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DYNAMICS OF CO_2 EMISSION FROM CHERNOZEMS UNDER AGRICULTURAL USE

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Aim. The comparison of the effect of hydrothermal conditions and various agricultural practices on the emission of CO_2 from chernozems in the Left-Bank Forest-Steppe of Ukraine. **Methods.** The dynamics of the intensity of carbon dioxide emissions from chernozem calcic (typical chernozem – in Ukrainian classification) was studied during the growing season of 2011–2012. The observations were based on two field experiments with various methods of soil tillage (6–7 years from the beginning of the experiment) and fertilization systems (21–22 years from the beginning of the experiment). Particularly, plowing at 20–22 cm, disking at 10–12 cm, cultivation at 6–8 cm and direct seeding using Great Plains drill were studied among the soil tillage methods. Mineral system ($N_{45}P_{50}K_{45}$), organic system (manure 8 t/ha) and combined organic-mineral system (manure 8 t/ha + $N_{45}P_{50}K_{45}$) were studied among fertilization systems. The intensity of CO_2 flux was determined using the non-stationary respiratory chambers by the alkaline absorption method, with averaging of the results during the day and the frequency of once a month. **Results.** During the warm period, the emission of carbon dioxide from the soil changes dynamically depending on temperature and humidity. The maximum of emission coincides with the periods of warm summer showers in June-July, the minimum values are characteristic for the late autumn period. The total emission losses of carbon in chernozems over the vegetation period ranged from 480 to 910 kg/ha and varied depending on the methods of tillage ± (4.0–6.0) % and fertilization systems ± (3.8–7.1) %. The changes in the intensity of CO_2 emission from the soil under different methods of soil tillage are associated with hydrothermal regime and the depth of crop residues location. The biggest difference is observed immediately after tillage, but in the spring period the differences are only 12–25 %, and after drying of the top layer of soil become even less. Direct seeding technology provides the greatest emission of CO_2 from chernozem, which is facilitated by better water regime and more complete mineralization of plant residues on the soil surface. Annual losses of carbon are the least under disking of soil at 10–12 cm. The changes in the intensity of CO_2 emission from the soil under different fertilization systems are associated with the involvement of the additional organic matter from plant residues and manure to the microbiological decomposition. The greatest emission was observed under the organic-mineral fertilization system, which increased the loss of carbon by 7–8 % in comparison with the mineral system in the unfavorable hydrothermal year and by 11–15 % in the more favorable year. These differences are observed mainly during the first half of the growing season when there is a clear tendency to increase the intensity of soil respiration. **Conclusions.** The hydrothermal conditions of the warm period of the year are decisive in the formation of the CO_2 emission flow from chernozems. Due to the improvement of agricultural practices, emissions might be reduced but not more that by 15 % of natural factor contribution.

Key words: soils, chernozems, CO_2 emission, soil tillage, fertilization systems.

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INTRODUCTION

Paris Climate Agreement, signed by 194 countries in December 2015, highlighted specifically the protection and enhancing the efficiency of absorbents and accumulators of greenhouse gases (Article 5, c. 1) [1]. One of the main global reserves of carbon and efficient absorbents of carbon dioxide from the atmosphere is soil. Global reserves of soil organic carbon in the two-meter-deep layer are estimated as 2,400 Gt and the annual emission of buried carbon – as 8.9 Gt [2]. Soil breathing is the second largest flow of carbon dioxide to the atmosphere, the first one being the World ocean, thus, even insignificant changes in the intensity of this flow may lead to abrupt changes in CO_2 concentration. According to the calculations of the international group of UNO experts on the issues of climate change, the total exhausts of carbon into atmosphere increased from 500 Gt in 1970 to about 700 Gt in 2011 due to economic land use [3]. Therefore, depending on the direction and conditions of use, soils may be both the source and reserve of CO_2, thus, the objective inventory of greenhouse gases within the framework of agroecological monitoring of greenhouse gases, exhausted by agricultural lands, will ensure more accurate control over the circulation of carbon in agroecosystems and the decrease in the level of CO_2 emission from them.

