissions from soil show, the correlation coefficient in meadow soil reaches 0.5, in arable soil – 0.6, and in forest soil – 0.5.

3. When simulating climate warming, a significant decrease in the total carbon after ten years, from

82339 kgC/ha to 81887 kgC/ha (the annual decrease difference will reach 452 kgC/ha), was identified in arable soil. Also, much lower carbon dioxide emissions were identified as a result of the decreased total carbon content.

4. Taking into account the impact of climate change on soil it has been determined that the total carbon content in meadow soil will decrease up to 740 kgC/ha during the first year, while the total carbon content in forest soil will increase up to 937 kgC/ha during the first year. In arable soil the largest amount of the total carbon, up to 830 kgC/ha, is lost during the first year, and in the tenth year the loss amounts to 452 kgC/ha, while in meadow soil the total carbon will decrease to 542 kgC/ha in the tenth year. After ten years the total carbon content in forest soil will increase up to 565 kgC/ha. Due to their stable carbon cycle, forest ecosystems make it possible to reliably reduce carbon dioxide by converting it into biomass and locking in soil and wood.

5. As determined from the performed simulating of carbon dioxide emissions in meadow soil, their value changed from 0.06 kg CO_2/m^2 to 4.9 kg CO_2/m^2 during the day. Carbon dioxide emissions in arable soils varied from 0.18 to 17.87 kg CO_2/m^2 during the year. The carbon dioxide emission quantity simulated in forest soil changed from 0.19 to 7.71 kg CO_2/m^2. The average quantity of carbon dioxide emission amounts to 2.15 kg CO_2/m^2. Compared to average carbon dioxide emissions in arable soil, forest soil discharges by 2.6 times less, while meadow soil by 1.6 times more of carbon dioxide.

Conflict of Interest

The authors declare no conflict of interest.

References

1. BALTRĖNAS P., PRANSKEVIČIUS M., LIETUVNINKAS A. Investigation and evaluation of carbon dioxide emissions from soil in Neris Regional Park. J Environ Eng Landsc Manag. **19** (2), 122, **2011**.
2. Intergovernmental Panel on Climate Change (IPCC) Climate Change 2014: Mitigation of Climate Change Retrieved from Cambridge, United Kingdom and New York, NY, USA. **2014**.
3. Food and Agriculture Organization (FAO) Statistical Yearbook 2016 World Food and Agriculture. **2020**.
4. CHEN P., YANG J., JIANG Z., ZHU E., MO C. Prediction of future carbon footprint and ecosystem service value of carbon sequestration response to nitrogen fertilizer rates in rice production. Sci Total Environ. **735**, 139506, **2020**.
5. YIN S., ZHANG X., LYU J., ZHI Y., CHEN F., WANG L., LIU C., ZHOU S. Carbon sequestration and emissions mitigation in paddy fields based on the DNDC model: A review. Artif Intell Agriculture. **4**, 149, **2020**.
6. PAUSTIAN K., LEHMANN J., OGLE S., REAY D., ROBERTSON G.P., SMITH P. Climate-smart soils. Nature. **532** (7597), 57, **2016.**
7. CHANGE, I.C. Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 1454, **2014**.
8. TUBIELLO F.N., SALVATORE M., FERRARA A.F., HOUSE J., FEDERICI S., ROSSI S., BIACALANI R., GOLEC R.D.C., JACOBS H., FLAMIN A., PROSPERI P., CARDENAS-GALINDO O., SCHMIDHUBER J., SANCHEZ M.J., SRIVASTAVA N., SMITH P. The contribution of agriculture, forestry and other land use activities to global warming, 1990-2012. Glob Change Biol. **21** (7), 2660, **2015**.
9. BALTRĖNAS P., PRANSKEVIČIUS M., LIETUVNINKAS A. Investigation and assessment of dependences of the total carbon on pH in Neris regional park soil. J Environ Eng Landsc Manag. **18** (3), 187, **2010**.
10. KVASAUSKAS M., BALTRĖNAS P. Research on anaerobically treated organic waste suitability for soil fertilisation. J Environ Eng Landsc Manag. **7** (4), 211, **2009**.
11. JANKAITĖ A. Soil remediation from heavy metals using mathematical modeling. J Environ Eng Landsc Manag. **17** (2), 129, **2009**.
12. DENG Q., HUI D., WANG J., YU C. L., LI C., REDDY K. C., DENNIS S. Assessing the impacts of tillage and fertilization management on nitrous oxide emissions in a cornfield using the DNDC model. J Geophys Res Biogeosci. **121** (2), 349, **2016**.
13. GANDAHI R., KHANIF M. Y., OAD F.C., HANAFI M.M., OTHMAN R. Estimation of greenhouse gases emission from a rice field of Kelantan, Malaysia by using DNDC model, Pakistan. J Agric Sci. **52** (1), 257, **2015**.
14. INGRAHAM P.A., SALAS W.A. Assessing nitrous oxide and nitrate leaching mitigation potential in US corn crop systems using the DNDC model. Agric Syst. **175**, 87, **2019**.
15. KATAYANAGI N., FUMOTO T., HAYANO M., TAKATA Y., KUWAGATA T., SHIRATO Y., SAWANO S., KAJIURA M., SUDO S., ISHIGOOKA Y., YAGI, K. Development of a method for estimating total CH4 emission from rice paddies in Japan using the DNDC-Rice model. Sci Total Environ. **547**, 440, **2016**.
16. MINH N.Đ., TRỊNH M.V., WASSMANN R., SANDER B.O., HÒA T.Đ., LÊ TRANG N., KHẢI N.M. Simulation of Methane Emission from Rice Paddy Fields in Vu Gia-Thu Bồn River Basin of Vietnam Using the DNDC Model: Field Validation and Sensitivity Analysis, VNU. J Sci Earth Environ Sci. **31** (1), 48, **2015**.
17. WU X., KANG X., LIU W., CUI X., HAO Y., WANG Y. Using the DNDC model to simulate the potential of carbon budget in the meadow and desert steppes in Inner Mongolia, China. J soils and sediments. **18** (1), 75, **2018**.
18. CUI G., WANG J. Improving the DNDC biogeochemistry model to simulate soil temperature and emissions of nitrous oxide and carbon dioxide in cold regions. Sci Total Environ. **687**, 70, **2019**.
19. ZHAO Z., CAO L., DENG J., SHA Z., CHU C., ZHOU D., WU S., LV W. Modeling CH_4 and N_2O emission patterns and mitigation potential from paddy fields in Shanghai, China with the DNDC model. Agric Syst. **178**, 102743, **2020**.

