AGROLOGY

ISSN 2617-6106 (print)
ISSN 2617-6114 (online)
Agrology, 2024, 7(3), 107–111
doi: 10.32819/202414

Original researches

Received: 26.06.2024
Revised: 24.07.2024
Accepted: 11.08.2024

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Cite this article: Polevoy, A., Mykytiuk, O., Barsukova, O., & Husieva, K. (2024). Climate change and greenhouse gas emissions from soils under the winter wheat agroecosystem in Ukraine. Agrology, 7(3), 107–111. doi: 10.32819/202414

Climate change and greenhouse gas emissions from soils under the winter wheat agroecosystem in Ukraine

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Abstract. The issue of global climate change is one of the most important challenges for modern environmental science. In this regard, assessment of greenhouse gas emissions from soils under agroecosystems is an extremely important task. The main purpose of the study was to assess the potential emissions of greenhouse gases (CO_2 and N_2O) from the soils under the winter wheat agroecosystem during its spring-summer growing season under the climate change in Ukraine. A comprehensive model of greenhouse gas emissions from agroecosystem soils was used as a theoretical basis. The study considered the main agroclimatic regions of Ukraine, such as Polissia, Forest-Steppe, Northern Steppe, and Southern Steppe. The modelling was performed for average long-term conditions of 1981–2020 and under scenario conditions (using the RCP4.5 climate scenario) for the decades of 2021–2030, 2031–2040, and 2041–2050. Estimates of CO_2 emissions were obtained for the agroclimatic regions of Ukraine. According to the results, the largest CO_2 emissions (0.886-0.940 t C-CO_2/ha) will be expected when the average productive moisture supplies in the arable soil layer for the spring-summer period of winter wheat vegetation are 20–40 mm and the air temperature is 12–15 °C. Rise in the level of moisture reserves, averaged for the period, for more than 40 mm and the air temperature of 11–12 °C is accompanied by decrease in the level of CO_2 emission (0.645–0.658 t C-CO_2/ha). In arid conditions, with a decrease in the period-average moisture supplies in the arable soil layer to less than 20 mm and heightened average air temperatures (14.5–15.2 °C), a decrease in CO_2 emissions is expected (0.755–0.770 t C-CO_2/ha). The study showed that the highest N_2O emission (1.087–1.703 kg N-N_2O/ha) is expected at a high level of moistening (Md being equal to 0.474–0.713 relative units and air temperature – 11.3–13.0 °C) with a high intensity of nitrification and denitrification processes. Conditions characterizing the average level of N_2O emission (0.657–0.890 kg N-N_2O/ha) are formed under the moistening at a level of Md equaling 0.296–0.447 relative units and air temperature of 13.4–14.7 °C. There is a slowdown in denitrification processes and an increase in the share of emissions owing to nitrification. It has been found that the lowest N_2O emission (0.508–0.537 kg N–N2O/ha) is expected under conditions of severe and very severe drought (according to the Md criterion), with a heightened temperature averaged at the level of 14.5–15.2 °C during the spring-summer period of winter wheat vegetation.

Keywords: winter wheat; moistening; air temperature; climate; emissions; nitrification; denitrification; greenhouse gases.

Introduction

The growth of the world population has significantly increased the demand for agricultural products, which has led to the expansion of cultivated areas, the intensification of agricultural production and, thereafter, an increase in greenhouse gas emissions from soils under agroecosystems. Amid the debate about the causes of climate change, the emerging concept is that modern climate change (e.g., rising temperatures) is primarily caused by anthropogenic emissions of greenhouse gases, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) (IPCC, 2001; Climate Changes, 2001).

The issue of global climate change is one of the most important problems of modern environmental science. In this regard, assessment of greenhouse gas emissions from ecosystem soil is an extremely important task. Several fundamental reviews have been prepared on the issue of greenhouse gas emissions from soil. According to an earlier review by Oertel et al. (2016), soils function as both sources and sinks for greenhouse gases (GHGs) including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Because both storage and emission capacities can be large, accurate quantitative estimates are needed to obtain reliable global budgets that are needed for land use management (agriculture and forestry), global change, and climate research. This paper discusses exclusively the processes associated with soil emissions and the parameters influencing them. It considers studies of soil emissions covering the most important land cover types and climate zones and introduces important systems for measuring soil emissions. A more recent review of research on this issue (Chataut et al., 2023) contains an analysis that begins with an examination of the variables influencing greenhouse gas emissions, and covers both inorganic factors (such as nitrogen, phosphorus, and potassium fertilizers) and organic factors (animal manure, composted manure, biosolids, and crop species). Field crops other than cereals, such as legumes, oilseeds, vegetables and fruits, account for a significant amount of greenhouse gas (GHG) emissions. This study highlights the need for additional research into the complex interactions of physical, chemical, and biological elements in the near future, as well as generation of mathematical models to simulate soil processes responsible for the production, consumption, and transportation of greenhouse gases.

