ISSN 1064-2293, Eurasian Soil Science, 2025, Vol. 58:112. © Pleiades Publishing, Ltd., 2025.

SOIL BIOLOGY

Impact of Biochar and Biochar-Based Plant Composts on the Microbiological Activity of Agrosoddy-Podzolic Soil

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Received January 29, 2025; revised April 7, 2025; accepted April 20, 2025

Abstract—In a 30-day incubation experiment, the impact of biochar and plant composts on basal and substrate-induced respiration and the activity of catalase, dehydrogenase, acid phosphatase, and urease enzymes in low-humus agrosoddy-podzolic soil was studied. Biochar was obtained by fast pyrolysis from birch wood at 600°C. Composts from plant materials with different nitrogen contents were formed with and without the addition of biochar. Biochar and composts were added to the soil in an amount of 1%. The application of all the studied ameliorants reliably increased both basal and substrate-induced respiration by 1.5–2.1 times. At the same time, biochar made a significantly greater contribution to the increase in the rate of substrate-induced respiration and the amount of microbial biomass carbon that plant-based composts. Analysis of microbial respiration indices attests to more favorable conditions for the functioning of microbial communities after the addition of biochar and composts into the soil. Increased microbiological activity was manifested in growing activity of the studied enzymes and organic matter mineralization. It is advisable to introduce biochar into the soil only in combination with organic fertilizers or use it as a component in composting organic waste.

Keywords: soil organic matter, basal respiration, microbial respiration indices, catalase, dehydrogenase, acid phosphatase, urease

DOI: 10.1134/S1064229325600289

INTRODUCTION

In recent decades, considerable attention of researchers has been directed to studying the properties and application of organic ameliorant—biochar (BC)—in agricultural practices [16, 32, 47]. BC is a high-carbon product of oxygen-free thermal transformation of organic substances. BC is stable and resistant to chemical and biochemical impacts; it is characterized by a large number of functional groups, has a porous structure, high specific surface area, and contains potassium, phosphorus, and other mineral nutrients necessary for plant life [46, 47, 60].

When introduced into the soil, BC ensures carbon sequestration for a long time, reduces greenhouse gas emissions, improves physical, physicochemical, and biological properties of the soil, and increases crop yields [5, 38, 56]. Under the influence of BC, the biogenicity of soils increases and the composition, structure, and activity of the microbial community change [24, 43, 52], which contributes to the intensification of biochemical cycles in the soil and improves the availability of nutrients and plant productivity [30, 47]. Several large reviews have recently been devoted to assessing the impact of BC on soil properties [52, 57, 59, 60]. In general, the analysis of literature data indicates the predominance of a positive effect of BC on the environment, soil properties, and soil fertility [29, 48, 65]. However, some aspects of the use of this ameliorant are still controversial and require further study. This concerns microbiological and biochemical mechanisms of mineralization of soil organic matter [49, 51], as well as a possible increase in carbon dioxide emissions due to an increase in the total soil carbon pool and the provision of additional labile carbon substrate [39, 58].

A certain contribution to the solution of these issues is made by information on changes in the functioning of microorganisms and biological indicators of soils when BC is introduced into it [17, 20, 24]. It has been shown that BC can have different effects on the biomass and activity of soil microorganisms [30, 40]. Most studies have found an increase in these indicators, which is due to an increase in the availability of nutrients [46], optimization of the soil reaction [52, 59], adsorption of toxic compounds [60], and the provision of an ecological niche for microorganisms due to the high porosity of BC [52, 54]. An increase in microbiological activity, in turn, is often accompanied by the development of dehumification processes [50, 52] and an increase in the CO_2 emission [59]. According to other data, BC does not have a stimulating effect on the biomass of soil microorganisms and the intensity of mineralization processes [52]. There is also information about a decrease in microbial biomass [47, 59, 60]. The reasons for this are not entirely clear, but they may be associated with both changes in soil properties (pH, water regime) and with the direct negative impact of toxic mineral or organic components contained in the BC.

