Carbon cycle in ecosystems with native and anthropogenically transformed Grey-Luvic Phaeozems

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Abstract. The article presents data on the spatial and temporal variability of the carbon cycle processes in different types of natural and agricultural ecosystems functioning on Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic. Ecological monitoring of respiration, hydrothermal and chemical properties of soil and productivity of vegetation cover was conducted in six natural and agricultural ecosystems. It was found that soils of the forest and garden ecosystems emit 7.2 – 47.9 % more carbon into the atmosphere than soils of the agroecosystems and the ecosystems with herbaceous phytocenoses. It was revealed that soils (humus horizon of 20 cm thickness) stored up to 3.3 tonnes/ha of carbon (increase in soil organic carbon (SOC) stock), while tree leaves and herbage assimilated up to 7.5 tonnes/ha of carbon in the garden ecosystem during the growing season.

1 Introduction

One strategy to achieve carbon neutrality is to use soils of agricultural lands as a pool of carbon sequestration. Organic carbon stocks in soils of agroecosystems are significantly lower than in soils of natural ecosystems [1, 2, 3].

Native Grey-Luvic Phaeozems and Greyic Phaeozems Albic, which have not undergone significant changes due to human activities, have a stable carbon balance [4]. They are able to accumulate and store carbon assimilated from the atmosphere, which helps reduce the greenhouse effect and slow climate change. Greyic Phaeozems Albic Hortic are the most promising in terms of carbon accumulation potential. According to modern estimates, regions with predominance of Greyic Phaeozems Albic Hortic in the structure of agricultural lands, where carbon-saving agro-technologies are implemented, have the maximum rate of carbon sequestration [5, 6]. The application of low-carbon agro-technologies leads to a significant increase in soil carbon stocks. This affects a number of soil processes associated with the transformation of organic matter. Increasing soil carbon stocks is a key process that contributes to soil fertility [5].

Anthropogenically transformed Grey-Luvic Phaeozems and Greyic Phaeozems Albic can also have a negative impact on the carbon balance and climate processes. For example,

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tillage or urban development can lead to loss of organic matter and increase carbon emissions to the atmosphere [7, 8].

The intensity of soil CO_2 emission depends on a number of external environmental factors [9, 10, 11] and soil properties. The management of soil properties will make it possible to achieve the carbon balance in natural-anthropogenic and anthropogenic ecosystems.

The purpose of the work was to explore the peculiarities of spatial and temporal variability of the carbon cycle processes in natural and anthropogenically modified ecosystems functioning on Grey-Luvic Phaeozems and their agrogenic modifications.

2 Objects and methods

The research was conducted on the territory of the Agrobiological Station of Kursk State University, located in the northern part of the Kursk agglomeration.

Soils of six key sites represented by the natural, natural-anthropogenic, and anthropogenic ecosystems were selected as objects of the research: forest ecosystem (snythe oak forest), mixed grass meadow, lawn ecosystem (soil contamination with heavy metals – Pb and Cd at a dose of five maximum permissible concentrations (MPC)) and three types of agroecosystems (apple orchard, perennial grasses, weed-free fallow). Soil cover of the ecosystems was represented by Grey-Luvic Phaeozems (the forest ecosystem, the mixed grass meadow, the lawn ecosystem) and Grey-Luvic Phaeozems Hortic (the agroecosystems).

To assess the seasonal dynamics of CO_2 emission from the surface of the soils, ecological monitoring was conducted from May to September 2023 (once a month). The chamber method was applied with an infrared CO_2 gas analyser AZ7752 (Az Instrument, Korea) calibrated to Li-820 (LI-COR Biosciences, USA) and CO_2 concentration in the lower troposphere ~ 400 ppm to measure the soil surface CO_2 fluxes. The chamber volume was 1.56 litres. The area of the ground cover (bounding ring) was 95 cm^2. The number of bases in each ecosystem was 5, and the exposure time for the measurement was 3 min. The temperature (Checktemp HI98501 thermometer) and soil volumetric water content (MC-7828 SOIL moisture meter) were measured in parallel with measurements of the soil surface CO_2 fluxes [12].

The organic carbon content was found according to the Tyurin method (GOST 26213-91) to determine the dynamics of carbon accumulation and seasonal losses of carbon by soils in the each studied ecosystem. Samples of AU and PU horizons were taken in May and October.

Herbage productivity was investigated by the method of cutting on sample plots of $0.25 m^2$. Fresh fall biomass was sampled on the same sample plots. Sampling was carried out in June and October. Repetition was threefold. Carbon content of grass phytomass and fresh organic fall was determined by dry ashing method.