Recent decades have been characterized by progress in the development of mathematical models to simulate greenhouse gas emissions. There has been a fundamental (comprehensive) review of the main process-based approaches to modelling N_2O emissions from agricultural soils (Gabbrielli et al., 2024). A generalization of modelling approaches has emerged to address uncertainties arising from variability in N_2O emissions, providing a powerful methodology for studying two emission processes (i.e., nitrification and denitrification) and representing the interrelated dynamics between soil, atmosphere, and crops. This paper provides an extensive overview of commonly used models simulating N_2O under various farming systems and management practices. Algorithms used to model N_2O emissions were reviewed and compared, adopting a common notation system. The selected models (APSIM, ARMOSA, CERES-EGC, CROPSYST, CoupModel, DAYCENT, DNDC, DSSAT, EPIC, SPACSYS, and STICS) were classified according to the approaches used to model transformation of nitrogen forms in the soil and major factors in nitrogen cycle and subsequent gaseous emissions.

Algorithms of six widely used agroecological models were compared (Xing et al., 2023). Agricultural soils are the most important anthropogenic source of nitrous oxide (N_2O) emissions. This occurs in two main ways: 1) microbial-mediated oxidation of ammonium to nitrite and nitrate; 2) denitrification. Most agroecological models explicitly consider these two ways, although with various degrees of process understanding and empiricism. Models that consider the influence of multiple environmental factors on N_2O emissions can provide estimates of N_2O fluxes from complex agricultural systems. These models can be used to prognosticate greenhouse gas emissions from agroecosystem soils, analyze historical data, and produce estimates for diverse future climate scenarios, predict the impacts of various management practices on greenhouse gas emissions from crop fields, and model and quantify the effects of emission mitigation strategies. This can be exemplified by the DNDC model, which was used to prognosticate changes in greenhouse gas emissions owing to the interaction between climate warming and grassland management during a 30-year simulation in the north of England (Barneze et al., 2022), in Canadian conditions (Grant et al., 2004), for the territory of Saxony (Butterbach-Bahl et al., 2004), and under conditions of Poland (Sup et al., 2011). Among widely used models, there are CropSyst, a long-term, multi-crop and daily model for cropping system simulation developed as an analytical tool for studying the influence of climate, soils, and management on farming system productivity and the environment (Stöckle et al., 2003), as well as the DAYCENT model – specifically designed to simulate nitrogen and carbon fluxes with regard to soil, crop, and water dynamics (Parton et al., 1994).

It should be noted that for the soil and climatic conditions of Ukraine, studies related to the assessment of future potential greenhouse gas emissions have not virtually been made.

Our study was aimed at assessment of potential emissions of greenhouse gases (CO_2 and N_2O) from the soils under the winter wheat agroecosystem during the spring-summer growing season under climate change in Ukraine.

Materials and methods

The complex model of greenhouse gas emissions from the agroecosystem soils that we created (Polovyi & Bozhko, 2021) was used as a theoretical basis for quantitative assessment of emissions of the greenhouse gases CO_2 and N_2O from the soils under the winter wheat agroecosystem during the spring-summer growing season. The study considered the following agroclimatic regions of Ukraine: Polissia (Zhytomyr Oblast, with predominantly sod-podzol soils), Forest-Steppe (Vinnytsia Oblast, with predominantly podzolized chernozems), Northern Steppe (Dnipropetrovsk Oblast, with predominantly regular chernozems), and Southern Steppe (Kherson Oblast, with predominantly southern chernozems). The modelling was performed for average long-term conditions for 1981–2020 and according to scenario conditions (by means of the climate scenario RCP4.5 (Stepanenko, Polovyi, 2018) for decades of 2021–2030, 2031–2040 and 2041–2050. The moistening regime was assessed using the Shashko aridity index Md (Polovyi, 2012).

Results

CO_2 emissions. The movement of gases in the ‘soil-plant-atmosphere’ system is determined by the temperature and moistening regimes, biological and biochemical processes occurring in the soil, and the status of the vegetation cover.