In addition to its direct use as a soil ameliorant, BC has recently been widely used in the production of organic fertilizers and composts [37, 61, 62, 66, 67]. The use of BC as a component of a compost mixture reduces the duration of composting, which determines the possibility of rapid utilization of plant residues, activates mineralization and humification processes [31, 41], contributes to an increase in the stability of the system of humic substances [44, 50], as well as to the preservation of mineral nutrients in compost and the creation of favorable habitats for microorganisms, enhancing their activity [35, 36, 64].

The prospect of using composts with BC determines the need to study various aspects of their impact on soil properties. Particular attention should be paid to studying the effect of composts on biological soil properties, since the complex of soil microorganisms, being the main agent of decomposition of organic matter, has a huge impact on the content and condition of soil organic matter [7, 18, 26]. The most informative indicators for assessing the state and functional activity of soil microorganisms are indicators of the biological activity of soils: soil respiration, including substrate-induced respiration; enzymatic activity; intensity of nitrogen fixation; as well as indicators of the abundance and number of soil microorganisms [28, 42, 63].

It should be noted that research on the use of composts obtained with BC as a component of the composted mixture is just developing. To date, there are quite a lot of works devoted to the study of the effect of BC on the microbiological aspects of composting, while studies of the effect of composts obtained using BC on the microbiological properties of soils are few. Thus, in addition to increasing the content of mineral nutrients and improving the aggregate state of the soil, under the influence of composts with BC, stimulation of the microbial population, stabilization of soil organic matter, a decrease in CO_2 and N_2O emissions, and an increase in the enzymatic activity of the soil were noted [29, 41]. In this case, as a control, soils without the addition of composts are usually used, and not soils with composts obtained without BC.

The aim of this work is to determine the influence of biochar and composts based on it on the microbiological activity of agrosoddy-podzolic soil.

OBJECTS AND METHODS

The study of the influence of BC and composts formed on the basis of plant residues with and without the addition of BC on the activity of microbiological processes in agrosoddy-podzolic soil was carried out in a 30-day incubation experiment.

Fresh topsoil (0–20 cm) samples of the low-humus agrosoddy-podzolic soil (Albic Retisol (Aric, Loamic, Ochric)) of the Gatchina district of Leningrad region were used in the experiment. The soil was characterized by the following parameters: pH_{KCl} 5.3, humus content 2.08%, total nitrogen 0.084%, available nitrogen ($N\text{-}NO_3$) 13.7 mg/kg, ($N\text{-}NH_4$) 14.8 mg/kg, available phosphorus (P_2O_5) 265 mg/kg, and available potassium (K_2O) 134 mg/kg. Biochar was obtained by fast pyrolysis of birch wood at 600°C. It the carbon content of 85.6%, the nitrogen content of 0.43%, the content of water-soluble carbon compounds of 0.0096%, pH_{P_2O} 8.1, and the ash content of 1.8%; BC particles of 0.5–2 mm in size were used in the experiment.

Composts were formed by joint composting of BC and plant residues differing in the enrichment of organic matter with nitrogen (high in the aboveground biomass of clover *Trifolium pratense* L., medium in the aboveground biomass of rye *Secale cereal* L., and low in the oats *Avena sativa* L. straw). For comparison, traditional composts based on the same plant residues, but without the addition of BC, were studied. Composts with BC as a component of the compost mixture have a significant potential for improving the agroecological state of soils (Table 1). Their detailed characteristics were presented earlier [50].

The experimental design included 8 variants in 3-fold repetition:

1. soil without additives (S),
2. soil with added BC (S + BC),
3. soil with added clover-based compost (S + C_{clover})
4. soil with added compost based on clover and BC (S + BC-C_{clover}),
5. soil with added rye-based compost (S + C_{rye}),
6. soil with added compost based on rye and BC (S + BC-C_{rye}),
7. soil with added oats-based compost (S + C_{oats}),
8. soil with added compost based on oats and BC (S + BC-C_{oats}).

The experiment was conducted in plastic vessels with a volume of 0.45 L at natural air temperature and soil moisture of 60% of the total water-holding capacity. Biochar and composts were added to the soil at a rate of 1% of the soil mass.

