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# Positive experience in the application of soil- and carbon-saving agricultural technologies with the introduction of biochar in the conditions of the Russian Far East

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**Abstract.** Based on the positive results of a long-term field experiment on the introduction of bio-coal for vegetable crops in the Primorsky Territory on soils of heavy chemical composition, its sequestration effect and positive effect on the water-physical properties of soils were proved. After the first year of application of biochar, a significant decrease in $CO_2$ flux in the field without a drainage system was shown by 4.5% at a dose of 1 kg/m$^2$ of biochar and by 36.6% at a dose of 3 kg/m$^2$ of biochar compared with a site without biochar. The decrease in $CO_2$ flux indicates the reclamation effect of biochar due to its high sorption properties affecting the sequestration capacity of the soil. After the second year of application of biochar, the greatest decrease in $CO_2$ flux was observed when 1 kg/m$^2$ was applied. The greatest difference between the values of the $CO_2$ flux at the control site and the sites with the introduction of biochar was noted in September after the abnormal amount of precipitation recorded in August (521 mm). So, at the control site in September, the $CO_2$ flux was 2,276 mg $CO_2$ m$^{-2}$ h$^{-1}$, at the site with the addition of 1 kg/m$^2$ of biochar, the $CO_2$ flux was 560 mg $CO_2$ m$^{-2}$ h$^{-1}$, at the site with the addition of 3 kg/m$^2$ – 975 mg $CO_2$ m$^{-2}$ h$^{-1}$.

## 1 Introduction

The use of low-carbon technologies in Russian agriculture and the preservation of soil fertility is becoming increasingly relevant, especially given the global demand for decarbonization. The search for solutions in which soil tillage is minimal, and the absorption of carbon and nitrogen within soil cycles becomes more complete, comes to the

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fore of modern agroecological applied research. In this regard, it is necessary to create domestic climate projects for Russia's participation in both domestic and foreign agricultural markets.

Most soils in the Far Eastern region are heavy in terms of granulometric composition and, with active mechanical treatment, the soil structure is destroyed and soil fertility is lost. The search for effective green technologies, the preservation of soil fertility and the reduction of the carbon footprint of agricultural enterprises is the main goal for Russia.

Despite the fact that biochar is becoming a fairly popular technology in world practice, used to improve soil quality and recycle organic waste, the number of publications evaluating the effects of biochar in different soil and climatic conditions remains insufficient [1-3]. Despite the attractiveness of using biochar as a soil improver and the high efficiency of its use in some experiments, it is important to understand that soil and climatic conditions are the main factors determining both the environmental and economic effects of applying biochar.

The biggest question that arises when evaluating the effectiveness of biochar is the shelf life of this product in the soil [4]. The porous structure of biochar is considered an important factor for improving the water-physical properties of the soil and increasing its water retention capacity [5-8].

## 2 Materials and methods

To assess the effectiveness of using biochar as a low-carbon technology, we have established a long-term vegetation field experiment. It was held on the territory of the Primorsky Vegetable Experimental Station of the branch of the Federal State Educational Institution (Surazhevka village, Primorsky region) during the spring and autumn periods of 2018 and 2019. On the territory of the station, two fields were selected that were comparable in terms of terrain and soil conditions, one of which had a drainage system, the other did not. Each of the fields was divided into three plots with an area of 21.6 $m^2$ (1.8 X 12 m), which included a control plot without biochar, a plot with 1 kg/m2 of biochar and a plot with 3 kg/$m^2$ of biochar.

Biochar was applied to the soil manually once in June 2018 in a surface horizon of 0-10 cm. A more detailed application scheme and its description can be found in our previous works [9-12].

The soil in the studied areas is represented by Luvic Anthrosols. The initial characteristics of the arable soil layer in the study area are presented in Table 1.

**Table 1.** Characteristics of the arable layer (0-10 cm) of agricultural soils before the experiment.

| Soil properties | Values | |
|---|---|---|
| | Field without drainage system | Field with drainage system |
| Sand, % | 18 | 7 |
| silt, % | 57 | 68 |
| Clay, % | 26 | 25 |
| Density (g cm-$^1$) | 1.2 | 1.2 |
| Organic carbon (%) | 2.6 | 2.1 |
| pH (in 1 mol $dm^{-3}$ KCl) | 5.45 | 5.43 |
| $K_2O$ (mg $kg^{-1}$) | 200 | 104 |
| $P_2O_5$ (mg $kg^{-1}$) | 140 | 90 |
| N-eh (mg $kg^{-1}$) | 133 | 129 |

The biochar used in the work was obtained from the woody remains of Betula alba birch by slow pyrolysis at a temperature of 360-380 ° C by Krasilov & Co. (Russia). Before using biochar in the experiment, its properties were evaluated according to the international SHISH standard. The biocar used is environmentally friendly, has a high-strength (H/C =

0.052 and O/C = 0.145) and highly porous structure (pore surface area 73.25 $m^2/g$), contains 78.13% carbon, pH2O is 8.09 ± 0.07, water absorption capacity in the original fraction is 110% ± 6.56%. After the biochar was found in the soil for 4 and 16 months, the change in the properties of biochar was evaluated, the results of which are described in detail in the work of Bovsun et al. [10].

