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The influence of the biochar application on the CO_2 emission from Luvic Anthrosols in the south of Primorsky region (Russian Far East)

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Abstract. Under the conditions of a field experiment in plots with different water-air conditions, the effect of wood biochar on CO_2 emissions was studied during one growing season (from July 13, 2018 to October 25, 2018). It was revealed that the application of biochar in the field without a drainage system reduces CO_2 emissions. Thus, the cumulative flow of CO_2 at the biochar dose application of 3 $kg \cdot m^{-2}$ decreased by 36.6% compared to the control. The biochar application at a dose of 1 $kg \cdot m^{-2}$ reduced the cumulative flow by 4.5% compared to the control. The biochar application increased CO_2 emissions in the field with a drainage system. The biochar application at dose of 3 $kg \cdot m^{-2}$ increased the cumulative flow by 39.9% while the dose of 1 $kg \cdot m^{-2}$ increased it by 16% as compared to the site without the biochar application.

1. Introduction

Biochar is a high-carbon and highly porous product that is obtained by pyrolysis of biomass. Due to its highly porous carbonaceous structure, it is able to improve water retention and increase the soil surface area [1]. It has a number of physicochemical properties that affect pH, soil aggregation, nutrient availability, and organic carbon availability [2].

An important property of biochar, especially in the current state of the environment, is the sequestration of carbon. It is believed that through carbon sequestration, biochar can store inorganic carbon in the soil mass and reduce greenhouse gas emissions. Confirmation of this theory can be found in the works of a number of authors [3–7]. For example, a decrease in the CO_2 flux was recorded in a study by Wu Di et al. They investigated the effect of biochar at doses of 1.3 and 0.8 $kg \cdot m^{-2}$ in combination with nitrogen fertilizers on acidic sandy and clayey alkaline soils for 62 days. The cumulative CO_2 flux was found to decrease by 11.8% compared to the site where only nitrogen fertilizers were applied [5].

Despite scientific publications confirming the sequestration effect of biochar, there are works with the opposite result [8–11]. Thus, in the work of Hawthorme et al. [8], the use of biochar (1% biochar, 10% biochar, 1% biochar with 200 kg·ha^{-1} nitrogen and 10% biochar with 200 kg·ha^{-1} nitrogen) increased the flow of CO_2 and CH_4 compared to the control. One can find works where the application of biochar did not give either a positive or a negative effect [12–15]. Probably, the explanation for the difference in research results is the complex process of greenhouse gas emissions. This process depends on the microbiological, physical and chemical processes of all soil components and therefore strongly depends on environmental conditions. Thus, the prediction of the effect of biochar remains very difficult.

The purpose of this work is to study the effect of biochar on CO_2 emissions from Luvic Anthrosols in the south of Primorsky region (Russian Far East).

2. Methodology

2.1. Fields and soil sampling

The effect of biochar on CO_2 emissions was studied in a field vegetation experiment. The field experiment was laid in June 2018 on the territory of the Primorskaya Vegetable Experimental Station of the All-Russian Scientific Research Institute of Vegetables (Surazhevka village, Primorsky Territory, Russian Federation). Two adjacent fields were selected within the station, one of which has a drainage system, the other does not. Biochar in doses of 0 kg·m^{-2} (control), 1 and 3 kg·m^{-2} were applied to experimental plots in fields with and without drainage systems (table 1) and mixed with the topsoil horizon.

Table 1. Scheme of the experiment.

Field without drainage system			Field with drainage system		
BC0 [a]	BC1	BC3	BCD0	BCD1	BCD3

[a] 0, 1, 3 – application doses of biochar (BC), kg·m^{-2}.

According to the World Reference Base of Soil Resources, the soil in the studied areas is represented by Luvic Anthrosols. The arable layer of the control area in the field without a drainage system has an average carbon granulometric composition (60% physical sand, 40% physical clay), close to the neutral reaction of the medium ($pH_{H2O} = 6.8$; $pH_{KCl} = 5.45$) and a carbon content of 2.62%.