Statistical processing of data and graphic design were carried out using Microsoft Excel 2007 tools.

3 Results

During the ecological monitoring of the hydrothermal properties of soils in the studied ecosystems, it was established that soil temperature and moisture were characterised by spatial and temporal variability. Soil temperature varied from 11.6 to 21.3 °C during the season. The minimum values of soil temperature occurred at the beginning and end of the season (May and October), while the maximum values occurred in the middle and second half of the season (July – August). Soil temperatures in the forest and apple orchard ecosystems were generally lower than in the other studied ecosystems within each month (Fig. 1).

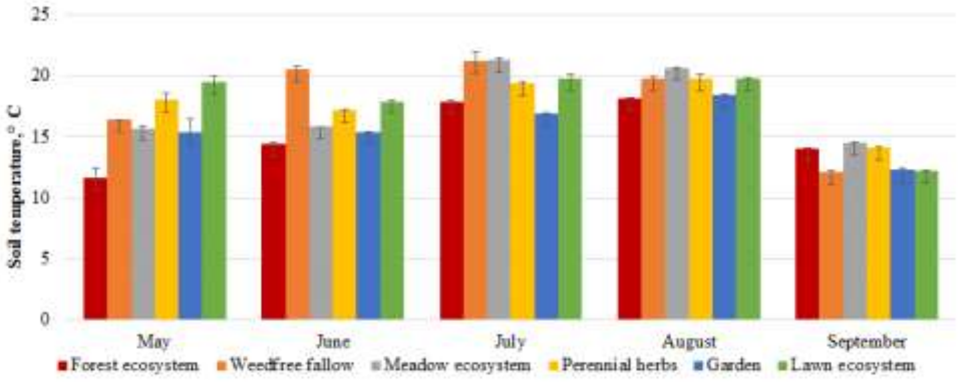

Fig. 1. Seasonal temperature dynamics of Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic of the studied ecosystems (0 – 10 cm layer).

Seasonal variations of soil moisture ranged from 6.1 to 15.8 % at different sites during the study period. Maximum fluctuations were observed in the forest and lawn ecosystems, as well as in the weed-free fallow agroecosystem (Fig. 2).

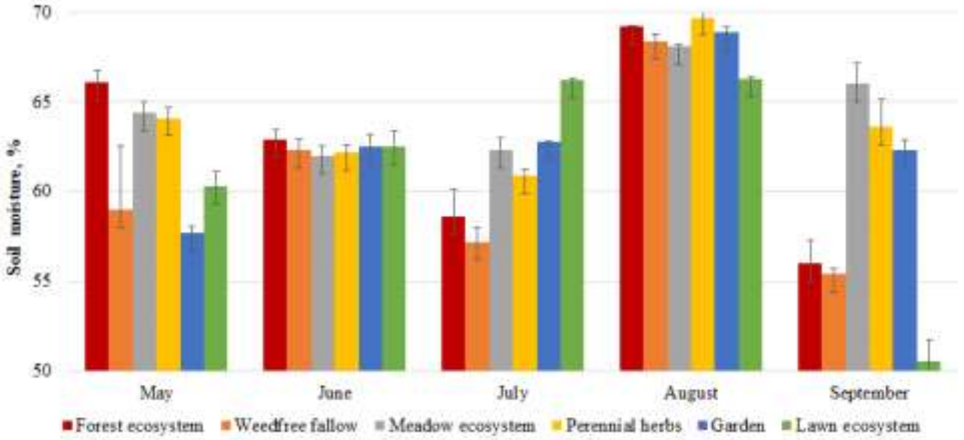

Fig. 2. Seasonal moisture dynamics of Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic of the studied ecosystems (0 – 10 cm layer).

Soil moisture in all the studied sites had no significant differences in June and August (the maximum difference ranged from 0.9 to 3.4%). Soil moisture did not have significant differences in the meadow ecosystem and perennial grasses agroecosystem during the whole study period. Maximum differences in soil moisture were characteristic for September (up to 15.5%) while comparing the studied ecosystems.

The soil CO_2 emission indicator had similar dynamics, characterised by minimums of the indicator in May – June and maximums in July in the studied ecosystems (Fig. 3).

