Agroecological assessment of the efficiency of utilization of quail manure in the restoration of disturbed sod-podzolic soils with the formation of a stable herbage

Andrey Stepanov[1], *Peter* Vasenev[1*], and *Ivan* Vasenev[1]

[1]RSAU-MTAA, Ecology Department, 127434 Timiryazevskaya Ul., 49, Moscow, Russia

Abstract. The most acute environmental problems of our time include large volumes of bird droppings produced annually at large livestock complexes. At the same time, the sod-podzolic soils dominating in the Non-Chernozem zone of the European part of Russia are characterized by low reserves of humus, which quickly fall with intensive agricultural use and soil anthropogenic degradation. To restore degraded sod-podzolic soils, a peat-sand substrate enriched with compost from quail manure without and with the application of phosphogypsum to stabilize organic compounds of compost was used with the support of project No. 075-15-2021-1030 of the Ministry of Science and Higher Education of Russia. The vegetation experiment showed the maximum increase in plant biomass of the herbage in the variant with the combined use of compost and phosphogypsum: respectively, 30% higher than the control one. In the summer, there is an increased intensity of soil CO_2 emissions in the variants with compost, but with a multiple more active increase in grass biomass growing, so one can talk about the atmosphere carbon sequestering nature of the technology of utilization of quail droppings during the restoration of disturbed sod-podzolic soils with the formation of a stable herbage.

Keywords: Agroecology, Atmosphere carbon sequestering, Bird droppings, Ecological assessment, Manure utilization, Sod-podzolic soils, Soil CO_2 emission, Stable herbage

1 Introduction

The most acute environmental problems of our time include large volumes of manure and bird droppings produced annually at large livestock complexes [1]. They are raw materials for agroecologically attractive, very valuable [2] and potentially profitable organic fertilizers.

However, in most cases higher profitable large livestock complexes are very narrowly localized, that seriously complicates the logistics of their manure and bird droppings application and requires the development of the best available technologies for environmentally safe and cost-effective their use [3-5].

At the same time, the sod-podzolic soils dominating in the Non-Chernozem zone of the European and Western Siberian parts of Russia are characterized by a low thickness of their humus-accumulative horizon and low reserves of soil organic matter (SOM or humus), which quickly fall after intensive farming use and due to soil anthropogenic degradation.

Along with this, against the background of rapidly developing global climate changes characteristic of the XXI century, there is a fastly growing interest in more intensive, but environmentally safe agricultural use of these lands [6, 7] with a relatively stable soil moisture regime and a growing amount of active temperatures from year to year [8, 9].

Quail poultry farms producing nutritionally valuable meat and eggs belong to the actively developing direction of animal husbandry in central Russia, where with the growing welfare of a significant part of the population, the demand for higher-quality food is steadily growing ap.

Herewith, quail manure (droppings) is characterized by an increased content of macro- and micro-elements of plant nutrition, which makes it especially attractive for use as compost for the restoration of degraded sod-podzolic soils with the formation of a stable herbage.

Moreover, at the same time, the tasks of reducing greenhouse gas emissions into the atmosphere can be evidently solved, which is extremely important for mitigating or slowing down the processes of global climate change and can bring additional funding to projects for the restoration of degraded lands.

The goal of this paper is to give ecological assessment of the efficiency of quail manure utilization in the restoration of disturbed sod-podzolic soils with the formation of a stable herbage and stabilization of the carbon balance of the regenerated topsoil in conditions of representative for Moscow region Agroecological Experimental Station of the RSAU-MTAA.

* Corresponding author: vasenev@rgau-msha.ru

2 Materials and Methods

The research was carried out at the Agroecological Experimental Station of the Russian State Agrarian University - Moscow Timiryazev Agricultural Academy (RSAU-MTAA - Fig. 1) in the fall of 2022 and summer of 2023 with unusually high precipitation in the May to August period (644 mm, that is 215% of the average May-August precipitation in 2011-2022 - Table 1).