Some of the main measures, facilitating carbon sequestration in soil, include forestation (about 0.6 t C/ha per year), transforming into pastures (≈0.5 t C/ha per year), introduction of organic materials (≈0.6 t C/ha per year), covering of plant residues (≈0.35 t C/ha per year), minimization or refusal from tillage (≈0.3 t C/ha per year), crop rotations (≈0.2 t C/ha per year) [4]. At the same time, due to high spatial inhomogeneity of the content and reserves of organic carbon in the soil profile as well as a wide range of indefiniteness of analytic methods of determining the weight fraction of C in soil, the objective estimation of changes in the carbon pool under the agricultural production is possible only for rather a large period of time [5–6]. This is the primary reason why there are different opinions of researchers regarding zero tillage [7].

On the other hand, the monitoring of the intensity of CO_2 flux allows estimating the effect of different aspects of anthropogenic activity on the impairment of the balance between the terrestrial reservoirs of carbon and atmosphere for a short period of time. Both stationary respiration chambers and equipment, and movable devices of different constructions, principles of action and producers are successfully used for this purpose. In this respect, it is especially relevant to have the algorithm of building a series of observations in time, which could neutralize or consider the daily dynamics of CO_2 emission from soil, closely related to the dynamics of microbiological activity [8]. In addition, to obtain the representative data, it is also important to consider the processes of gas exchange, spatial inhomogeneity of soils, *etc*. [9–10]. The processes of carbon dioxide formation in soil and those of gas exchange with atmospheric air depend on the type of soil, its physical and chemical properties and hydrothermal conditions [11]. The latter are decisive in forming the daily and seasonal dynamics of CO_2 emission by soil as well as such specific manifestations as, for instance, the Birch effect – a rapid increase in the flux of carbon dioxide after the wetting of dry soil [12], or vice versa – the increase in carbon sequestration in soil due to the processes of particle aggregation at the expense of the frequency in wetting-drying cycles [13].

Therefore, the quantitative estimation of the volumes of carbon dioxide emission from soil at the introduction of different agrarian measures or at different directions (scenarios) of land use may be an efficient instrument of controlling and managing carbon sequestration in soil. At the same time, the method of these observations needs improving and possibly standardization due to strongly expressed dynamics of CO_2 emission from soil. The aim of this work is to compare the relevance of the effect of the natural agent – hydrothermal conditions, and different agrarian measures on CO_2 production from the soil with the consideration of the temporal dynamics of their changes.

MATERIALS AND METHODS

The studies were conducted in two permanent field experiments on typical chernozem, located within Kharkiv upland territory of the Left-Bank Forest-Steppe of Ukraine. The observation of CO_2 emission for different methods of soil tillage was done at the in-person division of the Agriculture chair of the Kharkiv National Agrarian University named after V.V. Dokuchaev at typical heavy-loamy chernozem with the following parameters of the arable layer (0–30 cm): humus according to Turin – 4.9–5.1 %, total nitrogen – 0.25 %, forms of mobile phosphorus and potassium according to Chirikov – 100 mg/kg and 150 mg/kg of soil respectively. Four different methods of the main soil tillage were selected for study in the four-field grain-growing and weeding crop rotation, namely:

- plowing with a plough PLN-4-35 at 20–22 cm;
- disking with a disk DMT-4 at 10–12 cm;
- pre-sowing cultivation using the cultivator KPE-3.8 at 6–8 cm;
- direct seeding using Great Plains drill (Great Britain) (without the main soil tillage).

The experiment was started in 2005. The area of experimental plots was 400 sq.m., their location in the experiment was consecutive, with three repeats.