Agrochemical parameters of soils were determined using standard methods [3, 10, 13, 15]: exchangeable acidity by potentiometric method using 1 N KCl (soil : extractant ratio of 1 : 2.5); total carbon by dry combustion (EA3028-HT analyzer) and oxidation with potassium dichromate (Tyurin's method); total nitrogen by dry combustion (EA3028-HT analyzer) and Tyurin's microchromic method [3].

Table 1. Characteristics of composts based on plant residues obtained with and without the addition of BC [51]

Compost variant	pH_{H_2O}	C/N	Humic acids, % of C_{tot}
Clover compost	7.35 ± 0.03a	20.2 ± 0.72ab	18.8 ± 0.34ab
Clover compost + BC	7.64 ± 0.07b	19.6 ± 0.25a	34.4 ± 0.36d
Rye compost	7.28 ± 0.11b	32.2 ± 0.36d	14.6 ± 0.38a
Rye compost + BC	7.68 ± 0.05b	28.8 ± 0.60c	26.4 ± 0.46c
Oats compost	7.34 ± 0.04a	39.2 ± 0.38f	15.8 ± 0.22a
Oats compost + BC	7.96 ± 0.02c	37.0 ± 0.36e	24.8 ± 0.46c

Numbers with letters (a–f) differ at $P < 0.05$; (±) standard deviation

To assess the functional activity of soil microorganisms in the experimental variants, methods for determining microbial respiration (basal and substrate-induced) and enzymatic activity of soils were used.

Basal respiration (BR) of soils was determined by the absorption method with titrimetric termination after incubation of samples at a temperature of 22°C for 24 h [11, 13, 34]. Substrate-induced respiration (SIR) was studied in a similar way 3 h after the introduction of 0.2 mL of 10% glucose solution into the soil. The determination was also carried out by the absorption method with titrimetric termination. Basal respiration was expressed in μg C–CO_2/(g h). SIR was expressed in μg C–CO_2/(g h) and μL CO_2/(g h). The microbial biomass carbon content (C_{mic}) (μg C/g) was calculated using the formula [1, 19, 27]:

$$C_{\text{mic}} = \text{SIR}\left(\mu\text{L CO}_2\left(\text{g h}\right)\right) \times 40.04 + 0.37.$$

The BR and SIR indicators were used to determine the microbial metabolic quotient $q\text{CO}_2 = \text{BR}/\text{C}_{\text{mic}}$ (unit-specific respiration of microbial biomass or microbial metabolic quotient), the efficiency of organic matter use by microorganisms C_{mic}/C_{org} (%), and the coefficient of microbial respiration $Q_R = \text{BR}/\text{SIR}$ were calculated.

To assess the enzymatic activity of the soil, four enzymes were selected: catalase, dehydrogenase, acid phosphatase, and urease. These enzymes are highly sensitive to various impacts and perform important functions in the biochemical processes in soils.

Catalase activity was determined using the Johnson and Temple method [21] based on measuring the rate of H_2O_2 decomposition during its interaction with soil. The rate of H_2O_2 decomposition was estimated by the amount of undecomposed peroxide, which was determined by permanganometric titration. Catalase activity was expressed in mL 0.1 N $KMnO_4$/(g soil 20 min).

Dehydrogenase activity was determined by the Lenard method [21, 53] using 2,3,5-triphenyltetrazolium chloride (TTC). TTC is reduced to 2,3,5-triphenylformazan (TPF), which has a red color. The color intensity was measured using a KFK-3 photoelectrocolorimeter with a blue filter at a wavelength of 490 nm. Dehydrogenase activity was expressed in mg TPF/(10 g soil day).

The activity of acid phosphatase was determined by the Galstyan method [21]. The method is based on the quantitative accounting of *n*-nitrophenol, which is formed during the enzymatic hydrolysis *of n*-nitrophenol phosphate and produces a yellow color in an alkaline medium. The color intensity was measured by the photocolorimetric method. The activity of acid phosphatase was expressed in mg P_2O_5/(g soil 30 min).