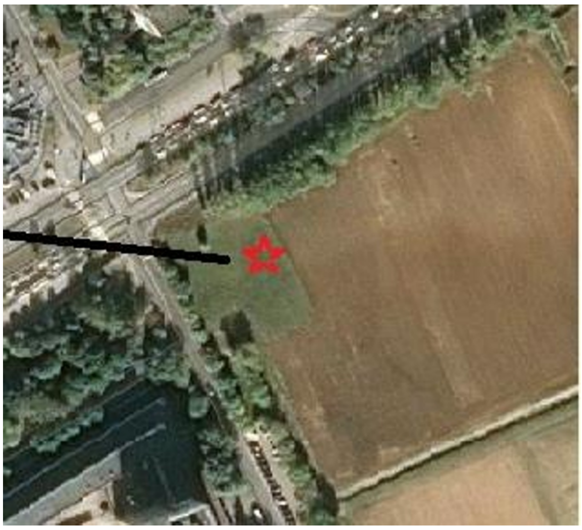


Fig. 1. The location (55°50'24"N 37°33'02"E) of the Field experiment with quail manure compost at the Agroecological Experimental Station of the RSAU-MTAA.

Table 1. Weather conditions in May - August period of 2023 in comparison with the average data for it in 2011-2022.

Month	De-cade	Average air temperature, °C			Precipitation amount, mm		
		2011-2022		2023	2011-2022		2023
May	1	13.6	8.6	13.9	61	11	73
	2		16.4			4	
	3		16.5			58	
June	1	17.3	15.8	18.1	77	35	140
	2		19.8			1	
	3		18.6			104	
July	1	19.7	21.7	19.4	84	6	305
	2		17.1			143	
	3		19.3			156	
August	1	17.6	24.1	20.6	78	0	126
	2		21.5			117	
	3		16.6			9	
May-August		17.1		18.0	300		644

Profile of the erosion-disturbed sod-podzolic soils at the Agroecological Experimental Station of the RSAU-MTAA consist of the following horizons:

- AEBp around 20 cm of thickness - heterogeneous over-compacted and significantly disaggregated sandy loam and loam plowing horizon with morphons of original humus-accumulated, eluvial and transitional eluvial-illuvial horizons;
- EBt around 10-15 cm of thickness - heterogeneous over-compacted and significantly disaggregated transitional eluvial-illuvial horizon with eluvial sand loamy and illuvial clay loamy morphons;
- Bt around 60-65 cm of thickness - compact clay loamy illuvial horizon by moraine origin.

Its strongly degraded plowing horizon is over-compacted, acidic and has low stocks of moisture, soil organic carbon (SOC), nitrates and mobile sulfur with mid-level content of mobile phosphorous and potassium (Table 2).

Table 2. Average values and standard deviation (M±δ) of the physical, physical-chemical and chemical parameters of the plowing horizon of the erosion-disturbed sod-podzolic soil in location of the field experiment

Bulk density, g/cm^3	Soil moisture, %	pH_{KCl}	SOC,%
1.32±0.07	8.4±1.9	5.04 ± 0.18	0.80 ± 0.08

Nutrient mobile forms, mg/kg				
NO_3^-	NH_4^+	P_2O_5	K_2O	S
4.67±1.45	40.2±4.5	72.4±2.3	61.9±14.0	1.33±1.10

During the regenerative amelioration of the turf horizon of the erosion-disturbed sod-podzolic soil there was created 15-cm regenerative organo-mineral horizon from the peat-sandy soil-ground (with a weight ratio peat to sand of 1 to 3) traditionally used in phytoremediation projects with application of compost from quail droppings in doses of 2.0 t/ha in combination with phosphogypsum in doses of 4.5 t/ha and 6.0 t/ha or without it.

Compost from quail droppings is characterized by high residual moisture, pH, high content of the total nitrogen and by the very high content of mobile phosphorous and potassium (Table 3).

