Biochar made from chicken manure - a fertilizer that can ensure the carbon neutrality of agricultural soils in conditions of elevated temperatures

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Abstract. Amendment of soil with biochar instead of mineral or organic fertilizers might be one of techniques wich reduce carbon dioxide emissions into the atmosphere. The effect of biochar based on chicken manure on the biomass and respiratory activity of agricultural soil microorganisms was evaluated in lab conditions at normal (average climatic norm for the vegetation season in central Russia, 15 °C) and elevated (25 and 35 °C) temperatures. It was shown that the introduction of 10% biochar by mass did not lead to an increase emission of CO_2 from the soil relative to the control at 15 °C for 60 days of the experiment. An increase in temperature caused an increase in carbon dioxide emissions from the control soil by 35% and 91% and a decrease in moisture by 24% and 42% at 25 and 35°C, respectively. Microbial biomass increased in the control soil by 32% at 25°C and decreased by 34% at 35°C. Soil amendment with biochar led to the leveling of the effect of elevated temperatures on all three parameters. Thus, biochar made from chicken manure allowed one of the characteristics of soil fertility to be preserved and did not lead to the loss of greenhouse gases.

1 Introduction

According to the IPCC report [1] Agriculture, Forestry and Other Land Uses sector on average, accounted for 13-21% of global total anthropogenic greenhouse gas (GHG) emissions in the period 2010-2019. A large contribution to the emission of atmospheric gases is made by the type of soil cultivation, namely the type of plowing, the type and doses of fertilizers used, the use of organic fertilizer, and the type of the main plant crop. All of the above factors affect the functioning of the soil microbiome and, as a result, change the respiratory activity of soil heterotrophs and the rate of carbon sequestration. It is important to note that soil is the third largest carbon storage pool on Earth, it contains 2-3 times more carbon than the atmosphere [2-3]. It is known that an increase in temperature leads to an

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acceleration of soil organic matter mineralization, a loss of soil organic carbon reserves, and, as a result, an increase in CO_2 emissions into the atmosphere [4]. The temperature sensitivity of soil respiration is often expressed as the Q10 value; that is, the factor by which soil respiration increases by a 10°C increase in temperature. The values of the Q10 ranged from 1.5 to 2.0 (the value of increase of soil respiration activity with an increase in soil temperature by 10ºC) according most commonly used models like Community Land Model, CLM, CASA and TEM, but this models don't use regional characteristics of soils [5-6]. However, several studies suggest that Q10 is variable, with values ranging from 1 to larger than 12 [7-8]. Zhou et al. [9] showed, on a global scale, that small inaccuracies with regard to Q10 may result in large errors in the estimation of carbon dynamics. Soil carbon sequestration (i.e., safely capturing and storing carbon that may have been released or left in the atmosphere) is possible when the balance between soil carbon input and mineralization in the soil microbiome is positive. Carbon sequestration in agricultural soils is important because it can not only reduce atmospheric carbon dioxide content, but also increase soil fertility [10-11], which in turn will lead to increased fixation of carbon in plant biomass. It is known that the application of organic fertilizers containing "speed" carbon (for example, manure, litter, compost) leads to an increase in the count and activity of the soil microorganisms, and, accordingly, increased emission of CO_2. As an alternative, it is suggested to use "slow fertilizers" such as biochar. Biochar is a product of thermal decomposition of biomass under anaerobic conditions. It should be noted that during pyrolysis process less amount of greenhouse gases are released as compared to composting. Due to biochar's high porosity, high content of macro- and microelements, it can be used as soil fertilizer [12–18]. According to the literature, the application of biochar as soil fertilizer leads to an increase in crop yield [19–28].

In the present work, the effect of biochar based on chicken manure on carbon dioxide emissions from soil was estimated at normal and elevated temperatures. The soil samples were obtained from the agricultural fields, and three temperature regimes were simulated 15°C which is the average temperature of the vegetation season in central Russia, 25 °C and 35°C.

2 Materials and Methods

2.1 Soil sampling

Experiment was carried out using samples of gray forest soil typical of central Russia. The soil was collected on the experimental fields of KFU (Laishevsky district, Republic of Tatarstan, Russia, 55.639721, 49.309492). Soil characteristics are presented in Table 1.