Urease activity was determined by the Romeiko and Malinskaya method [21]. The method is based on the amount of ammonia formed during the decomposition of urea during its interaction with soil urease. The resulting ammonia is capable of binding into colored complexes when interacting with Nessler's reagent. The color intensity was measured by the photocolorimetric method. Urease activity was expressed in mg N-NH_4/(g soil day).

Statistical processing of the data was performed using IBM SPSS Statistics, Version 25. The significance of differences between the means was assessed using the Student–Newman–Keuls test at $P < 0.05$. Equality of variances was assessed using Levene's test.

RESULTS

The introduction of BC and all the studied composts led to a change in the physicochemical properties of the soil: the actual acidity decreased; and the content of organic carbon increased, as well as the nitrogen content and the C/N ratio in the variants with composts (Table 2). The exception was the variant with BC, in which an increase in the total nitrogen content was not detected, because of the extremely low content of this element in the BC. In addition, in this variant of the experiment, the C/N ratio, against the background of an increase in the total carbon content by 1.6 times, sharply expanded; accordingly, the degree of humification of the organic matter of the soil significantly decreased.

The addition of organic material to the soil resulted in a 1.5–2.1-fold increase in both BR and SIR (Fig. 1). In addition, an almost two-fold increase in the content

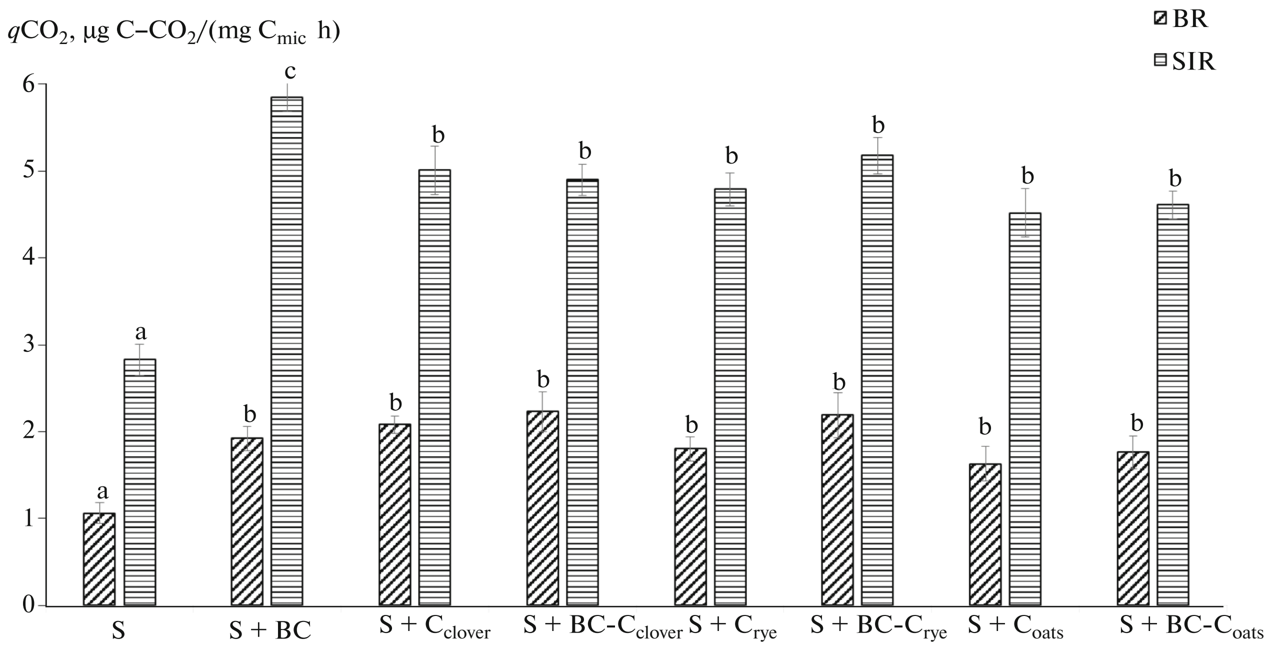

Fig. 1. Values of BR and SIR of the agrosoddydy-podzolic soil in the experimental variants. Columns with letters (a–c) reliably differ at $P \leq 0.05$ according to the Student–Newman–Keuls criterion (ANOVA) for BR and SIR taken separately.

of microbial biomass carbon was observed (Table 3). It ranged from 230 μg/g in the control to 370–473 μg/g in the experimental variants. The maximum value was found in the soil with BC. The share of microbial biomass carbon in all experimental variants was 2–3% of the total organic carbon content.