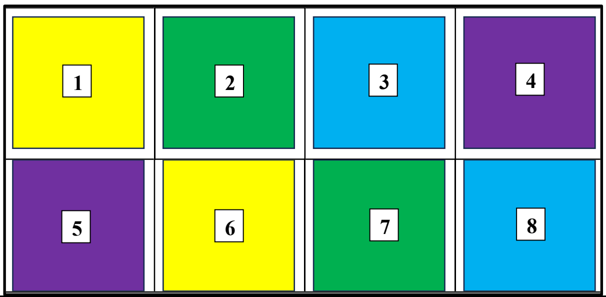
Table 3. Average values and standard deviation (M±δ) of the moisture, pH and content of the main nutrients in the compost

Soil moisture, %	pH_{H2O}	Mobile forms, mg/kg		Total nitrogen, %
		P_2O_5	K_2O	
47.8±2.9	9.21±0.02	3050±50	4550±50	1.80±0.05

Phosphogypsum is characterized by the increased content of the whole set of necessary for plants macro- and micro-nutrients: phosphorous – 1–1,4%, sulfur – up to 38%, siliceous – 0,26%, zinc – 0,03% – and has a lot of calcium (21%), cations of which are able to neutralize the acid medium of the soil and essentially increase the saturation of soil absorbing complex.

The scheme of the micro-plot field experiment with plots of 4 m^2 (2 m x 2 m - Fig. 2) included control variant (without the use of compost), variants with compost from quail droppings (2.0 t/ha) and with the use of compost (2.0 t/ha) in combination with an increasing doses of phosphogypsum (in doses of 4.5 t/ha and 6.0 t/ha), which were added to the peat-sand soil-ground traditionally used in phytoremediation projects.

In the seed method of lawn creation, a grass mixture was used with the following composition: pasture ryegrass (*Lolium perenne*) (40%), red Maxim 1 fescue (*Festuca rubra*) (40%), red Greenlight fescue (*Festuca rubra*) (10%), meadow bluegrass (*Poa pratensis*) (10%). Seeding rate: 200 g per plot.



Variant of the experiment	Compost, t/ha	Phosphogypsum, t/ha	Plot No.
I	-	-	1; 6
II	2.0	-	2; 7
III	2.0	4.5	3; 8
IV	2.0	6.0	4; 5

Fig. 2. The location scheme of the micro-plot field experiment.

To carry out seasonal monitoring of CO_2 fluxes at all plots after the initial formation of the grass cover in August 2022, the bases of the over-ground exposure chambers installed during the observation periods were installed (Fig. 3).

September 2022

October 2022

Fig. 3. The micro-plot field experiment with the bases of the over-ground exposure chambers.

Monitoring of organic carbon content in the topsoil, of soil regimes and of the dynamics of the growth of herbaceous biomass were carried out using traditional methods of agroecological monitoring [9-12] and land functional-and-ecological assessment [13-16]. Monitoring of soil moisture and temperature conditions – using IoT sensors and portable electronic devices: a soil thermometer Checktemp 1 and a moisture meter Theratrobe HH2. Determination of soil carbon dioxide emissions – using a portable gas analyzer LiCor-820 *in situ* [17]. Accounting of aboveground biomass and its growth rate – by the method of sequential mowing and IoT sensors CropTalker [18].

3 Results and Discussion

Composition and properties of the regenerative horizon (Table 4) initially differ quite significantly from the humus-accumulative and arable horizon of the full-profile sod-podzolic soils dominating in the region [8, 9, 11, 13, 15], but after three months the differences are significantly smoothed out for nitrite and exchangeable calcium and magnesium. Moreover, in variants with the use of compost, this can happen even faster than in the control version of the horizon regenerated on the basis of a peat-sand mixture (Tab. 4).