Greenhouse gas fluxes were measured in the laboratory using a Picaro G2508 laser gas analyzer (Picarro Inc., Santa Clara, California, USA).

Three buckets with intact soil samples taken at the experimental sites were placed in a glass chamber of the gas analyzer with a volume of one liter, equipped with a lid with an O-ring and inlet and outlet holes for moving gas connected to the gas analyzer by Teflon tubes. The flow measurement time was 5 minutes (53 measurements per minute/265 measurements in 5 minutes). Thus, three five-minute measurements were obtained for each site (9 measurements for all sites).

The temperature and air pressure in the laboratory were measured using the Vaisala WXT520 weather sensor (Vaisala, Helsinki, Finland).

$CO_2$ fluxes were calculated using the formula (equation 1):

$$F_{gas} = \frac{\frac{\Delta[Gas]}{\Delta t} \cdot V \cdot \rho}{A} \quad (1)$$

*Fgas* = gas flow expressed in µmol $CO_2$ $m^{-2}$ $s^{-1}$; Δ[Gas]/Δ*t* is the change in gas concentration over time, expressed in µmol $mol^{-}1$ $s^{-}1$; *V* is the total volume of the chamber in $m^3$; *A* - the area of the camera in $m^2$; *p* is the molar density of air in mol $m^{-3}$.

The coefficient of determination $R_2$ was used in the calculation of Δ*[Gas]*/Δ*t* to assess the reliability of the measured flow data.

## 3 Results and Discussion

After the first growing season (4 months, 2018) of the influence of biochar, a significant decrease in the $CO_2$ flux in a field without a drainage system was shown by 4.5% at a dose of 1 $kg/m^2$ biochar and by 36.6% at a dose of 3 $kg/m^2$ biochar compared to a site without biochar. The decrease in CO2 flux testifies to the reclamation effect of biochar due to its high sorption properties affecting the sequestration capacity of the soil. In a field with a drainage system, the application of biochar showed a negative effect on the $CO_2$ flow and led to an increase of 39.4% in the area with a dose of 1 $kg/m^2$ and 16% with a dose of 3 $kg/m^2$. It is assumed that the negative effect of biochar is associated with the inability of the drainage system to remove moisture from the soil space due to its partial sorption by biochar, which causes deterioration of the water-air condition of the soil.

After the second growing season (16 months, 2019), in a field without a drainage system, the greatest decrease in $CO_2$ flux was observed when 1 $kg/m^2$ of biochar was applied.

In monthly dynamics, the largest difference between the values of $CO_2$ flux was observed in September between the control site and the sites with the introduction of biochar in September, which was due to the abnormal amount of precipitation recorded in August (521 mm). So, at the control site in September, the $CO_2$ flux was 2,276 mg $CO_2$ $m^{-2}$ $h^{-1}$, at the site with the addition of 1 $kg/m^2$ of biochar, the $CO_2$ flux was 560 mg $CO_2$ $m^{-2}$ $h^{-1}$, at the site with the addition of 3 $kg/m^2$ – 975 mg $CO_2$ $m^{-2}$ $h^{-1}$.

The smallest difference between the $CO_2$ fluxes at the control site and the sites with the introduction of biowaste was observed in June, which could be the reason for the lack of organic matter intake due to the absence of agricultural crops. In June, at the control site, the $CO_2$ flux was 57 mg $CO_2$ $m^{-2}$ $h^{-1}$, at the site with the addition of 1 kg/$m^2$ of biochar – 23 mg $CO_2$ $m^{-2}$ $h^{-1}$, at the site with the addition of 3 kg/$m^2$ of biochar – 35 mg $CO_2$ $m^{-2}$ $h^{-1}$.

The monthly dynamics of the $CO_2$ flow in the field with a drainage system showed that when applying biochar, the $CO_2$ flow increases. The greatest increase was observed when applying 3 kg/$m^2$ of biochar.

The smallest difference in $CO_2$ flow rates in areas without a drainage system was noted in June. A $CO_2$ flux value of 8 mg $CO_2$ $m^{-2}$ $h^{-1}$ was recorded at the control site. At the site with the introduction of 1 kg/$m^2$ of biochar, the $CO_2$ flux was 13 mg $CO_2$ $m^{-2}$ $h^{-1}$, at the site with the introduction of 3 kg/$m^2$ of biochar - 11 mg $CO_2$ $m^{-2}$ $h^{-1}$.

The greatest difference between the control site and the sites with the introduction of biochar was recorded in September. The control section showed a flow value of 188 mg CO2 $m^{-2}$ $h^{-1}$. At the site with the addition of 1 kg/$m^2$ of biochar, the CO2 flux value was 181 mg $CO_2$ $m^{-2}$ $h^{-1}$, at the site with the addition of 3 kg/$m^2$ – 427 mg $CO_2$ $m^{-2}$ $h^{-1}$.