Further, the paper consuders the results of modelling CO_2 emission from the agroecosystem soils during the spring-summer season of winter wheat vegetation over the main agroclimatic zones of Ukraine under the climate change conditions (Table 1). In Polissia, under average long-term conditions (with the productive moisture reserves in the arable soil layer of 34 mm and the air temperature of 13.0 °C), CO_2 emissions into the atmosphere will comprise 0.673 t C-CO_2/ha. With an increase in moisture reserves to 48 mm and a decrease in temperature to 11.3–11.5 °C in the first and second decades, CO_2 emissions will decline slightly (to 0.645–0.647 t C-CO_2/ha). For the third decade, CO_2 emissions will amount to 0.658 t C-CO_2/ha with a slight decrease in soil moisture (up to 43 mm) and an increase in air temperature to 12.1 °C.

Table 1
Dynamics of CO_2 emissions from the winter wheat agroecosystem and productive moisture reserves in the arable soil layer (W)

Period	Years	Agroclimatic regions of Ukraine							
		Polissia		Forest-steppe		Northern steppe		Southern steppe	
		CO_2 emissions, t C-CO_2/ha	W, mm	CO_2 emissions, t C-CO_2/ha	W, mm	CO_2 emissions, t C-CO_2/ha	W, mm	CO_2 emissions, t C-CO_2/ha	W, mm
Perenial	1981–2020	0.673	34	0.940	31	0.937	25	0.770	15
RCP 4.5	2021–2030	0.645	47	0.833	33	0.886	21	0.759	15
RCP 4.5	2031–2040	0.647	48	0.812	37	0.918	29	0.755	17
RCP 4.5	2041–2050	0.658	43	0.829	37	0.908	20	0.764	18

Under average long-term conditions in the Forest-Steppe with the moisture reserves of 31 mm and air temperature of 13.5 °C, CO_2 emission will comprise 0.940 t C-CO_2/ha. In the first decade, with an increase in soil moisture to 33 mm at an air temperature of 12.3 °C, CO_2 emissions will amount to 0.833 t C-CO_2/ha. In the second decade, the moisture reserves will increase to 37 mm (at an air temperature of 11.4 °C) and emissions will decrease to 0.812 t C-CO_2/ha. In the third decade, with the same moisture reserves but higher air temperatures, CO_2 emissions will slightly increase to 0.829 t C-CO_2/ha.

In the Northern Steppe, with the long-term moisture reserves of 25 mm and the air temperature of 14.7 °C, the CO_2 emissions comprise 0.937 t C-CO_2/ha. In the first and third decades, with moisture reserves of 20–21 mm and an air temperature of 13.4–13.8 °C, the emissions amounted to 0.886–0.908 t C-CO_2/ha; in the second decade, a slightly higher level of soil moistening is expected (up to 29 mm) and a certain increase in air temperature (up to 14.2 °C), emissions will increase to 0.918 t C-CO_2/ha.

In the arid Southern Steppe under average long-term conditions (with moisture reserves of 15 mm, air temperature of 15.2 °C), the CO_2 emissions will make up 0.770 t C-CO_2/ha. In the first and second decades, with almost the same moistening, but with a slightly (0.5–0.7 °C) lower air temperature, the emission will be 0.755–0.759 t C-CO_2/ha. A slight increase in the air humidity and temperature in the third decade will bring CO_2 emissions closer to the long-term level (0.764 t C-CO_2/ha). Thus, the largest CO_2 emissions (0.886–0.940 t C-CO_2/ha) will be expected under productive moisture reserves in the arable soil layer, averaging 20–40 mm during the spring-summer season of winter wheat vegetation, combined with an air temperature of 12–15 °C. Excess of the period-average level of moisture reserves of more than 40 mm and air temperature of 11–12 °C is accompanied by decrease in the level of CO_2 emission (0.645–0.658 t C-CO_2/ha). In arid conditions, under a decrease in the moisture reserves in the arable soil layer averaged for the spring-summer season of winter wheat vegetation below 20 mm and heightened average air temperatures for the spring-summer season of winter wheat vegetation (14.5–15.2 °C), a decrease in CO_2 emissions is expected (0.755–0.770 t C-CO_2/ha).

N_2O emissions. The process of N_2O emissions is based on denitrification and nitrification of nitrogen forms, the intensity of which is determined by the moisture-temperature regime of the soil and the content of mineral nitrogen in the soil. Nitrification occurs predominantly in well-aerated soils with moderate water content, while denitrification occurs under anaerobic conditions, mainly in heavy soils with poor drainage. The contribution of each process to N_2O emissions is controlled and limited by soil biogeochemistry.