2.2 Biochar

Chicken manure (CM) used for pyrolysis was obtained from the large-scale farm (Naberezhnye Chelny, Tatarstan, Russia, 55.668788, 52.441136). Biochar was produced using slow pyrolysis at peak temperature 400^{0}C and residence times 2 h in the pilot pyrolysis machine with 200-L retort. The temperature was monitored using thermocouple Fisher-Rosemount Limited 1075, type T-EZI 26. The control of temperature was conducted manually using the burner's gas supply. The resulting biochar was crushed to a powder state. The biochar sample was characterized by the content of Ctot – 30.1%, Ntot - 3.42%, Psoluble – 1.13 g/kg, Ksoluble – 1.4 g/kg.

2.3 Incubation experiment

Soil incubation temperatures were chosen as 15º (average soil temperature for the Republic Tatarstan during the growing season according to the data of meteorological monitoring by KFU), 25º and 30ºC. Biochar was added into the soil in an amount of 10% by weight, soil moisture was brought up to 60% of the total soil moisture capacity. On the 1st day after biochar amendment in both samples – initial soil (S) and soil with biochar (B), the following parameters were determined: pH according to ISO 10390:2005, humidity according to ISO 11465:1993, organic matter (OM) content according to ISO 10694:1995, organic carbon (Corg) content according to , dissolved organic carbon (DOC) content according to Gonet and Debska [29], soil basal respiration activity (RA) according to ISO 16072:2002, microbial biomass (MB) according to ISO 14240-1:1997. Then, samples were incubated in 1-liter vessels for 60 days. After the end of incubation, similar characteristics were determined.

2.4 Statistical analysis

All measurements were conducted in three replicates; the results obtained are expressed as the mean ± standard deviation. The Mann–Whitney U Test was used to determine statistically significant differences ($p < 0.05$). Statistical analysis was performed in Statistica 10.0 software (StatSoft Inc., USA).

3 Results

The addition of biochar into the soil in an amount of 10% by weight led to a change of soil agrochemical characteristics (Table 1): an increase in pH to 7.47, an increase in the content of OM by 12%, an increase in DOC by 84%, and an increase in Corg by 12%. The addition of biochar after the first day of incubation did not lead to a significant increase in soil basal respiration activity, however, the soil microbial biomass was increased by 22%. The RA level of 0.0009 mgCO_2/p*gsoil corresponds to the average RA values (0.0013–0.0605 mgCO_2/g*h) for gray forest soils [30].

Table. 1. Characteristics of Soil Sample and Soil Sample with Biochar.

Parameter	Samples	
	S	B
Humidity, %	15±2	15±2
pH	7.23±0.5	7.47±0.4
OM, mg/g	47.0±1.5	53.1±1.7
Corg, mg/g	17.6±2.6	19.64±1.9
DOC mg/g	4.55±0.48	8.40±1.05
RA, mgCO_2/h*gsoil	0.0009±0.0001	0.0009±0.0001
MB, Cmic mg/g	0.74±0.12	0.90±0.18

The influence of various temperatures of incubation on the physicochemical and microbiological characteristics of gray forest soil was evaluated after 60 days. Incubation of soil samples at elevated temperatures (25°C and 35°C) led to a decrease soil moisture by 26 and 21%, respectively (Figure 1).

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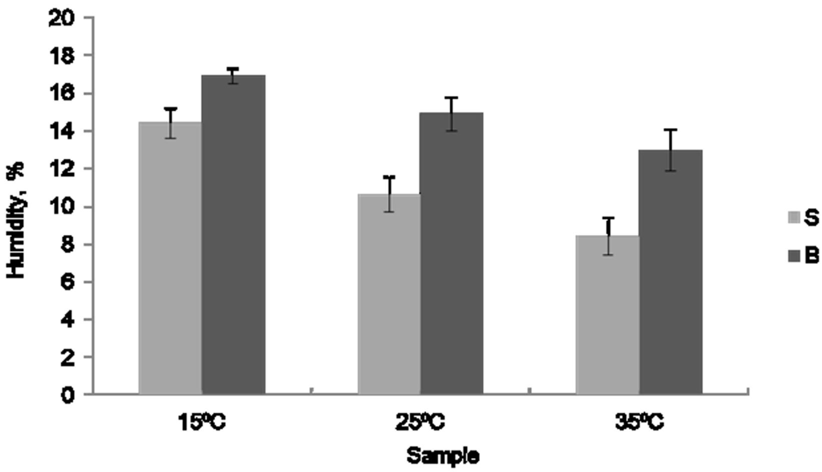

Fig 1. Influence of temperature regimes on soil moisture and soils with biochar introduced.