In a field without a drainage system, the total $CO_2$ flux during the growing season showed a decrease in values when applying biochar both at the beginning and at the end of the growing season. At the beginning of the growing season, the introduction of biochar in doses of 1 kg/ $m^2$ and 3 kg/$m^2$ led to a decrease in $CO_2$ flux by 63.6% and 56.2%, respectively, compared with the site without biochar application.

By the end of the growing season, the total $CO_2$ flux with the introduction of biochar at a dose of 1 kg/m2 was 1,828 mg $CO_2$ $m^{-2}$ $h^{-1}$, which is 57.7% lower than the total flux at the site without the introduction of biochar (4,318 $CO_2$ mg $m^{-2}$ $h^{-1}$). At the site with a biochar application dose of 3 kg/$m^2$, the total $CO_2$ flux was 2,200 mg $CO_2$ $m^{-2}$ $h^{-1}$, which is 49% lower than the total flux at the site without the use of biochar.

In general, it can be noted that the values of the total $CO_2$ flux according to the results of the second growing season of the study were significantly higher than after the first growing season. After the second growing season, there was a greater percentage decrease in the flow when applying biochar than in the first growing season. Such changes may be associated with different agricultural crops grown on the plots, a significant difference in the weather conditions of the study.

In a field with a drainage system, the total $CO_2$ flux during the growing season showed an increase in values when applying biochar. At the site with the addition of 1 kg/$m^2$ of bio-coal, an increase in $CO_2$ flux values by 22-38% was observed during the entire growing season compared with the control.

During the entire growing season, an increase in $CO_2$ flux values by 3-24% compared to the control was observed at the site with the introduction of 3 kg/$m^2$ of biochar. At the beginning of the growing season, the application of biochar in doses of 1 kg/$m^2$ and 3 kg/$m^2$ led to an increase in $CO_2$ flux by 38.7% and 3.4%, respectively, compared with the site without biochar application.

By the end of the growing season, the cumulative $CO_2$ flux with the introduction of biochar in the amount of 1 kg/$m^2$ amounted to 1035 mg $CO_2$ $m^2$ $h^{-1}$, which is 22.6% higher than the total flow at the site without the introduction of biochar (801 $CO_2$ mg $m^2$ $h^{-1}$). At the site with a biochar application dose of 3 kg/$m^2$, the cumulative $CO_2$ flux was 1054 mg $CO_2$ $m^{-2}$ $h^{-1}$, which is 24% higher than the cumulative flux at the site without the use of biochar.

It is worth noting that in a field without a drainage system, the value of the cumulative flow in the control area is 5 times higher than the values of the cumulative flow in a field with a drainage system. The value of the cumulative flow of the field without a drainage system with the addition of 1 kg/$m^2$ did not reach the level of the cumulative flow value in the area with a drainage system.

## 4 Conclusion

The greatest sequestration effect - 623 mg of $CO_2$ $m^{-2}$ $h^{-1}$ was obtained when applying 3 $kg/m^2$ when growing cabbage in a drainage-free area during the first growing season. In the second growing season, when growing soybeans in the same area, the sequestration capacity was 2,200 mg $CO_2$ $m^{-2}$ $h^{-1}$ relative to the control.

Thus, for a field with an area of 1 hectare sown with cabbage on un-drained dark humus beds, under similar climatic conditions and the introduction of wood biochar at a dose of 3 $kg/m^2$ during the growing season (5 months), emissions of approximately 23 tons of $CO_2$ can be reduced. However, it should be taken into account that the change of crops, soil and climatic conditions, and the type of biochar can give completely different results, which means that regional adaptation of the technology of carbon deposition into soils using biochar is necessary.

In 2023, Verra released VM0044 Methodology for Biochar Usage in Soil and Non-Soil Applications, version v1.0, which outlines procedures for quantifying the reduction of greenhouse gas (GHG) emissions from the production of biochar and its use in approved soil and non-soil applications [13]. According to the 2019 Special Report of the Intergovernmental Panel on Climate Change, biochar could provide a mitigation potential of 1 Gt $CO_2$ per year by 2050 (conservative estimate) [13].

Due to the variety of soil and climatic conditions, as well as the presence of a large raw material base, the territory of Russia is promising both for scientific research in the field of biochar application and its mass application in various fields, including agriculture, which is especially important given the global demand for decarbonization. In this regard, it is necessary to create domestic climate projects for Russia's participation in both domestic and foreign agricultural markets.

According to the results of our research, the use of biochar can be economically beneficial in the agrosoils of the Far East. Most soils in the Far Eastern region are heavy in terms of granulometric composition and, during mechanical processing, they lose their agronomically valuable structure, due to which there is a loss of soil fertility, including loss of soil carbon and deterioration of the water-air regime. This is especially true for vegetable crops, the yield of which depends not only on the quantity of nutrients, but also on their availability to plants due to optimal conditions in the arable soil horizon.

As shown by a long-term field experiment, biochar is able to improve the water-air regime of soils, facilitate the granulometric composition, is able to reduce the values of carbon dioxide fluxes, affect the fluxes of nitrous oxide, ammonia, methane, and increase crop yields.

Thus, we see that the use of bio-coal in the agricultural sector of the Russian Federation can become the basis for climate projects and the creation of its own carbon markets.

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