The value of the microbial metabolic quotient qCO_2 in the soils of all experimental variants was estimated as increased ($qCO_2 \geq 4$ μg C–CO_2) [2, 8].

The results of the study of the enzymatic activity of the samples of agrosoddy-podzolic soil are presented in Table 4. In the control soil (without the addition of ameliorants), the degree of activity of catalase, dehydrogenase, and urease is low, and the activity of acid phosphatase is very low [6]. The change in the enzyme activity can be more clearly traced when expressing the data as a percentage of the control (Fig. 2).

The catalase activity of the agrosoddy-podzolic soil in all experimental variants increased by 14–48% compared to the control. The highest catalase activity was observed in the soil with the addition of compost formed on the basis of BC from oats straw and in the soil with BC. Dehydrogenase was more sensitive to the introduction of the studied ameliorants, especially BC. Its activity increased significantly compared to the control (by 39–69%). The introduction of the studied materials into the soil also increased the urease activity in all experimental variants (by 7–34%). At the same

Table 2. Physicochemical properties of the agrosoddydy-podzolic soil in the experimental variants

Variant	pH_{KCl}	C_{tot}, %	N_{tot}, %	C/N
S	5.4 ± 0.15	1.19 ± 0.05	0.08 ± 0.00	14.9
S + BC	6.3 ± 0.16	1.88 ± 0.11	0.08 ± 0.00	22.6
S + C_{clover}	5.8 ± 0.08	1.30 ± 0.05	0.11 ± 0.01	12.0
S + BC-C_{clover}	6.1 ± 0.15	1.44 ± 0.08	0.12 ± 0.01	12.2
S + C_{rye}	5.8 ± 0.16	1.28 ± 0.04	0.09 ± 0.00	14.2
S + BC-C_{rye}	6.0 ± 0.17	1.40 ± 0.08	0.10 ± 0.00	14.3
S + C_{oats}	5.7± 0.12	1.32 ± 0.06	0.09 ± 0.01	14.0
S + BC-C_{oats}	5.9 ± 0.10	1.42 ± 0.06	0.10 ± 0.00	13.6

Hereinafter, S—soil without ameliorants; S + BC—soil with added BC; S + C_{clover}—soil with added clover compost; S + BC-Cclover—soil with added clover compost and BC; S + C_{rye}—soil with added rye compost; S + BC-C_{rye} (soil with added rye compost and BC); S + C_{oats}—soil with added oats compost; S + BC-C_{oats}—soil with added oats compost and BC; (±) standard deviation,