The control area in the drainage field has a heavy carbon granulometric composition (52% physical sand, 48% physical clay), close to the neutral reaction of the medium ($pH_{H2O} = 6.67$; $pH_{KCl} = 5.43$) and 2.05% carbon.

2.2. Biochar preparation

For the purpose of the study, biochar, produced from the wood remains of *Betula alba* by pyrolysis at a temperature of 360–380 °C, was selected. The biochar used is an environmentally friendly, high-quality product with a strong, highly porous structure (figure 1) and good sorption properties [16], with a high percentage of C (78%), a pH value of 8.09, an ash content in the range from 5.4 to 7.3% and contains volatile compounds in the range from 29 to 31.2% (tables 2 and 3).

The biochar properties were evaluated according to the IBI International Standard [17]. Before applying biochar to the soil, the following parameters were determined: pH according to the method of Rajkovich et al. [18]; ash and volatile substances by ASTM D1762-84 [19]. The content of C, N, H in the biochar was determined by an electronic CHNS analyzer PE2400 Perkin Elmer (USA). The content of Ca, Na, Mg, K, etc., with the exception of oxygen, which was determined by calculation, was determined on a Shimadzu EDX-800 X-ray fluorescent analyzer (Shimadzu, Japan). The electron microscopy of biochar was determined on a scanning electron microscope (FE-SEM) Sigma (Carl Zeiss, Germany).

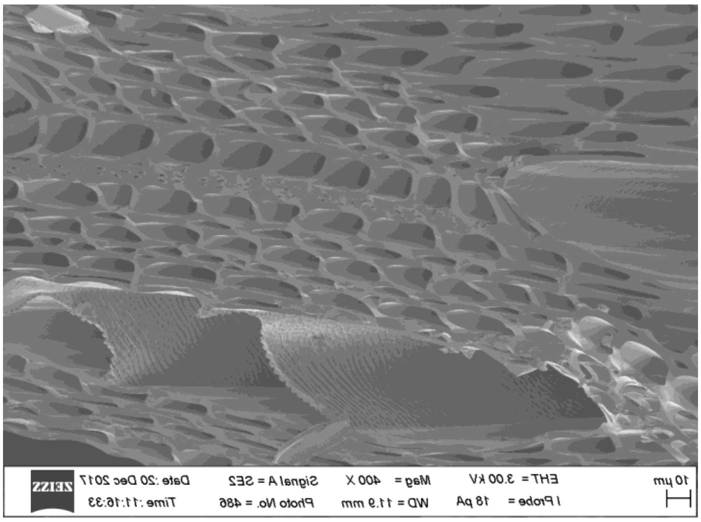

Figure 1. Microstructure of wood-derived biochar *Betula alba* by pyrolysis at a temperature of 360–380 °C.

Table 2. Physicochemical parameters of biochar from *Betula alba*.

Parameter	Fraction size	Values
Volatiles, % of dry matter	unchanged biochar	31.2
	1 mm	29
	0.25 mm	31
Ash-content, % of dry matter	unchanged biochar	5.4
	1 mm	6.0
	0.25 mm	7.3

2.3. Analytical methods

CO_2 emissions were measured in the spring-autumn period from July 13, 2018 to October 25, 2018. Emissions were measured by the chamber method in laboratory conditions in soil samples using a Picarro G2508 laser gas analyzer (Picarro Inc., Santa Clara, CA, USA), which provides simultaneous determination of nitrous oxide (N_2O), methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3) and water (H_2O) with a 5-minute measurement accuracy of < 200 ppb for CO_2 and < 5 ppb for CH_4.

Soil samples were taken in the field in an undisturbed structure in 78.5 cm^3 aluminum bottles and covered with a lid. After sampling, the soil samples were transported to the laboratory, where CO_2 emissions in them were measured. For this, three aluminum bottles without lids were placed in a closed chamber of a gas analyzer with a volume of 1 dm^3, and the gas concentration was measured for 5 min.