The observation of CO_2 emission at different fertilization systems was done using a permanent experiment in agroecological monitoring at the territory of the State enterprise "The Experimental Station of Hrakivske" (Chuhuiv district of Kharkiv region). The soil was typical medium-humus heavy-loamy chernozem of forest layers. The arable layer of the soil contains: humus according to Turin 5.6–5.8 %, easily hydrolyzed nitrogen – 120–140 mg/kg of soil, forms of mobile phosphorus and potassium according to Chirikov – 80–100 and 90–110 mg/kg of soil respectively.

The emission of CO_2 was studied in the following experimental variants:

- control (no fertilizers);
- mineral system ($N_{45}P_{50}K_{45}$);
- organic system (humus, 8 t/ha);
- organic-mineral system (humus, 8 t/ha + $N_{45}P_{50}K_{45}$).

The location of plots in the experiment was blockwise randomized, with three repeats. The experiment has been conducted since 1990. The rotation of crops was as follows: fallow, winter wheat, sugar beet, vetch, oats, winter wheat, corn for silo, barley with alfalfa, alfalfa, winter wheat, corn for silos, sunflower. Mineral fertilizers were scattered in the form of ammonia nitrate, granulated superphosphate, potassium chloride and potassium magnesia.

The average daily emission of CO_2 from the soil surface was studied according to Karpachevsky method in each experiment during the vegetation period (April-October) of 2011–2012. The carbon dioxide fixation was conducted in non-stationary non-ventilated respiration chambers using a solution of 0.2 n NaOH at the exposure for 20 min with further titering in field conditions [14]. The measurements were conducted 5 times during the day with further averaging of the results. The measurements of the intensity of carbon dioxide emission were conducted along with the determination of soil temperature at the depth of 10 cm using Savinov thermometer and soil humidity by the thermostatic and gravimetric method according to the regulatory document DSTU ISO 11465.

RESULTS AND DISCUSSION

Soil tillage is one of the most relevant kinds of human activity in terms of the impact on the course of processes of organic matter mineralization and the formation and emission of carbon dioxide. The decrease in humus content in soil is observed for at least 100 years after the start of chernozem tillage [15]. On the other hand,

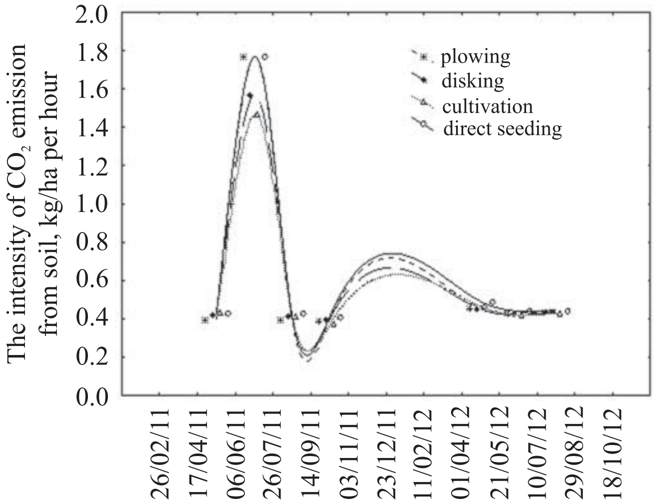

Fig. 1. The intensity of CO_2 emission from soil for different methods of tillage, 2011–2012

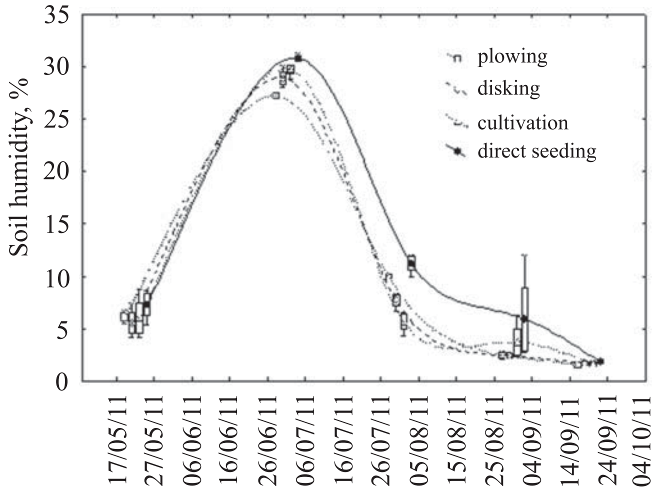

Fig. 2. The seasonal dynamics of the humidity of the chernozem arable layer for different methods of tillage, 2011