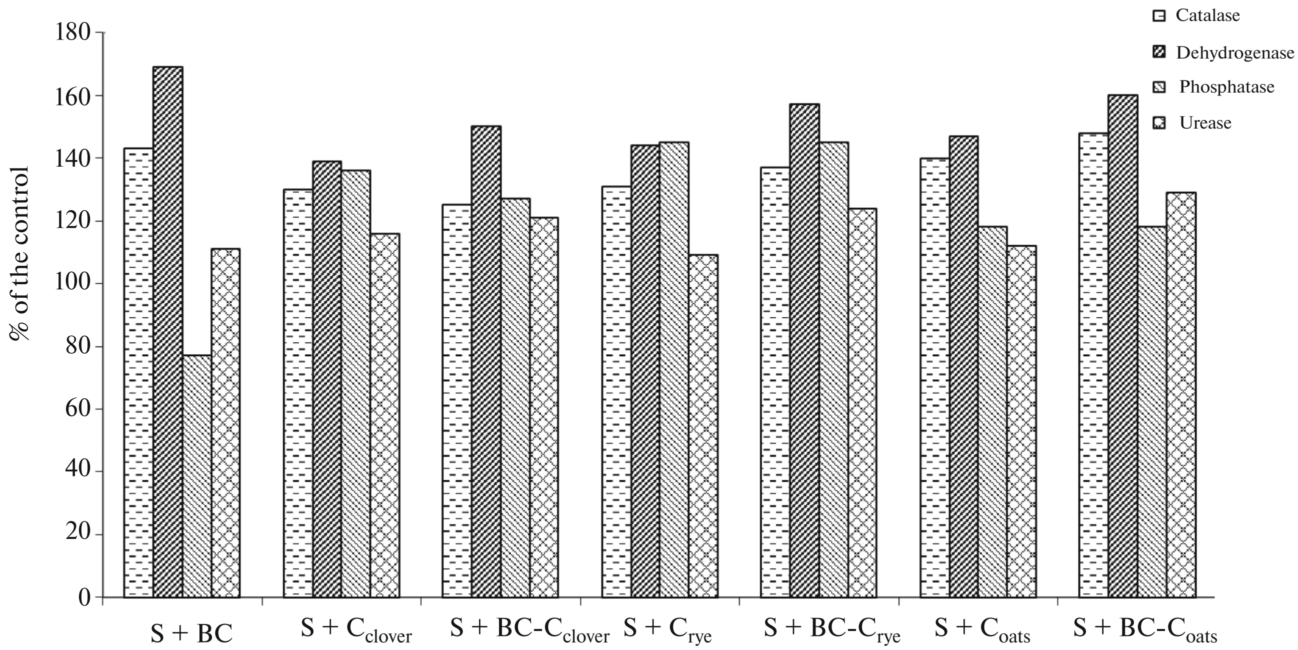

Fig. 2. Changes in the enzymatic activity of agrosoddydy-podzolic soil after adding BC and composts, % of the control (soil without added ameliorants).

Table 3. Indicators of microbial respiration of the agrosoddydy-podzolic soil in the experimental variants

Variant	C_{mic}, μg/g	qCO_2, μg C-CO_2/(mg C_{mic} h)	C_{mic}/C_{tot}, %	Q_R (BR/SIR*)
S	230 ± 12a	4.61 ± 0.07a	1.93	0.37
S + BC	473 ± 6d	4.96 ± 0.10ab	2.51	0.33
S + C_{clover}	406 ± 10bc	5.12 ± 0.08b	3.13	0.42
S + BC-C_{clover}	434 ± 16c	5.14 ± 0.12a	3.34	0.41
S + C_{rye}	389 ± 12b	4.84 ± 0.11a	2.78	0.39
S + BC-C_{rye}	420 ± 8c	5.21 ± 0.12b	3.28	0.42
S + C_{oats}	367 ± 15b	4.44 ± 0.15a	2.78	0.36
S + BC-C_{oats}	374 ± 12b	4.71 ± 0.10a	2.63	0.38

Numbers with letters (a–d) differ at $P < 0.05$; (±) standard deviation.

Table 4. Indicators of enzymatic activity of the agrosoddydy-podzolic soil in the experimental variants

Variant	Catalase, mL $KMnO_4$/(g 20 min)	Dehydrogenase, mg TPP/(10 g day)	Acid phosphatase, mg P_2O_5/(g 30 min)	Urease, mg N-NH_4/(g day)
S	1.82 ± 0.08a	4.24 ± 0.09a	0.22 ± 0.03b	3.85 ± 0.11a
S + BC	2.61 ± 0.11c	7.16 ± 0.07d	0.17 ± 0.02a	4.28 ± 0.06b
S + C_{clover}	2.37 ± 0.08b	5.89 ± 0.18b	0.30 ± 0.05cd	4.46 ± 0.13b
S + BC-C_{clover}	2.28 ± 0.09b	6.38 ± 0.08c	0.28 ± 0.01c	4.66 ± 0.07b
S + C_{rye}	2.38 ± 0.09b	6.11 ± 0.11c	0.32 ± 0.01d	4.21 ± 0.07b
S + BC-C_{rye}	2.49 ± 0.08bc	6.66 ± 0.07c	0.32 ± 0.03d	4.78 ± 0.07b
S + C_{oats}	2.55 ± 0.10c	6.23 ± 0.06c	0.26 ± 0.03c	4.30 ± 0.04b
S + BC-C_{oats}	2.68 ± 0.07c	6.78 ± 0.09c	0.26 ± 0.05c	4.98 ± 0.13b