Table 4. Average values and standard deviation (M±δ) of the pH and content of the exchangeable cations and main nutrients in the regenerative horizon of the erosion-disturbed sod-podzolic soils in the fall 2022

Variant	Month 2022	pH_{H2O}	Exchangeable cations, mmol/100 g	
			Ca	Mg
Control	VIII	7.67±0.08	114±6.9	20.2±0.5
	XI	7.94±0.02	45.2±4.1	20.3±1.5
Comp 2 t/ha	VIII	7.73±0.07	102±19.2	20.8±1.5
	XI	7.94±0.02	29.0±8.5	19.0±2.0
Comp 2 t/ha+ P-G 4,5 t/ha	VIII	7.30±0.06	131±12.4	20.0±1.2
	XI	7.76±0.04	37.7±4.2	17.0±1.1
Comp 2 t/ha +P-G 6 t/ha	VIII	7.21±0.03	142 ± 6.4	18.1±0.5
	XI	7.68±0.04	49.4±5.2	17.6±0.9

Variant	Month 2022	Nitrites, mg/kg	Mobile forms, mg/kg	
			P_2O_5	P_2O_5
Control	VIII	202±32.3	62.5±5.6	211±25.9
	XI	24.2±6.4	263±74.9	547±93.1
Comp 2 t/ha	VIII	130±29.0	329±99.3	422±57.1
	XI	24.8±4.1	317±93.2	1068±318
Comp 2 t/ha +P-G 4,5 t/ha	VIII	177±36.8	461±66.2	375±45.0
	XI	21.5±7.2	404±125	652±173
Comp 2 t/ha +P-G 6 t/ha	VIII	205±16.9	479±117	313±41.6
	XI	13.7±2.1	429±96.7	340±82.1

 https://doi.org/10.1051/bioconf/20248501077

The conducted studies have shown a relatively small, but statistically significant (even against the background of seasonal dynamics in summer 2023) decrease in comparison with the control variant of the bulk density of the turf topsoil (with a thickness of 6 cm) in both variants of compost application in combination with phosphogypsum (Fig. 4).

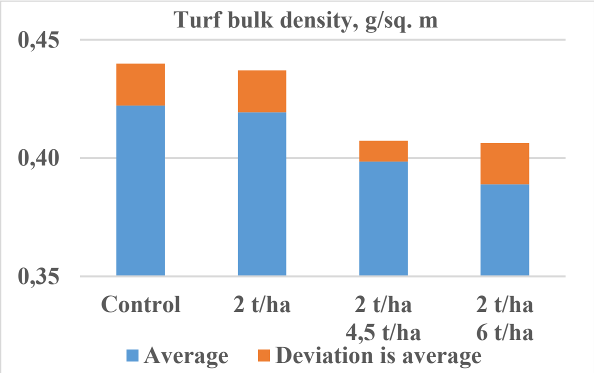


Fig. 4. Turf topsoil (0-6 cm) bulk density average for season values in the micro-plots of the field experiment with quail droppings compost (first line) and phosphogypsum (second line).

At the same time, in conditions of summer season 2022 with a sharply increased amount of precipitation, changes in the soil moisture content of the turf topsoil are enough obvious and statistically significant only in case of compost application without phosphogypsum (Fig. 5).

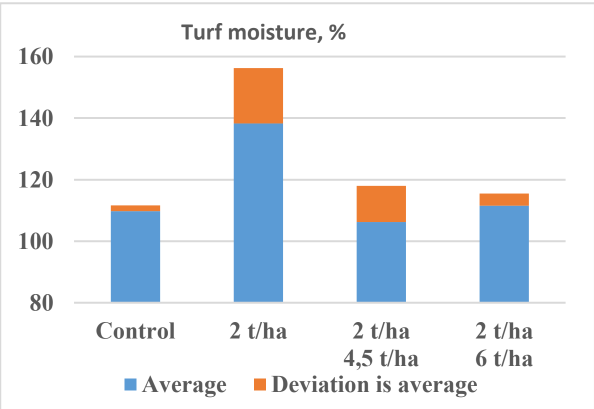


Fig. 5. Turf topsoil (0-6 cm) moisture average for season values in the micro-plots of the field experiment with quail droppings compost (first line) and phosphogypsum (second line).