the preservation of dense fallow with no mechanic tillage of soil stabilizes humus condition, promoting humus formation and sequestration of carbon [16]. As per V. V. Medvedev, on the one hand, combined tillage of soil, which prevailed in recent 20–30 years in Ukraine, promoted higher humification of organic fertilizers due to their deep introduction, while on the other, it increased the loss of organic matter due to excessively frequent tillage and long time in aerated condition [17]. At the same time, a contrary tendency was observed in a number of cases [16, 18]. The complexity of obtaining a single answer to the question about the direction and intensity of the impact of soil tillage on carbon circulation and soil breathing as its integral constituent is related to additional effects after the introduction of zero tillage, namely: the difference between the initial

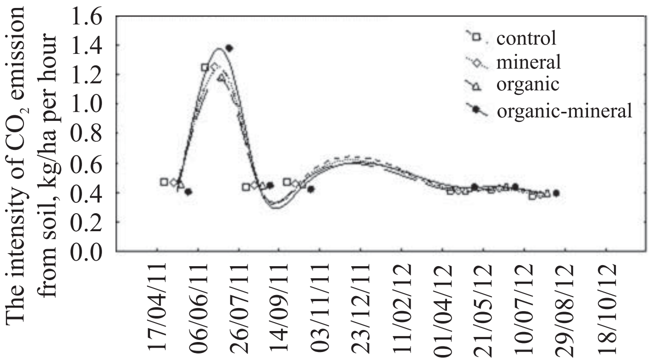

Fig. 3. The intensity of CO_2 emission from soil at different methods of tillage, 2011–2012

period and long implementation of no-tillage technology, considerable differentiation of the upper 20-cm soil layer by the content of organic carbon, biological activity, non-homogeneous hydrothermal regime and gas exchange depending on the degree of being covered with plant remains, *etc.* [19, 20].

At the beginning of investigations, in spring 2011 we observed an insignificant difference in breathing intensity between experimental variants (Fig. 1).

In summer, the concentration of CO_2 in the air is the highest over the densest plot with direct seeding, as the diffusion of gases occurs much slower than on the plowed plot. Joint observations of temperature and humidity of the soil demonstrated that the latter is the decisive factor in the jump-like increase in soil breathing after summer showers (Fig. 2).

The vegetation period of 2012 was drier and hotter than the previous one. In April the average daily air temperature exceeded the perennial indices almost twice, and in the following months – by 25–40 %. There was almost no precipitation in April (1.1 mm), in May the amount of precipitation was 55 % from the norm, in June – 70 %, in July – 35 %. In these conditions the impact of direct seeding technology on the emission of CO_2 from typical chernozem was manifested in even a more expressed way, especially at the beginning and at the end of the vegetation period (Fig. 1).

The increase in the carbon dioxide emission in case of direct seeding is a consequence of the fact that plant residues are located in the surface layer of soil which, in combination with the improvement in moisture supply for this layer, results in their higher mineralization. On the other hand, in case of systematic plowing, there is an observed decrease in the content of mobile organic matter in the arable layer of soil compared to the surface tillage and direct seeding. Therefore, the intensity of CO_2 emission from the soil surface is greatly determined by humidity and temperature of soil, which may be regulated by the main tillage of soil to some degree.