Incubation of soil and soil with biochar for 60 days at a temperature of 15°C did not lead to a significant change of soil pH (Figure 2). Soil incubation at elevated temperatures resulted in soil acidification, and no difference was found between samples after incubation under elevated temperatures of 25°C and 35°C.

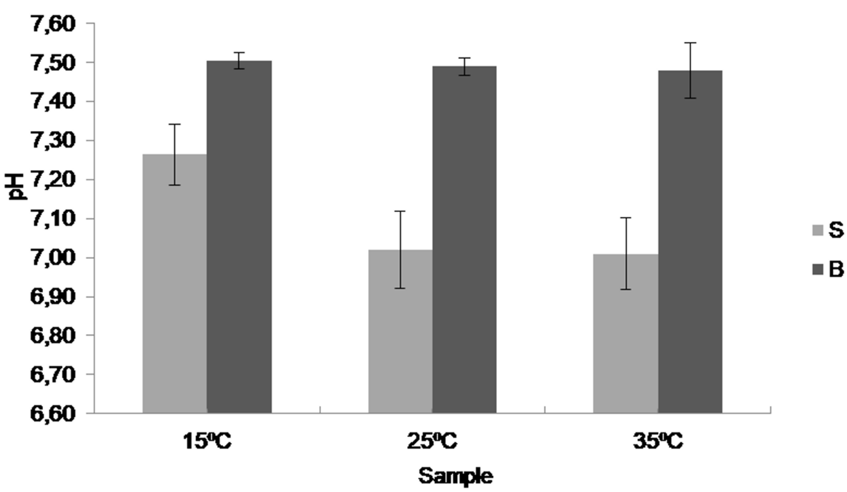

Fig. 2. Effect of temperature regime on the pH of soil and soils with biochar introduced.

There was no correlation between incubation temperature and OM content in soils without biochar. The content of OM increased by the end of the experiment by 3% in the case of incubation at 15°C, by 21% at 25°C, and by 7% at 35°C (Fig. 3). The addition of biochar (sample B) led to an increase in the content of OM after 60 days of incubation at a temperature of 15ºC by 7% and did not lead to a change in the content of OM at elevated temperatures of 25 ºC and 35 ºC in comparison with the first day.

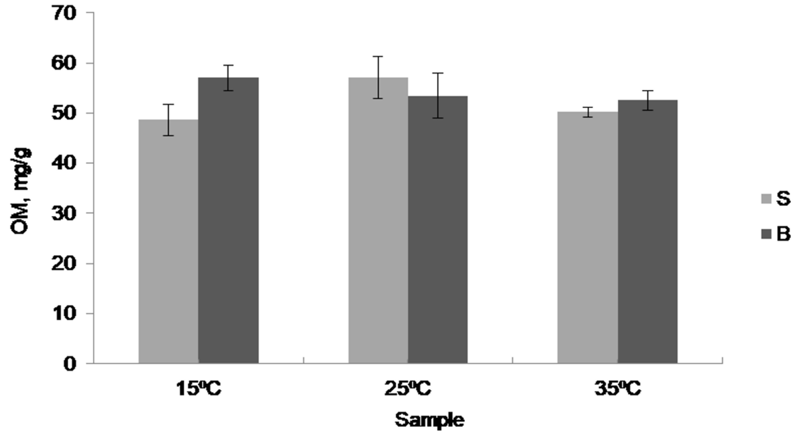

Fig. 3. Influence of the temperature regime on the content of OM in the soil and in the soil with the introduced biochar.

After 60 days of incubation, the content of Corg increased in both samples in all temperature regimes by 5–52% (Figure 4). The maximum increase in the content of Corg was noted for sample B after incubation at 25ºC 30 mg/g. In the case of incubation at 15ºC and 35ºC, no significant differences were found for the variants with and without the introduction of biochar.