A B

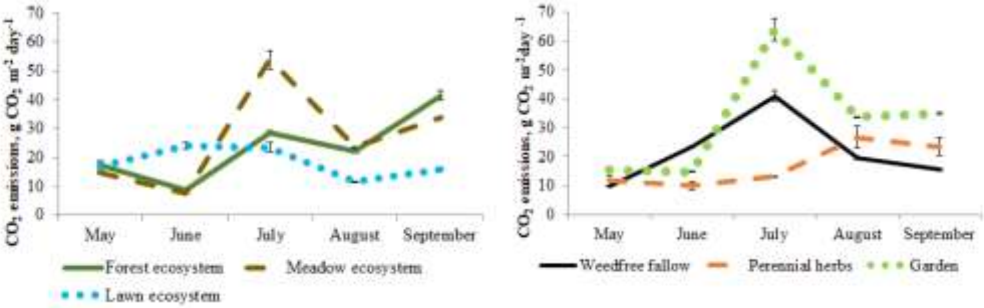

Fig. 3. Seasonal dynamics of CO_2 emission from Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic of the studied ecosystems: A – the natural and anthropogenic (lawn) ecosystems, B – the agroecosystems.

The exception was the forest ecosystem and perennial grasses agroecosystem, where the maximums occurred in August and September. The maximum emission values were characterised by soils of the lawn ecosystem (up to 23.9 g CO_2 m^{-2} day^{-1}) and the weed-free fallow (up to 23.6 g CO_2 m^{-2} day^{-1}) in spring and in the first half of summer. The highest values of this indicator were observed in soils of the forest ecosystem (up to 41.5 g CO_2 m^{-2} day^{-1}) and the garden agroecosystem (up to 64.0 g CO_2 m^{-2} day^{-1}) in the second half of summer and autumn.

A correlation relationship (Pearson's r) was also established between the soil CO_2 emission rate and soil temperature. It was r = 0.56 for the meadow ecosystem and r = 0.66 for the weed-free fallow agroecosystem (sample size – n = 50). There was the correlation between soil CO_2 emission rate and soil moisture equal to r = 0.66 in the forest ecosystem and r = 0.75 in the agroecosystem with perennial grasses (sample size – n = 50). The correlation relationship was weak in the other ecosystems.

The correlation analysis of the studied indicators, carried out separately for each month, allowed to reveal a strong correlation between the soil CO_2 emission and soil temperature in July (r = 0.78), an average one in September (r = 0.56), as well as a strong correlation between soil CO_2 emission and soil moisture in August (r = 0.76) (sample size – n = 10). Weak positive and negative correlations were observed between soil hydrothermal properties and the CO_2 emission index in other months.

The results of seasonal changes in the content and stock of organic carbon in AU and PU horizons showed that SOC accumulation (increase by 0.11 – 0.12% in content) occurred in soils of the meadow and garden ecosystems. In all the other ecosystems, SOC losses by soils were observed, reaching 0.34% (the forest ecosystem) (Table 1).

Table 1. Seasonal dynamics of SOC content and amount of carbon emitted during the growing season by Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic in the ecosystems of different types (AU and PU horizons 0 – 20 cm).

Mesoecosystem	**SOC, %**			**Soil density, g/cm^3**	***Stocks C, tonnes/ha**	****CO_2 emission**	*****C emission, tonnes/ha**
	Spring	**Autumn**	**LSD05**				
Grey-Luvic Phaeozems							
The forest	5.68	5.34	0.08	0.9	– 6.3	23.7	13.8
The meadow	2.96	3.07	0.06	1	2.3	21.9	12.8
The lawn	2.2	2.09	0.07	1.1	– 2.6	18.4	10.7

Grey-Luvic Phaeozems Hortic							
The weed-free fallow	2.67	2.49	0.08	0.8	– 2.8	21.9	12.8
The garden (the apple orchard)	5.68	5.80	0.07	1.4	3.3	32.6	19
The perennial grasses	3.42	3.36	0.07	1.1	– 1.3	17	9.9
LSD05****	0.08	0.07	-	0.05	0.2	1.1	0.6

*Losses / accumulation of the organic carbon stocks per season, tonnes/ha. **CO_2 emission averaged over the growing season, g CO_2 m^{-2} day^{-1}. ***Quantity of carbon emitted by the soil during the growing season, tonnes/ha. ****Fisher's Least Significant Difference (LSD) Test.

Soil density of the studied ecosystems varied markedly (0.8 – 1.4 g/cm^3). It reached maximum values in the garden ecosystem.

The highest amount of carbon was emitted into the atmosphere by soils of the garden agroecosystem (19.0 tonnes/ha) and the forest ecosystem (13.8 tonnes/ha). The minimum carbon emission was observed from the soil of the agroecosystem with perennial grasses (9.9 tonnes/ha). The average rate of CO_2 emission from the surface of the studied soils was similarly distributed.