As primarily the soil breathing depends on the amount of organic matter, accessible for microbiological destruction, and the conditions of its decomposition, the use of fertilizers, related to the involvement of additional energetic material, has a direct impact on CO_2 emission. This is evidently demonstrated in the experiment of observing the dynamics of CO_2 emission at different systems of fertilization, started in 1989. Prior to the beginning of our observations, the total active substance of introduced mineral fertilizers was $N_{945-1890}P_{880-1760}K_{765-1530}$ and 170 t/ha of humus which had a positive effect on the ratio of organic matter and carbon circulation. The averaged results of measurements demonstrate that, compared to the control with no fertilizers, the potential capability of soil for the production of CO_2 at long-standing use of the mineral system of fertilization tends to decrease, while at the organic and organic-mineral system it somewhat increases (Fig. 3). In our opinion, it occurs due to more intense mineralization of humus compounds in soil in case of the mineral system of fertilization, due to which the amount of organic matter, easily accessible for decomposition, gradually decreases. On the contrary, the introduction of additional energetic material in the form of organic fertilizers promotes the increase in the carbon dioxide flow from the soil.

During the warm season of 2011 the fluctuations in the intensity of carbon dioxide emission from soil into the atmosphere were about one mathematical order: from 2.0–2.6 kg/ha per hour after intensive showers in June and 0.3–0.4 kg/ha per hour in the driest period at the end of July – at the beginning of August. Compared to this range, the changes, caused by the improvement in the nutrition regime of soil in the experimental variants with different systems of fertilization are rather weak – in the range of 0.1–0.6 kg/ha per hour. In 2012 the difference in the intensity of soil breathing for different systems of fertilization was even higher (in the range of 0.2–0.3 kg/ha per hour) which is 26 % from the range of seasonal fluctuations of this index, with higher indices for the organic-mineral system compared to others. Therefore, the organic-mineral system promotes higher emission and the mineral system – lower emission. However, compared to seasonal changes in CO_2 emission, these differences are much less significant, manifested mostly during the first half of the vegetation period, when there is a clear tendency towards the increase in the intensity of soil breathing via enhanced microbiological activity.

According to the data of observations, we calculated immediate losses of carbon due to soil breathing which demonstrate that the direct seeding technology promoted enhanced flow of carbon dioxide (Table 1). In our opinion, the main reason lies in the fact that plant residues remained on the surface of soil and the mineralization processes prevailed due to the thinness of the mulch layer. Covering plant residues with soil in case of surface tillage decreased the access of oxygen to them and slowed mineralization down. This effect is preserved for plowing as well, but the decrease in the mineralization of plant residues occurs simultaneously with the increase in the mineralization of the organic matter of soil. Thus, plowing is inferior to surface ways of soil tillage by the amount of carbon emission loss.

In the experiment with different fertilization systems the total amount of carbon emission losses for the organic-mineral system of fertilization was 11.7 % higher than the control, and 15 % higher than the mineral system of fertilization (Table 2). In our opinion, the reason lies in the improvement of the nutrient regime for soil, which results in more intense carbon circulation. In addition, the decrease in the potential capability of soil to produce CO_2 in case of the mineral system of fertilization is related to the decrease in the amount of accessible organic matter in soil.

It is noteworthy that the total volume of carbon losses for the vegetation period of 2012 was much smaller compared to the previous year which, in our opinion, is related to drier conditions: the amount of precipitation for April 2012 was 1.1 mm against 53.9 mm in 2011, for June – 48.3 mm against 194.6 mm in 2011, for September – 7 mm against 16.2 mm in 2011. The difference in carbon loss between specific years of observations demonstrates that hydrothermal conditions of a warm season are decisive in the formation of the emission flux of CO_2 from chernozem. The improvement of the agricultural practice could decrease the emission to some extent, but, compared to the contribution of natural factors, it would not exceed 15 % from the total amount of soil carbon loss.