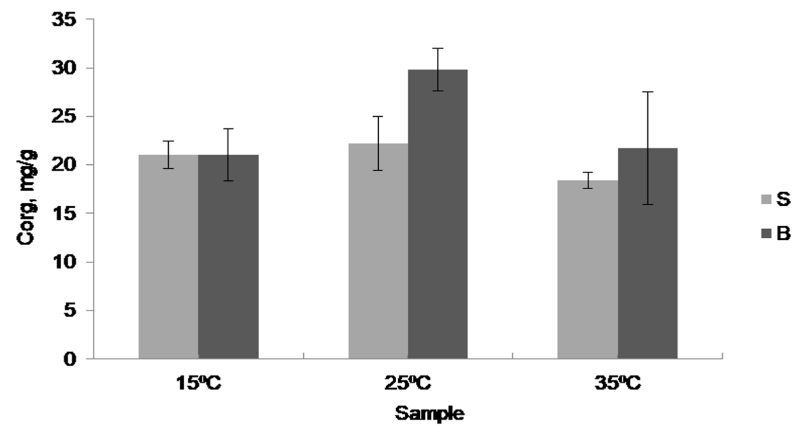

Fig. 4. Effect of temperature regime on the content of Corg in soil and in soil with biochar added
Source: compounded by the author.

Soil incubation for 60 days under all temperature conditions led to a decrease DOC content by 3.7-4.9 times (Figure 5). The addition of biochar into the soil in an amount of 10% by weight led to an increase in the content of DOC by 1.8 times. An inverse correlation was established between the temperature regime and the DOC content for option B (K = -0.92). After 60 days of incubation, the content of DOC in sample B decreased by 3.5-6.1 times. DOC content in samples B incubated at 15°C and 25°C was 1.9-2.1 times higher than that in samples S. After incubation at 35 ºC, the content of DOC did not differ significantly in the variant with and without the introduction of biochar.

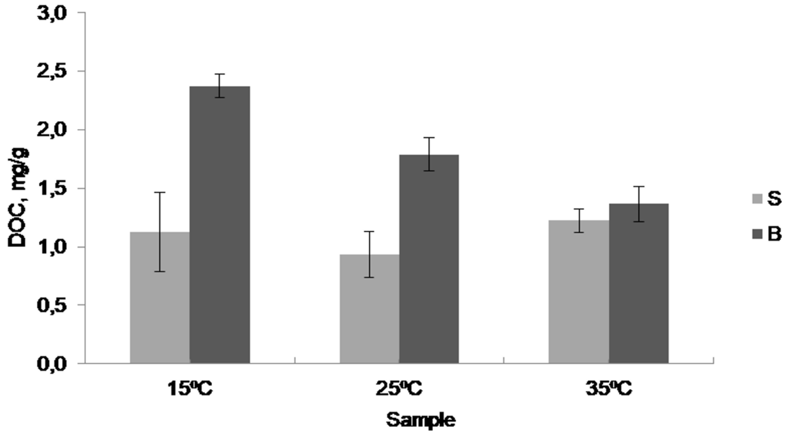

Fig. 5. Influence of temperature conditions on the content of DOC in the soil and in the soil with the introduced biochar.

The elevation of the temperatures in the soil samples without biochar led to an increase of carbon dioxide emissions by 1.3 and 1.9 times at 25 and 35 °C, respectively. A correlation (K=0.9) between the temperature of incubation and the respiration activity was established. The addition of biochar led to the decrease of the carbon dioxide emissions as compared with soils without biochar – by 1.7 and 1.6 times at 25 and 35°C, respectively. Interestingly, that the level of basal respiration revealed in the sample with biochar incubated at 35°C did not differ significantly from that in the control sample incubated at 15°C. It demonstrates that biochar might level the negative effect of elevated temperatures on mineralizing activity of soil microorganisms and therethrough contribute to carbon storage in soil.

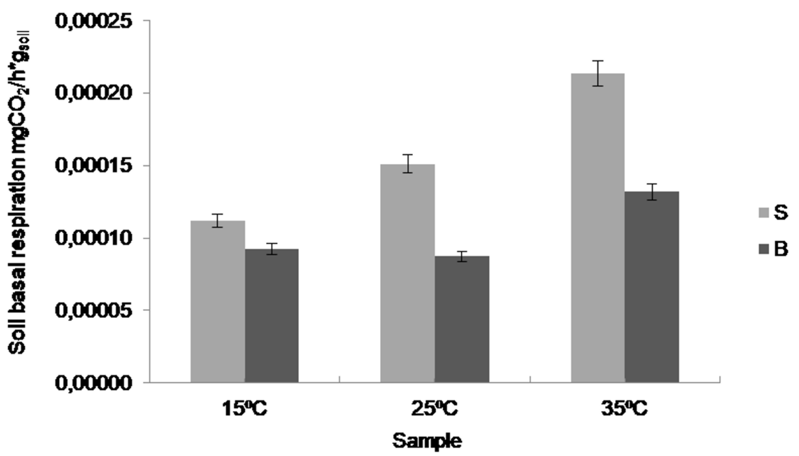

Fig. 6. Influence of temperature conditions on the basal respiratory activity of soil and soil with biochar applied.