The carbon content ranged from 35.3 to 43.8% in the phytomass and biomass of fallen debris, with a marked decrease in the carbon content in the produced phytomass of the lawn ecosystem (Table 2).

Table 2. Organic carbon content and stocks in absolutely dry mass of grass and dry mass of fall in ecosystems of different types.

Indicator	**Type of the ecosystems**				
	The forest	**The meadow**	**The lawn**	**The garden**	**The perennial grasses**
Carbon content, %	43.8±1.6	43.5±1.8	35.3±1.2	39.3±2.0	40.8±1.1
Carbon stocks, tonnes/ha	6.5±0.5	5.4±0.3	4.2±0.1	7.5±0.3	5.0±0.2

From 4.2 to 7.5 tonnes/ha of carbon was stored in phytomass and fresh fall in the studied ecosystems during the growing season. The forest ecosystem and the garden clearly prevailed by this indicator compared to the other ecosystems studied.

3 Discussion

The spatial and temporal variability of the CO_2 fluxes from the surface of Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic was conditioned by both of the hydrothermal conditions and the factor of anthropogenic transformation of soils in the studied ecosystems.

The influence of ecosystem type on the rates of soil CO_2 fluxes is confirmed by the data obtained by us. For example, the rates of soil CO_2 fluxes practically did not differ in May with a significant difference in soil hydrothermal conditions in the studied ecosystems, while in August, minimal differences in temperature (up to 2.5 °C) and soil moisture (up to 3.4%) were accompanied by increased variability of soil CO_2 fluxes in all the studied ecosystems. At the same time, the strong correlation (r = 0.76) between the CO_2 emission index and soil moisture was established exactly in August. That is, the variability of CO_2 fluxes from the surface of native and anthropogenically transformed Grey-Luvic

Phaeozems is determined by a complex of continuously interacting environmental factors. Multidimensional combinations of such factors lead to the emergence of both the diversity of the CO_2 fluxes in uniform environmental conditions and the emergence of quantitative similarity of the fluxes in very different environmental conditions [13].

The CO_2 flux rates diagnosed in 2023 from the surface of Grey-Luvic Phaeozems of the meadow ecosystem were comparable to the similar values obtained at the same site in 2018. The obtained data are extremely close not only in the configuration of the seasonal dynamics curves, but also in the values of the CO_2 emission rate averaged over the growing season (21.7 g CO_2 m^{-2} day^{-1} in 2018 and 29.7 g CO_2 m^{-2} day^{-1} in 2023). This can be explained by the similarity of climatic conditions in 2018 and 2023, characterised by abnormal rainfall in July (more than 176.9 mm) and abnormal drought in August (1.1 mm in 2023) and September (2.8 mm in 2018) [7]. The drought in August resulted in a significant decrease in the rate of CO_2 fluxes from soils in all the ecosystems except the perennial grasses. It can be explained by the fact that grass was actively forming phytomass after heavy rainfall and haying in July (a compensatory effect accompanied by a surge in the activity of root respiration and respiration of the remaining aboveground phytomass) [14].

Autumn minimums of the soil CO_2 fluxes in the lawn ecosystem and in the weed-free fallow agroecosystem are caused by suppression of soil microbiota and root activity as a result of soil contamination with heavy metals in the first case and absence of vegetative plants in the second case.

The maximum values of averaged for the vegetation season CO_2 emission rate and the maximum amount of organic carbon emitted into the atmosphere, characteristic of the forest and garden soils can be explained by the largest root system biomass and the largest microbial biomass compared to other study ecosystems. It is also confirmed by the data we obtained on these indicators for soils of the weed-free fallow agroecosystem, where the lowest flux rate is obviously due to the absence of root respiration and respiration of rhizosphere microbiota, as well as the minimum content of soil organic matter.

Contamination of Grey-Luvic Phaeozems of the lawn ecosystem with heavy metals (Pb and Cd at a dose of MPC) resulted in a 15.9% decrease in the rate of CO_2 fluxes from the soil surface, a loss of 2.3 tonnes/ha of soil organic carbon and a 22.2% decrease in phytocenosis productivity, compared to soils of the meadow ecosystem. Decrease in the rate of soil CO_2 fluxes was noted earlier when Grey-Luvic Phaeozems of Kursk agglomeration is contaminated with one element (Pb) and at a lower dose (1.2 MPC) [7]. Thus, Grey-Luvic Phaeozems have a high sensitivity to the heavy metal pollution, which should be taken into account when developing ways to increase the carbon sequestration under conditions of chemical pollution of soils.