The initial content of organic matter at the beginning of the main growing season (Fig. 6, 28.04.2023) varies slightly and statistically insignificantly between the variants of the experiment. The maximum differences between their average values do not exceed 2.5% SOM (1.25% SOC), which is no more than 10 relative percent of the SOM content and is typical for peat-sandy soils [22, 23].

At the end of the main growing season (Fig. 6, 22.09.2023), 2 variants of the experiment (with 2 t/ha of compost from quail droppings and with the compost application in combination with phosphogypsum in doses of 2.0 t/ha + 4.5 t/ha) showed obvious statistically significant and pronounced even against the background of seasonal dynamics accumulation of organic matter in the turf topsoil (6 cm thick). At the same time, the content of organic matter in the control version remained almost unchanged.

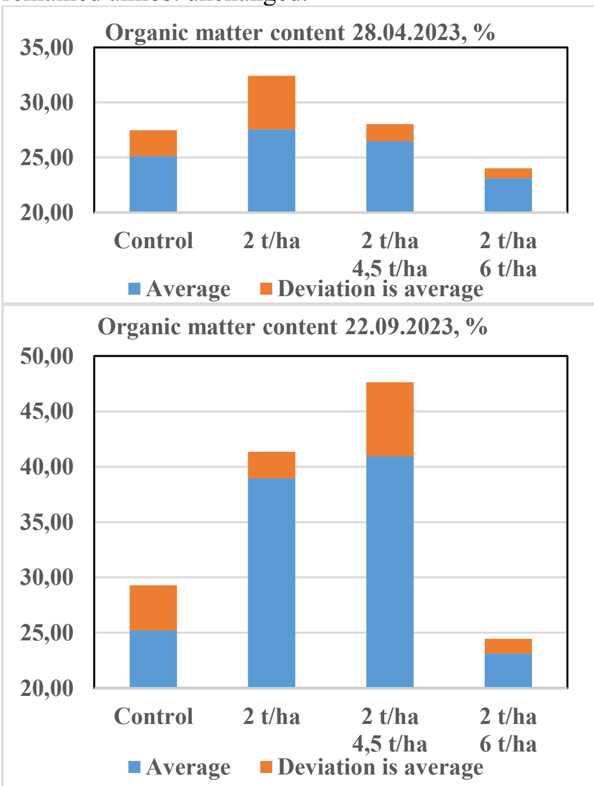


Fig. 6. Soil Organic matter content in the micro-plots of the field experiment with quail droppings compost (first line) and phosphogypsum (second line).

In most of the studied variants of soil-grounds, the seasonal dynamics of soil CO_2 emission is pronounced (Fig. 7), measured during the daytime, in the period between 10 a.m. and 3 p.m. The only variant with quail droppings compost has minimum season dynamics and the minimum difference in its average value of soil CO_2 emission from the control variant (Fig. 8).

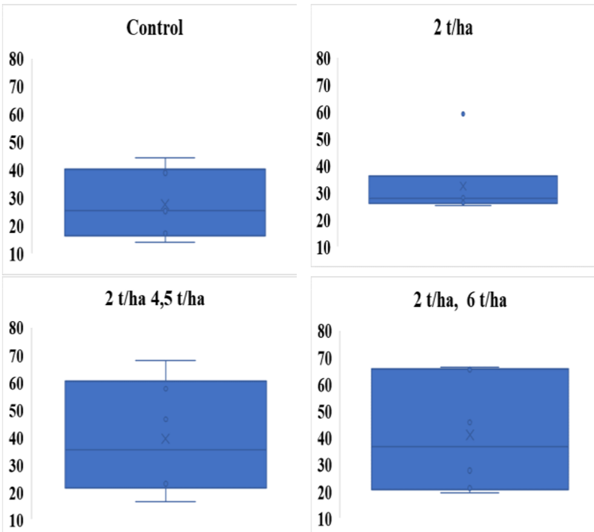


Fig. 7. Diagrams of the scope of seasonal dynamics of soil CO_2 emission by main variants of the micro-plot field experiment.