Table 1. The carbon emission loss from soil for different methods of the main tillage

The methods of soil tillage	Carbon emission losses for the vegetation period, kg/ha	
	2011	2012
Plowing	651	502
Disking	622	497
Cultivation	670	485
Direct seeding	701	525

Table 2. The carbon emission loss from soil for different methods of different systems of fertilization

The systems of fertilization	Carbon emission losses for the vegetation period, kg/ha	
	2011	2012
No fertilizers	813	482
Mineral	789	492
Organic	837	502
Organic-mineral	909	521

CONCLUSIONS

The intensity of carbon dioxide emission from soil and its dynamics during the vegetation period considerably depend on hydrothermal conditions which are a decisive factor in the formation of the emission flow of CO_2. The maximum of CO_2 emission from typical chernozem in the conditions of the Left-Bank Forest-Steppe of Ukraine occurs in June-July and coincides with the periods of warm summer showers, the minimal values are remarkable for late autumn period.

The methods of soil tillage impact the intensity of CO_2 emission from soil due to the change in temperature and water regime and the depth of covering after-harvest residues. Carbon losses for the vegetative period were found to be the highest for direct seeding technology, amounting to 525–701 kg/ha per year.

Long-standing application of different systems of fertilization has a considerable impact on the intensity of carbon dioxide emission from soil. The highest emission is observed for the organic-mineral system of fertilization which promotes the increase in the carbon emission losses compared to the mineral system and the background with no fertilizers by 7–8 % in the year, unfavorable in the hydrothermal regime, and by 11–15 % – in a more favorable year.

Динаміка емісії CO_2 з чорноземів при сільськогосподарському використанні

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Мета. порівняння впливу гідротермічних умов та агрозаходів на продукування CO_2 з чорноземів Лівобережного Лісостепу України. **Методи.** Досліджено динаміку інтенсивності виділення вуглекислого газу з чорноземів типових за вегетаційний період 2011–2012 рр. Спостереження проводили на тривалих польових дослідах з різних способів обробітку ґрунту (6–7 рік з початку досліду) та систем удобрення (21–22 роки з початку досліду). Серед способів обробітку вивчали оранку на 20–22 см, дискування на 10–12 см, культивацію на 6–8 см та прямий посів сівалкою Great plains, серед систем удобрення – мінеральну ($N_{45}P_{50}K_{45}$), органічну (гній 8 т/га) та органо-мінеральну систему (гній 8 т/га + $N_{45}P_{50}K_{45}$). Інтенсивність виділення CO_2 визначали у нестаціонарних респіраційних камерах за методом лужної абсорбції, з усередненням результатів впродовж доби та періодичністю раз на місяць. **Результати.** Встановлено, що протягом теплого періоду року виділення вуглекислого газу з ґрунту динамічно змінюється залежно від температури та вологості ґрунту. Максимум емісії припадає на червень–липень та співпадає з періодами теплих літніх злив, мінімальні значення притаманні пізньоосінньому періоду. Загальні емісійні втрати вуглецю чорноземами типовими Лівобережного Лісостепу України за вегетаційний період складають 480–910 кг/га та варіюють залежно від способів обробітку ґрунту ±(4,0–6,0) % і систем удобрення ± (3,8–7,1) %. Зміни інтенсивності виділення CO_2 з ґрунту за різних способів обробітку пов'язані із зміною гідротермічного режиму та глибиною заорювання поживних решток. Найбільша різниця спостерігається одразу після обробітку, у весняний період, відмінності складають лише 12–25 %, а після висушування верхнього шару ґрунту є ще меншими. За сумарними обсягами емісії CO_2 з чорнозему типового серед способів обробітку переважає технологія прямого посіву, чому сприяє кращий водний режим та більш повна мінералізація рослинних решток на поверхні ґрунту. За дискування на глибину 10–12 см річні втрати вуглецю найменші. Зміни інтенсивності виділення CO_2 з ґрунту за різних систем удобрення пов'язані із залученням до мікробіологічного розкладу додаткової органічної речовини рослинних решток та гною. Найбільша емісія спостерігається за органо-мінеральної системи удобрення, яка сприяє збільшенню емісійних втрат вуглецю порівняно із мінеральною системою та неудобреним фоном на 7–8 % у несприятливий за гідротермічним режимом рік та на 11–15 % – у більш сприятливий рік. Ці розбіжності проявляються переважно протягом першої половини вегетаційного періоду, коли спостерігається чітка тенденція до збільшення інтенсивності дихання ґрунту. **Висновки.** Гідротермічні умови теплого періоду року є вирішальними у формуванні емісійного потоку CO_2 з чорнозему. За рахунок удосконалення сільськогосподарської практики можна дещо знизити емісію, але порівняно із внеском природних чинників це не буде перевищувати 15 % від річного обсягу втрат ґрунтового вуглецю.