Seasonal dynamics of the organic carbon in soils of the meadow and garden ecosystems, expressed in the accumulation of carbon in soils, is explained by haying (5 times per the season) without biomass removal from the ecosystem. This contributed to the regular supply of increased amounts of fresh organic matter to the soil surface, followed by its gradual biodegradation and humification. Seasonal losses of the organic carbon by soils within the studied time period (May – September) are related to the time and conditions of mortmass formation (the forest and lawn ecosystems) or alienation (the perennial grasses agroecosystem) and absence (the weed-free fallow agroecosystem) of phytomass.

The amount of carbon assimilated by the biomass of herbaceous plants and the positive dynamics of SOC in the active soil layer in the studied garden and meadow ecosystems, as well as the depositing capacity of tree species and undergrowth of the forest ecosystem (oak forest) allows us to judge about their high sequestration potential. When assessing the dynamics of SOC stocks in the whole soil profile of Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic, the lawn ecosystem and agroecosystem with perennial grasses can also have carbon balance. While in the weed-free fallow agroecosystem it is potentially possible to state only carbon losses by soils.

4 Conclusions

1. The spatial variability of CO_2 emission from the surface of native and anthropogenically transformed Grey-Luvic Phaeozems is determined to a greater extent by the type of ecosystem and the nature of anthropogenic impact on the ecosystem as a whole and soils in particular.
2. Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic of the forest and garden ecosystems emit 7.2 – 47.9 % more carbon to the atmosphere than soils of the herbaceous phytocoenosis ecosystems and soils of the agroecosystems. This is due to both differences in soil hydrothermal conditions and intensity of root and microbial respiration.
3. Grey-Luvic Phaeozems and Grey-Luvic Phaeozems Hortic of the meadow and garden ecosystems deposited 2.3 and 3.3 tonnes/ha of organic carbon in humus horizons (AU and PU) during the growing season (May – September), respectively.
4. The fall and herbage of the apple orchard ecosystem assimilated up to 7.5 tonnes/ha of carbon during the growing season, which is 13.3 – 28% more than in the oak and meadow ecosystems.
5. The Pb and Cd contamination of Greyic Phaeozems Albic reduced the intensity of soil respiration by 15.9%.

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References

1. K. Paustian, S. Collier, J. Baldock, R. Burgess, J. Creque et al., Carbon Management, (**10) 6**, 567-587 (2019).
2. B. M. Kogut, V. M. Semenov, Z. S. Artemyeva, Agrochemistry, Humus Depletion and Soil Carbon Sequestra, **5**, 3-13 (2021)
3. V.N. Kudeyarov Soil science, Soil respiration and carbon sequestration **9**, 1011-1022 (2023)
4. A.S. Mostovaya, I.N. Kurganova, V.O. Lopes De Gerenyu, O.S. Khokhlova, A.V. Rusakov, A.S. Shapovalov, Bulletin of the Voronezh State University, **2**, 64-72 (2015)
5. V.A. Romanenkov, Yu. L. Meshalkina, A. Yu. Gorbacheva, V.A. Dobrovolskaya, A.N. Krenke, Proceedings of the Rus. Acad. of Sc., **87 (4)**, 584-596 (2023)
6. K. Paustian, S. Collier, J. Baldock, R. Burgess, J. Creque et al. Carbon Management, **10 (6)**, 567-587 (2019)
7. N.P. Nevedrov, D.A. Sarzhanov, E.P. Protsenko, I.I. Vasenev, Eurasian Soil Science, **54 (1)**, 80-88 (2021)
8. V.N. Kudeyarov, *Present-day estimates of carbon cycling at global scale and for territory of Russia,* 17-24, (Pushchino, 2004)
9. J.G. Martin, P.V Bolstad, Soil Biology and Biochemistry, **41**, 530–543 (2009)
10. I.I. Vasenev, T.V. Raskatova, MarGTU Bulletin, **2**, 83-92 (2009)
11. A.N. Zadorozhniy, M.V. Semenov, A.K. Khodzhaeva, V.M. Semenov, Agrochemistry, **10**, 75-92 (2010)
12. D.G. Zamolodchikova et al. *Monitoring of greenhouse gas fluxes in natural ecosystems*, 279, (Amirite, Saratov, 2017)
13. I.N. Kurganova et al. *A methodological guide for determining CO_2 emissions from soils in various types of ecosystems*, 79 (Pushchino, 2023)