Numbers with letters (a–d) differ at $P < 0.05$; (±) standard deviation.

time, in composts with the addition of BC, compared to plant-based composts, increased values of urease activity were observed. As for the activity of acid phosphatase, the introduction of composts into the soil stimulated the activity of this enzyme (by 18–45%). On the contrary, when BC was added, the activity of acid phosphatase in the soil was reduced compared to the control (by 23%).

DISCUSSION

The introduction of organic materials into the soil has a significant impact on the soil functioning and its properties: physical and physicochemical parameters, biological activity, the content and environmental stability of humus [9, 14, 23, 25]. At the same time, the nature and direction of changes largely depend on the quality of the organic material.

In the experiment under consideration, the total pool of organic matter in the agrosoddy-podzolic soil was replenished with components that were at different stages of biochemical transformation and characterized by different resistance to biodegradation. BC is a compound with high biothermodynamic stability. In contrast, the bulk of traditional composts are represented by weakly humified labile components that, when released into the soil, are easily biodegraded and quickly mineralized. Composts formed with the participation of BC, in addition to labile compounds, contain a significant proportion of stabilized humic substances [45, 50].

Despite significant differences in the quality of organic material introduced into the soil, the effect of both BC and composts on the physicochemical parameters of agrosoddy-podzolic soil can be assessed as positive. The introduction of the studied materials into the soil contributed to a decrease in acidity and an increase in the content of organic matter, which, in turn, enhanced the rate of BR and SIR and the functional activity of soil microorganisms. The differences in soil BR when introducing BC and composts were insignificant, while SIR and C_{mic} values were significantly higher when introducing BC.

The three-fold excess of the SIR (305% of the BR) in the variant with the addition of BC into the soil is explained by the combination of a large number of microorganisms developing on the surface of BC and an insignificant amount of organic matter available for decomposition in the agrosoddy-podzolic soil [36]. Therefore, when adding an energy substrate to it, microorganisms demonstrate a sharp increase in the CO_2 production. In the experimental variants with the introduction of composts, the microbiological situation is significantly more balanced, since the introduction of an additional energy substrate causes an increase in the CO_2 production comparable to, or slightly less than that in the soil without composts. The most favorable microbiological situation is formed when adding clover composts to the soil, both with and without BC. It should be noted that the differences in BR and SID between composts with and without BC in all the experimental variants are of the same nature, which is probably explained by the specific composition of the microflora formed in the composts [25]. However, additional research is required to provide an unambiguous answer to this question.

The content of C_{mic} in the soil with compost decreased along with the decrease in the nitrogen enrichment of the plant material from which the compost was obtained: clover > rye > oats. It is interesting that in the compost–compost with BC pair, regardless of the type of plant material used to obtain the compost, the introduction of compost with BC always led to higher values of C_{mic}.

It should be noted that the microbial biomass carbon is part of the total organic carbon of the soil, and the C_{mic}/C_{org} ratio serves as an indicator of its quality reflecting the efficiency of the use of organic matter by soil microorganisms [7, 12]. At the same time, a higher value of the C_{mic}/C_{org} ratio indicates the availability of organic matter for microbial decomposition and, accordingly, better binding of organic matter in the microbial biomass.

In this experiment, despite the maximum value of C_{mic} in the soil with added BC, the C_{mic}/C_{org} ratio was significantly inferior to all variants with compost application. This indicates the relative stability of organic matter in the soil with BC, its lower availability for decomposition by microorganisms, while the added composts make the soil organic matter more labile, as indicated by the increased amounts of microbial carbon included in the total soil organic carbon.