The results of modelling these processes during the spring-summer season of growing winter wheat under climate change conditions are shown in Table 2 according to the main agroclimatic zones of Ukraine. Under average long-term agrometeorological conditions, N_2O emission, which mostly occurs owing to nitrification, is observed in Polissia. Its share is 62.4 % of the total value (1.046 kg N-N_2O /ha). The moistening conditions, characterized by the Shashko's moistening index (0.487 relative units), can be classified as slightly arid, with the air temperature of 13.0 °C.

Moderately humid conditions for the first and second decades, expected under the RCP4.5 scenario with a Shashko's moistening coefficient of 0.597–0.677 relative units and air temperature of 11.3–11.5 °C, will lead to a change in the ratio of N_2O emission between its two components (nitrification and denitrification). With greater soil moistening, nitrification slows down and the intensity of the denitrification process increases. As presented in Table 2, the share of emission owing to denitrification will increase to 64.1–65.3% of the total emissions (1.698–1.703 kg N-N_2O/ha). A slight deterioration in moistening conditions to a value of Md indicator close to the conditions characterized as an average drought and an air temperature of 12.1 °C in the third decade will reduce the share of emissions owing to denitrification to 52.3% of the total emissions (1.321 kg N-N_2O/ha).

Table 2
Dynamics of N_2O emission owing to nitrification and denitrification from the winter wheat agroecosystem and the Shashko moistening indicator (Md)

Period	Years	Agroclimatic regions of Ukraine											
		Polissia			Forest-steppe			Northern steppe			Southern steppe		
		N_2O emission, кg N-N_2O/ha		Md, rel. units	N_2O emission, кg N-N_2O/ha		Md, rel. units	N_2O mission, кg N-N_2O/ha		Md, rel. units	N_2O emission, кg N-N_2O/ha		Md, rel. units
		nitrification	denitrification		nitrification	denitrification		nitrification	denitrification		nitrification	denitrification	
Perennial	1981–2020	0.653	0.393	0.487	0.519	0.137	0.480	0.676	0.090	0.323	0.529	0.010	0.277
RCP4.5	2021–2030	0.589	1.109	0.597	0.603	0.307	0.527	0.609	0.048	0.296	0.515	0.009	0.187
RCP4.5	2031–2040	0.573	1.130	0.677	0.551	0.536	0.713	0.613	0.277	0.447	0.508	0.007	0.333
RCP4.5	2041–2050	0.635	0.691	0.474	0.585	0.594	0.511	0.631	0.051	0.327	0.537	0.012	0.234

The average long-term conditions of the Forest-Steppe with an Md value of 0.480 rel. units with an air temperature of 13.5 °C will be characterized by a significant predominance of N_2O emission owing to nitrification; its share will comprise 79.1% of the total emission value (0.656 kg N-N_2O/ha). Certain improvement in moistening conditions in the first decade (Md increased to 0.527 relative units at an air temperature of 12.3 °C) led to a slight change in the ratio of two N_2O emission streams, and the latter due to nitrification will account for 66.2% of the total amount (0.910 kg N-N_2O/ha). At the same time, there will be an increase in the absolute value of N_2O emission owing to denitrification compared to the long-term value (0.307 compared to 0.137 kg N-N_2O/ha). In the second and third decades, with moistening indicators Md of 0.511–0.713 relative units and air temperatures of 11.4–12.1 °C, the amount of emission due to the both processes will be almost equal and the total emission will comprise 1.087–1.179 kg N-N_2O/ha.

In the Northern Steppe, the N_2O emission flux owing to nitrification is predominant. Under average long-term conditions (Md is equal to 0.323 relative units, characterizing very dry conditions, and the air temperature makes up 14.7 °C), the emission flux owing to nitrification is 88.2% with a total amount of 0.766 kg N-N_2O /ha. A similar situation is expected in the first decade, when moistening conditions will further deteriorate at an air temperature of 13.4 °C. The emissions of N_2O owing to nitrification will comprise 92.7% for a total of 0.657 kg N-N_2O/ha. In the second decade, the moistening regime will improve (Md will increase to 0.447 relative units) at an air temperature of 14.2 °C; thereafter, the share of N_2O emission owing to nitrification will slightly decrease (up to 68.9%) and the share of N_2O emission owing to denitrification will increase (up to 31.1%).