20. SHAH S.H.H., LI Y., WANG J., COLLINS A.L. Optimizing farmyard manure and cattle slurry applications for intensively managed grasslands based on UK-DNDC model simulations. Sci Total Environ. **714**, 136672, **2020**.
21. WANG Z., ZHANG X., LIU L., WANG S., ZHAO L., WU X., ZHANG W., HUANG X. Inhibition of methane emissions from Chinese rice fields by nitrogen deposition based on the DNDC model. Agric Syst. **184**, 102919, **2020**.
22. ZHANG J., HU K., LI K., ZHENG C., LI B. Simulating the effects of long-term discontinuous and continuous fertilization with straw return on crop yields and soil organic carbon dynamics using the DNDC model. Soil Tillage Res. **165**, 314, **2017.**
23. KHALIL M.I., FORNARA D.A., OSBORNE B. Simulation and validation of long-term changes in soil organic carbon under permanent grassland using the DNDC model. Geoderma. **361**, 114014, **2020**.
24. DNDC user guide. Available online: http://www.dndc.sr.unh.edu/?page_id=4. (accessed on 12 of September 2021).
25. MARCINKONIS S., LAZAUSKAS S., POVILAITIS V., BOOTH C. Impacts of long-term intensive organic inputs on carbon index correlations in meadow ecosystems. Ecol. **55** (2), 98, **2009**.
26. PRANSKEVIČIUS M. Research and assessment of total carbon content and carbon dioxide emissions from soils of different land-use purpose. Doctoral dissertation. 157, **2011**.
27. TAFT H.E., CROSS P.A., HASTINGS A., YELURIPATI J., JONES D.L. Estimating greenhouse gases emissions from horticultural peat soils using a DNDC modelling approach. J Env Man. **233**, 694, **2019**.
28. HWANG W., CHANYANG K.I.M., KIJONG C.H.O., SEUNGHUN H.Y.U.N. Characteristics of greenhouse gas emissions from rice paddy fields in South Korea under climate change scenario RCP-8.5 using the DNDC model. Pedosphere. **31** (2), 341, **2021**.
29. ABDALLA M., SAUNDERS M., HASTINGS A., WILLIAMS M., SMITH P., OSBORNE B., LANIGAN G., JONES M.B. Simulating the impacts of land use in Northwest Europe on Net Ecosystem Exchange (NEE): The role of arable ecosystems, grasslands and forest plantations in climate change mitigation. Sci Total Environ. **465**, 336, **2013**.
30. DE BROGNIEZ D., BALLABIO C., STEVENS A., JONES R.J.A., MONTANARELLA L., VAN WESEMAEL B. A map of the topsoil organic carbon content of Europe generated by a generalized additive model. Eur J Soil Sci. **66**, 134, **2015**.
31. SMITH W.N., GRANT B.B., DESJARDINS R.I., WORTH D., LI C., BOLES E.C., HUFFMAN E.C. A tool to link agricultural activity data with the DNDC model to estimate GHG emission factor in Canada. Agric Ecosyst Environ. **136**, 309, **2010**.