The addition of biochar led to an increase in microbial biomass on the 1st day of the experiment compared to the soil without biochar (Table 1), however, by day 60, no difference between the samples with and without biochar incubated at normal temperature was observed (Figure7). An increase in microbial biomass in a soil sample (S) by 1.3 times after incubation at 25°C and a decrease in microbial biomass by 1.5 after incubation at

35°C (a temperature beyond the optimum for soil microbiota) was estimated. The addition of biochar led to the absence of significant differences ($P<0.5$) in the microbial biomass of soil incubated at 15°C and soil with biochar incubated under all studied temperature regimes.

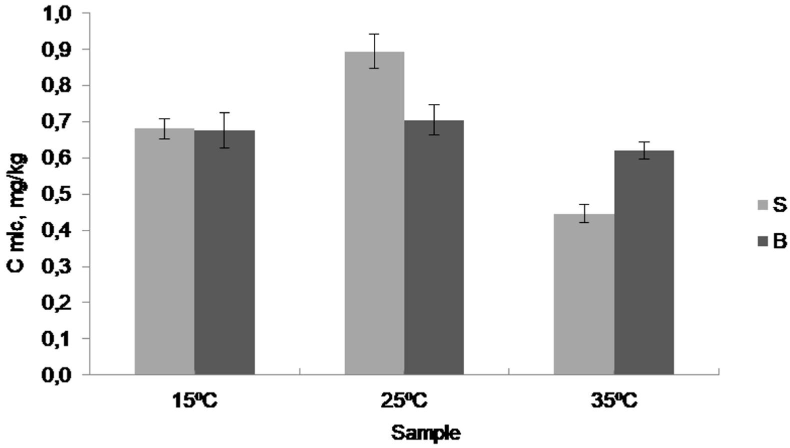

Fig. 7. Influence of temperature conditions on the microbial biomass in soil and soil with biochar applied.

4 Discussion

After incubation at different temperatures, no significant differences in moisture were found in soil samples with addition of biochar (B). Due to its high porosity, biochar enables reduction of the negative effects of droughts by increasing the water-holding capacity of soils. Many authors showed an increase in the moisture content/soil water capacity of the soil after the addition of biochar into the soil due to the improvement of its structure [31–34]. The introduction of biochar led to the leveling of the effect of temperature on soil pH. The availability of nutrients and the activity of the soil microbes depend on the pH level of the soil [35]. It has been shown that the introduction of biochar into acidic soils leads to optimization of soil pH and improvement of soil physicochemical characteristics, as a result of which microbial activity increases [36-37]. Many authors have shown in long-term and short-term experiments that the addition of biochar into the soil leads to an increase in the carbon content in the soil, a decrease in nutrient leaching, and an increase in soil water capacity [38–42]. However, it is not known whether the established effects will persist with changes in temperature regimes, in particular, with an increase in soil temperature. Yang et al [17] found an increase in DOC by 34–69% ($p < 0.05$) due to the release of DOC from biochar with its high concentration (15734 mg/kg) and low absorption capacity of soil DOM. However, the possibility of DOM sorption by biochar was also established, which explains the absence of changes in the DOC content after the introduction of biochar into the soil [18]. Basal respiration activity of the soil microbiome is often used to assess its metabolic activity and the physiological state of microorganisms [43]. As a result of mineralization activity of soil microorganisms, carbon dioxide is released from soil. The release of CO_2 into the atmosphere during the decomposition of soil organic matter makes a significant contribution to the increase in the content of greenhouse gases. At the same time, the intensity of the metabolic activity of the soil microbiome, and, accordingly, the respiration activity, depends on the temperature and soil moisture [44]. The literature provides data both on an increase in the respiration activity of soils and on the absence of changes in the respiration activity of soils after the introduction of biochar into it [35, 45–48]. A number of studies show that the introduction of biochar into different types of soils at different doses (30–100 t/ha) does not lead to a change in MB, but increases respiration activity [18, 35].

5 Conclusion

Our results showed significant differences between soil moisture, soil respiration activity, and soil microbial biomass for soil samples incubated under different temperature with and without biochar addition. It is shown that the use of biochar made from chicken manure as a fertilizer reduced the effect of elevated temperatures on soil properties and greenhouse gas emissions.

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