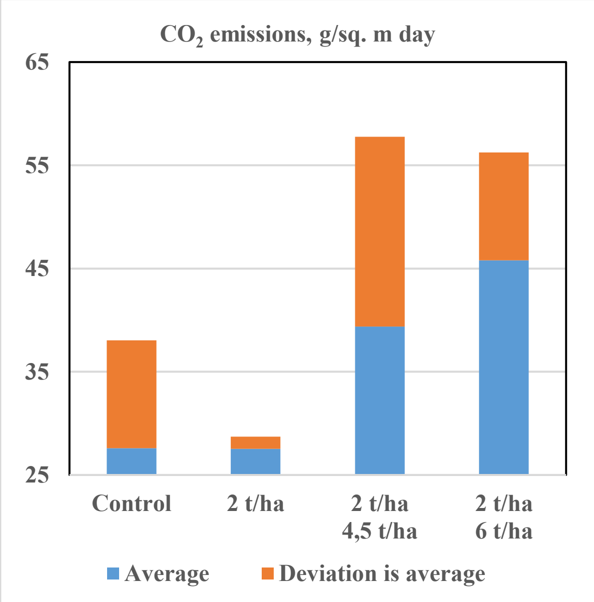


Fig. 8. Soil CO_2 emission average for season values in the micro-plots of the field experiment with quail droppings compost (first line) and phosphogypsum (second line).

There are more pronounced differences in average value of soil CO_2 emission between the control variant and the variants with the quail compost application in combination with phosphogypsum (Fig. 8). They are characterized by sharp increasing the average value of soil CO_2 emission against the background of its pronounced seasonal dynamics.

The spring projective coverage at the beginning of the main growing season (Fig. 9, 28.04.2023) was highest and most stable in the control variant.

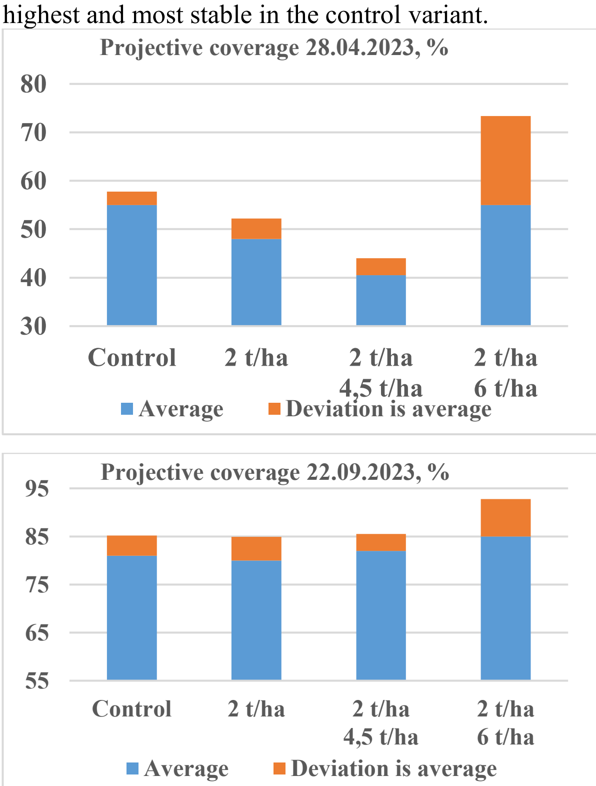


Fig. 9. Projective coverage in the micro-plots of the field experiment with quail droppings compost (first line) and phosphogypsum (second line).

At the end of season differences between all investigated experimental versions on the projective coverage are becoming obviously nonessential (Fig. 9, 22.09.2023) - at the level from 82 till 85%.

There are most pronounced between the experimental variants in the rate of formation of the above-ground grassy biomass (Fig. 9). In 3 variants of the experiment (with 1.5 t/ha of phosphogypsum and with the use of phosphogypsum in combination with compost from quail droppings in doses of 4.5 t/ha + 2.0 t/ha and of 6.0 t/ha + 2.0 t/ha), they are obviously statistically reliable and reach more than 4-multiple exceedances - with a relatively low variation between repetitions.