Ключові слова: ґрунти, чорноземи, емісія CO_2, обробіток ґрунту, системи удобрення.

Динамика эмиссии CO_2 из черноземов при сельскохозяйственном использовании

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Цель. сравнение влияния гидротермических условий и различных агроприемов на продуцирование CO_2 из черноземов Левобережной Лесостепи Украины. **Методы.** Исследована динамика интенсивности выделения углекислого газа из черноземов типичных за вегетационный период 2011–2012 гг. Наблюдения проводили на длительных полевых опытах с различными способами обработки почвы (6–7 лет с начала опыта) и системами удобрения (21–22 года с начала опыта). Среди способов обработки изучали вспашку на 20–22 см, дискование на 10–12 см, культивацию на 6–8 см и прямой посев сеялкой Great plains, а среди систем удобрения – минеральную ($N_{45}P_{50}K_{45}$), органическую (навоз 8 т/га) и органо-минеральную систему (навоз 8 т/га + $N_{45}P_{50}K_{45}$). Интенсивность выделения CO_2 определяли в нестационарных респирационных камерах методом щелочной абсорбции, с усреднением результатов в течение суток и периодичностью раз в месяц. **Результаты.** Установлено, что в течение теплого периода года выделение углекислого газа из почвы динамично изменяется в зависимости от температуры и влажности почвы. Максимум эмиссии приходится на июнь–июль и совпадает с периодами теплых летних ливней, минимальные значения характерны для поздне-осеннего периода. Общие эмиссионные потери углерода черноземами типичными тяжелосуглинистыми Левобережной Лесостепи Украины за вегетационный период колебались в пределах от 480 до 910 кг/га и варьировали в зависимости от способов обработки почвы ±(4,0–6,0) % и систем удобрения ± (3,8–7,1) %. Изменения интенсивности выделения CO_2 из почвы при различных способах обработки связана с изменением гидротермического режима и глубиной запахивания пожнивных остатков. Самая большая разница наблюдается сразу после обработки, в весенний период различия составляют лишь 12–25 %, а после высушивания верхнего слоя почвы становятся еще меньше. По суммарным объемам эмиссии CO_2 из чернозема типичного среди способов основной обработки преобладает технология прямого посева, чему способствует лучший водный режим и более полная минерализация растительных остатков на поверхности почвы. При дисковании на глубину 10–12 см годовые потери углерода наименьшие. Изменения интенсивности выделения CO_2 из почвы при различных системах удобрения связаны с вовлечением в микробиологическое разложение дополнительного органического вещества растительных остатков и навоза. Наибольшая эмиссия наблюдается при органо-минеральной системе удобрения, которая способствует увеличению эмиссионных потерь углерода по сравнению с минеральной системой и неудобренным фоном на 7–8 % в неблагоприятный по гидротермическому режиму год и на 11–15 % – в более благоприятный год. Эти различия проявляются преимущественно в течение первой половины вегетационного периода, когда наблюдается четкая тенденция к увеличению интенсивности дыхания почвы. **Выводы.** Гидротермические условия теплого периода года являются решающими в формировании эмиссионного потока CO_2 из чернозема. За счет совершенствования сельскохозяйственной практики можно несколько снизить эмиссию, но по сравнению с вкладом природных факторов это не будет превышать 15 % от годового объема потерь почвенного углерода.

Ключевые слова: почвы, черноземы, эмиссия CO_2, обработка почвы, системы удобрения.

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