The total emission will be 0.682 kg N-N_2O/ha. Moistening conditions are expected to worsen in the third decade. According to the Md criterion (0.327 relative units), they will be characterized as severe drought. The air temperature will comprise 13.8 °C. The denitrification process will slow down, while the amount of emissions due to nitrification will slightly increase, accounting for 0.631 kg N-N_2O/ha in total.

The agroclimatic conditions of the Southern Steppe, both long-term and scenario ones, are characterized by the Md criterion as very dry, and the first decade – as very dry, and there are almost no denitrification processes (they amount to 0.007–0.012 kg N-N_2O/ha). The total emission of N_2O under long-term conditions will comprise 0.539 g N-N_2O/ha, and in scenario years it is expected to be in the range of 0.515–0.537 kg N-N_2O/ha at an air temperature of 14.5–14.9 °C.

Thus, the highest N_2O emission (1.089–1.703 kg N-N_2O/ha) during the spring-summer period of winter wheat vegetation is expected under a high level of moistening (Md equal to 0.474–0.713 relative units and air temperature of 11.3–13.0 °C), at high intensity of nitrification and denitrification processes. Conditions characterizing the average level of N_2O emission (0.706–0.890 kg N-N_2O/ha) are formed under moistening at a level of Md equaling 0.298–0.447 relative units and air temperature of 13.4–14.7 °C. There is a slowdown in denitrification processes and an increase in the share of emissions resulting from nitrification. The lowest N_2O emission (0.508–0.537 kg N-N_2O/ha) is expected under the conditions of severe and very severe drought (according to the Md criterion), with a heightened temperature averaged for the spring-summer season of winter wheat vegetation of 14.5–15.2 °C.

Discussion

The main feature of agroecological models is that the models make it possible to quickly and effectively assess the consequences of management decisions made under possible climate change of various time scales and determine agricultural adaptation measures in order to reduce greenhouse gas emissions.

The estimates we obtained in the experiments for the potential CO_2 emission from the soils under winter wheat agroecosystem during the spring-summer growing season under average long-term conditions for the Forest-Steppe (0.940 t C-CO_2/ha) and the Northern Steppe zone (0.937 t C-CO_2/ha) of Ukraine are consistent with the results obtained for arable lands in Europe (0.840 t C-CO_2/ha) (Vleeshouwers & Verhagen, 2002). In the conditions of the northeastern part of the Forest-Steppe of Ukraine, in experiments involving various fertilizer applications and different corn field tillage systems, results showed CO_2 emissions of 0.789–0.909 t C-CO_2/ha for the different fertilizer variants and 0.622–0.701 t C-CO_2/ha for the various soil cultivation methods. Those values serve as additional confirmation of the reality of our potential estimates of CO_2 emissions under average long-term conditions. In the conditions of the non-chernozem zone (Shylova, 2014), in a long-term stationary experiment, the dynamics of CO_2 release from sod-podzolic sabulous soil was studied depending on a cultivted crop, the fertilizer application system, the nature of soil use, as well as diverse soil types.

Long-term studies have shown (Shylova, 2014) that the production of carbon dioxide by the same crop in different years varies depending on hydrothermal conditions, and fluctuations between the minimum and maximum emission of C-CO_2 comprise: 111–467 kg/ha C-$CO_2$for barley, 429–1356 kg/ha for lupine, 141–1,033 kg/ha for fallow, 792–1,259 kg/ha for winter wheat, 521–883 kg/ha for potatoes, and 521–2,321 kg/ha for fallow lands. In our estimations, soil and climatic conditions similar to thos in the study (Shilova, 2014) will be the conditions of Polissia, where CO_2 emission according to long-term data was at the level of 0.673 t C-CO_2/ha, which is quite close to the data obtained in conditions of the Non-Black Earth Region. An assessment of the potential N_2O emission during the spring-summer period of growing winter wheat under average long-term conditions showed that it is highest in Polissia (1.046 kg N-N_2O/ha), lower in the Forest-Steppe (0.706 kg N-N_2O/ha) and Northern Steppe (0.766 kg N-N_2O/ha), and the lowest in the Southern Steppe (0.539 kg N-N_2O/ha). These data correlate with the studies of N_2O emissions from European arable soils, which are estimated to be 0.2–6.6 kg N-N_2O/ha year (Kaiser, 1996). Annual N_2O emissions were estimated under conditions of Saxony (Butterbach-Bahl, 2004) by means of the DNDC model. Agricultural and forest soils were considered. The emission was 0.5–26.0 kg N-N_2O/ha year for the first group of soils and 0.04–19.76 kg N-N_2O/ha year for the second one. The data on N_2O emissions in the soil-climatic zones of Ukraine which we obtained under average long-term conditions are consistent with these values. It is of significant interest to compare the scenario data we obtained for CO_2 and N_2O emissions with the scenario data obtained in accordance with another model (Sup et al., 2011) for a territory where soil and climatic conditions are relatively close to the conditions of Ukraine.