There are most pronounced differences between the control variant and all variants with application of the compost without or with phosphogypsum in the rate of formation of the above-ground grassy biomass (Fig. 10). In case of compost application total mass of the seasonally accumulated grassy biomass was in 5 times higher than in the control variant.

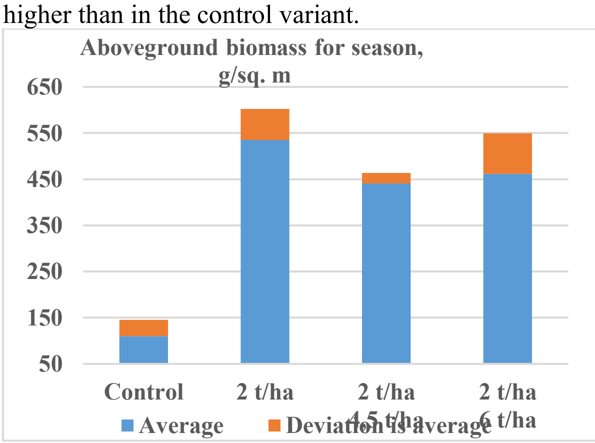


Fig. 10. Total for a season average values of the aboveground grass biomass in the micro-plots of the field experiment with compost (first line) and phosphogypsum (second line).

Summing up the seasonal accumulation of organic carbon in the turf topsoil (ΔCorg-s), in the aboveground grassy (∑Corg-gr) and its root biomass (∑Corg-r) minus the total carbon emissions for the season in the form of measured in situ soil CO_2 fluxes (∑C- CO_2) allows us to quantify integral carbon fluxes between the soil-plant systems studied in the field experiment and in the surface layer of atmospheric air (Table 5).

Table 5. Assessment of the integral carbon fluxes between the soil-plant systems studied in the field experiment and the surface layer of atmospheric air per summer season May-August 2023.

Variant	ΔCorg-s, g/sq. m	∑Corg-gr, g/sq. m	∑Corg-r, g/sq. m p	∑C-CO_2, g/sq. m	Total carbon sink, g/sq. m
Control	12	55	17	903	-819
Comp 2 t/ha	1434	267	80	902	879
Comp 2 t/ha +P-G 4,5 t/ha	1733	220	66	1289	730
Comp 2 t/ha +P-G 6 t/ha	4	231	69	1499	-1195

The analysis shows a pronounced change of the dominant soil CO_2 emission to the total atmospheric carbon sink in the experimental variants with 2 t/ha of compost from quail droppings and with the use of compost in combination with phosphogypsum in doses of 2.0 t/ha + 4.5 t/ha.

This allows one to consider the application of compost from quail droppings for the regeneration of the erosively disturbed sod-podzolic soils as prototype of the best available amelioration technology, taking into account the compost application aftereffect on the stabilization of carbon balance, the formation of large amount of herbaceous biomass and environmentally safe and profitable disposal of organic waste from the highly concentrated animal production.

4 Conclusions

The conducted studies have shown the really small environmental risks in case of utilization of compost from the quail dropping in doze of 2 t per ha for the restoration of erosionally disturbed sod-podzolic soils in the typical for Moscow region landscape conditions.

Moreover, application of this compost as an enhancer of the traditionally used in the greening design turf-sandy soil-ground allow essentially improve its functional-and-environmental features including water and pH regimes regulation, nutrient content and soil exchangeable capacity and saturation stabilization, carbon accumulation and support of positive carbon balance in case of intensively used agricultural grasslands and urban loans.

The use of compost from the quail dropping in doze already of 2 t per ha contributed to the fast and significant accumulation of organic carbon in the turf topsoil of the studied disturbed and regenerated sod-podzolic soils.

All these allow one to consider the application of compost from quail droppings for the regeneration of the erosively disturbed sod-podzolic soils as prototype of the best available amelioration technology, taking into account the compost application aftereffect on the stabilization of carbon balance, the formation of large amount of herbaceous biomass and environmentally safe and profitable disposal of organic waste from the highly concentrated animal production.