The increase in the respiratory activity of the studied soil at application of organic materials is consistent with the increased value of the microbial metabolic quotient. The value of qCO_2 is one of the informative indicators of the ecophysiological state of the soil microbial community [11, 29]. It was found that high values of this indicator attest to increased expenses of microorganisms for maintaining vital activity and indicate a high rate of microbial biomass dying off suggesting a possible soil carbon loss [2, 8, 30]. This may be due to the predominance of microbial populations of fast-growing *r*-strategists at the initial stages of organic matter transformation upon the introduction of BC and composts into the soil [33].

Thus, the analysis of relative indices of microbial respiration indicates more favorable conditions for the functioning of microbial communities after the introduction of both BC and composts into the soil. In turn, this can positively change the conditions for the transformation of organic matter in the studied low-humus soil.

As is known, the soil enzyme pool, especially extracellular soil enzymes responsible for the processes of oxidation and hydrolysis of organic compounds, directly influences the turnover of soil organic matter. They serve to ensure a balance between mineralization and humification in the soil and determine the rate of formation of easily available organic compounds for microorganisms [4, 26].

According to the obtained data, the introduction of BC and plant composts contributed to a change in the activity of soil enzymes to varying degrees. Biochar, when introduced into the soil, increased the activity of dehydrogenase to the greatest extent, but decreased the activity of acid phosphatase. Such a decrease in the activity of acid phosphatase may be associated with both a significant increase in the content of available phosphorus compounds in the soil and a decrease in soil acidity [22, 55]. In this experiment, the acidity in the soil decreased under the influence of the added BC, which was probably the main reason for the inhibition of acid phosphatase activity in this variant. However, the issue of a more accurate determination of the effect of BC on the relationship of enzymatic activity with other soil properties remains open and requires further study.

The effect of composts formed with and without the addition of BC on the enzymatic activity of soils, despite the differences in the original plant material, was comparable. All composts increased the activity of both oxidases and hydrolases, which increases the intensity of the organic matter transformation. At the same time, BC as a component of the compost mixture contributed to a greater increase in the activity of dehydrogenase and urease and had virtually no effect on the activity of acid phosphatase.

CONCLUSIONS

The studies conducted in a short-term incubation experiment allowed us to characterize the main changes in the activity of microorganisms in the agrosoddy-podzolic sandy loamy soil when adding BC and plant composts formed with and without the addition of BC, as well as to assess the possible environmental consequences and prospects for using BC in agricultural practices. It was shown that traditional composts and composts with BC are comparable in terms of the ecological and physiological state of microbiota. The introduction of all the studied organic materials into the soil led to a reliable increase in the rate of basal respiration and the content of microbial biomass and was accompanied by a reliable increase in the activity of oxidation–reduction and hydrolytic enzymes. The soil with the added BC was characterized by the maximum amount of microbial carbon and, at the same time, its reduced share in the total carbon, which indicates a relatively high resistance of organic matter to decomposition by microorganisms. In contrast, added composts made soil organic matter more labile, as indicated by increased amounts of microbial carbon included in the total soil organic carbon.

Thus, both BC and composts obtained with the addition of BC have a positive effect on the activity of soil microorganisms and increase mineralization of organic matter in the soil. However, if additional sources of nutrients and energy material are involved in this process when composts are added to the soil, then, when BC is added, the reserves of soil organic matter are used to ensure the energy expenditure of microorganisms.

In this regard, in order to make the most of the positive effects of using BC as a soil ameliorant and minimize the negative effects, it is advisable to: (1) apply BC to the soil only in combination with organic fertilizers, which will help to avoid the development of dehumification processes and increase the stability of humus and soils in general and (2) actively use BC as a component in the composting of organic waste.

FUNDING

This work was supported by the project no. 123042000071-8 “From carbon polygon to carbon regulation: potential and ways of development of sequestration carbon industry on the territory of the Leningrad Region and St. Petersburg”.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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Translated by D. Konyushkov