The DNDC model was used in eastern Poland (Sup et al., 2011) to simulate carbon fluxes occurring at the atmosphere-ecosystem interface. In the considered full 4-year crop rotation, assumed climate change in future scenarios led to a decrease in the rate of carbon accumulation. In the C_{2000} baseline scenario, soil under winter wheat emitted 1б868 and 1б725 kg C-CO_2/ha year into the atmosphere under tillage and reduced tillage, respectively. It was noted that with rising temperatures and decling average precipitation, the intensity of CO_2 emissions under winter wheat has decreased. In the C_{2030} scenario, this resulted in emission 61 and 83 kg C-CO_2/ha year reduction for tillage and reduced tillage, respectively. In the C_{2050} scenario, emissions were 1,721 and 1,541 kg C-CO_2/ha year for both tillage systems. The emissions of CO_2 from winter wheat decreased from the base period. The relative similarity of climatic conditions allows us to compare the results obtained in the study by Sup (Sup et al., 2011) with our model data for the Forest-Steppe of Ukraine. Our calculations also assume a reduction in CO_2 emissions during the spring-summer period of winter wheat vegetation from a base level of 0.937 t C-CO_2/ha to 0.833 t C-CO_2/ha by 2030 and up to 0.828 t C-CO_2/ha by 2050. However, it should be noted that despite the fact that the trends in reduction of the rate of CO_2 emissions obtained in our calculations and in Sup et al. (2011) coincide, the numerical values of the parameters are almost half as large as the results in Sup et al. (2011).

The average cumulative annual N_2O emissions from soil calculated in Sup et al. (2011) for a 4-year crop rotation cycle by means of the DNDC model were different for each climate scenario and tillage system. In the C_{2000} baseline scenario, winter wheat N_2O emissions were 1.59 and 1.63 kg N-N_2O/ha year under tillage and reduced tillage, respectively. For the C_{2030} scenario, emissions were 1.25 and 1.41 kg N-N_2O/ha year for both tillage systems. Under the possible implementation of the C_{2050} scenario, the decrease in N_2O emissions compared to the baseline amounted to 0.39 kg N-N_2O/ha year. We revealed that the values of N_2O emission in the Forest-Steppe zone are 1.49–2.15 times (with some exceptions) less than in the paper by Sup et al. (2011). The differences in CO_2 emissions from modeling can be explained by various agrochemical conditions in winter wheat cultivation, such as nitrogen application rates, types of fertilizer, soil organic carbon content, pH, and soil texture, all of which differed.

Conclusions

Modeling of CO_2 and N_2O emissions from soils of the winter wheat agroecosystem during its spring-summer vegetation period allowed us to estimate the intensity of these processes under average long-term and scenario conditions.

For average long-term conditions in all the agroclimatic regions, a higher level of CO_2 emissions was observed. A decrease in emissions in the first decade and a gradual increase from the first to the third decade will be typical. Maximum values of CO_2 emissions will be observed with sufficient moisture in the arable soil layer and moderate air temperatures. In dry conditions and at elevated temperatures, a decrease in CO_2 emissions is expected.

With a high level of moisture and relatively low air temperature, a high intensity of nitrification and denitrification processes will be observed. The share of the contribution to the total N_2O emission due to denitrification decreases from Polissia to the Southern Steppe.

The lowest N_2O emission is expected under conditions of severe and very severe drought with elevated average air temperatures for the spring-summer vegetation period of winter wheat. Thus, for the conditions of Ukraine, based on experiments with a complex model of greenhouse gas emissions from the soil of the winter wheat agroecosystem and the RCP4.5 climate change scenario under future climate change, the following results were obtained: the features of the influence of temperature and moisture conditions on the intensity of CO_2 and N_2O emission processes were identified; quantitative estimates of the potential for CO_2 and N_2O emissions from the soils of the winter wheat agroecosystem were obtained for the agroclimatic zones of Ukraine for the period up to 2050.

The authors of the article declare no conflict of interest in connection with the publication of the article.

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