In the summer 2023 there was an increased intensity of soil CO_2 emissions in the variants with compost, but with a significantly (multiple) more active increase in grass biomass growing, we can talk about the atmosphere carbon sequestering nature of the technology of utilization of quail droppings during the restoration of disturbed sod-podzolic soils with the formation of a stable herbage.

References

1. S. De Neve, S. Sleutel, G. Hofman, Nutrient Cycling in Agroecosystems, **67**, 1, 13-20 (2003)
2. D. Vetterlein, R. F. Hüttl, Plant and Soil, **213**, 1-2 (1999).
3. J. Urra, C. Garbisu, I. Alkorta, **9**, 9, 542 (2019)
4. K. Grabas, A. Pawełczyk, W. Stręk [et al.], Waste and Biomass Valorization, **10**, 10, 3143-3155 (2019)
5. M. S. Ayilara, O. S. Olanrewaju, O. O. Babalola, O. Odeyemi // Sustainability. – 2020. – Vol. 12, No. 11. – P. 4456.
6. A. Tiefenbacher, T. Sandén, H. P. Haslmayr [et al.] // Agronomy. – 2021. – Vol. 11, No. 5.
7. E. Saadaoui, N. Ghazel, C. Ben Romdhane, N. Massoudi, International Journal of Environmental Studies, **74**, 4, 558-567 (2017)
8. V.I. Vasenev, J.J. Stoorvogel, I.I. Vasenev, Catena, **107**, 96–102 (2013)
9. V.I. Vasenev, J.J. Stoorvogel, N.D. Ananyeva, K.V. Ivashchenko, D.A. Sarzhanov, A.S. Epikhina, I.I. Vasenev, and R. Valentini, *Quantifying spatial–temporal variability of carbon stocks and fluxes in urban soils from local monitoring to regional modeling* in The Carbon Footprint Handbook, 185–221 (2015)
10. A.S. Yakovlev, M.A. Kaniskin, V.A. Terekhova, Eurasian Soil Science, **46**, 6 (2013).
11. M.M. Vizirskaya, A.S. Epikhina, V.I. Vasenev [et al.], Bulletin of the Peoples' Friendship University of Russia. Series: Agronomy and Animal Husbandry, 5, 38–48 (2013)
12. A.S. Shchepeleva, I.V. Vasenev, I.M. Mazirov, I.I. Vasenev, I.S. Prokhorov, D.D. Gosse, Urban Ecosystems, 20, 2, 309-321 (2017)
13. A.S. Shchepeleva, M.M. Vizirskaya, V.I. Vasenev, I.I. Vasenev, *Analysis of carbon stocks and fluxes of urban lawn ecosystems in Moscow megapolis* in Springer Geogr., 80–88 (2019)
14. V.I. Vasenev, S. Castaldi, M.M. Vizirskaya, N.D. Ananyeva, A.S. Shchepeleva, I.M. Mazirov, K.V. Ivashchenko, R. Valentini, I.I. Vasenev, *Urban soil respiration and its autotrophic and heterotrophic components compared to adjacent forest and cropland within the Moscow megapolis* in Springer Geography (2018)
15. I.I. Vasenev, A.V. Buzylev, Yu.A. Kurbatova [et al.] Agroecological modeling and design (RSAU-MTAA, Moscow, 2010)
16. I. Vasenev, M. Tikhonova, A. Avilova, *Forest soil quality analysis at the potential reference site for Moscow megalopolis environmental monitoring* in Proceedings of the 17th International Multidisciplinary Scientific Geoconference SGEM, 545–552 (2017).
17. M.T. Spynu, M.V. Tikhonova, E.M. Ilyushkova [et al.], AgroEcoInfo, 4(52) (2022)
18. Digital technologies of agroecological monitoring and optimization of agriculture (edited by I.I. Vasenev) (RSAU-MTAA, Moscow, 2022)