The emissions were calculated using MS Excel according to the following equation (equation 1):

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

where:

F_{gas} = Linear flow of the test gas (CO_2) in μmol CO_2 m^{-2} s^{-1};
Δ [Gas] / Δt – the number of gas particles at time t, expressed in μmol mol^{-1} s^{-1};
V – the total volume of the chamber, m^3;
A – the area of the investigated surface, m^2;
ρ – the molar density of air (mol m^{-3}), defined as P / RT, where P is the air pressure, Pa;
R – the universal gas constant, equal to 8.31 Pa $m^3 \cdot mol^{-1}K^{-1}$;
T – air temperature, K.

Table 3. The elemental composition of biochar from *Betula alba*.

Element	Content, %	Content, mg/kg per dry. weight	IBI MPC, mg/kg per dry weight
C	78.130	781.30	
N	0.084	0.84	
O	11.342	113.42	
H	4.044	40.44	
Ca	1.770	17.70	
Na	0.574	5.74	
Mg	0.424	4.24	
K	0.415	4.15	
Si	0.402	4.02	
Fe	0.235	2.35	
Mn	0.151	1.51	
Al	0.141	1.41	
Zn	0.057	0.57	416–7400
S	0.049	0.49	
Ti	0.045	0.45	
P	0.044	0.44	
Cu	0.014	0.14	143–6000
Sr	0.008	0.08	
Cr	0.005	0.05	93–1200
Ni	0.004	0.04	47–420

The reliability of the received flow data was assessed in accordance with the value of the determination coefficient R_2. The values of flows with a determination coefficient of less than 0.96 were not taken into account in the calculations.

The air pressure and temperature indicators required for calculating emissions were determined simultaneously with the concentration measurement in the laboratory using a portable weather transducer Vaisala Weather Transmitter WXT520 (Vaisala, Helsinki, Finland).

3. Results and discussion

According to studies on soils with a heavy granulometric composition, the application of biochar reduces the CH_4 emission well. Thus, in the study of Wu Zhen at al. in a 6-year study on Irragric Anthrosols with a silty clay loam texture, the use of biochar at a dose of 2 $kg \cdot m^{-2}$ reduced CH_4 emissions by 11.2–17.5% [4]. In the study of Lui Jieyun at al. [20], the application of 2.4 $kg \cdot m^{-2}$ biochar on Stagnic Anthrosols reduced CH_4 emissions by 4.3% in the early rice system, by 47.1% in the late rice system, and by 80.9% in the fallow seasons. In the study by Cui at al. CH_4 emissions decreased by 32.1% when 2 $kg \cdot m^{-2}$ of biochar was used for Gleyic Luvisols [21]. It is noted that the application of biochar on soils with a heavy particle size distribution does not have a significant effect on the CO_2 emission. Nevertheless, a significant decrease in CO_2 emissions by 43% in comparison with the control when using 0.5% biochar on silt loam soil is shown in the work of Mukherjee at al. [22].

The measurement of CO_2 emissions during the growing season of 2018 showed a significant decrease in the cumulative CO_2 flux in the variants of the experiment with doses of biochar application to the field without a drainage system. A decrease in the cumulative CO_2 flux by 27.6% was recorded after the first month of application (measurement on July 13–14, 2018) at the site with a biochar application dose of 3 kg·m^{-2} (BC3kg) compared to the experiment without biochar application (BC0) and continued throughout the entire growing season (figure 2). Thus, by the end of the growing season (measurements on October 25, 2018), the cumulative CO_2 flux was 1078.6 CO_2 mg m^{-2} h^{-1} in the experiment variant with biochar at a dose of 3 kg·m^{-2}, which is 28.2% less than the cumulative flux in the experiment variant without adding biochar (1701.9 CO_2 mg m^{-2} h^{-1}). In the variant of the experiment with a biochar application dose of 1 kg·m^{-2}, the cumulative flow was increased by 8.2% compared to the variant of the experiment without biochar and amounted to 1624.6 CO_2 mg m^{-2} h^{-1}.

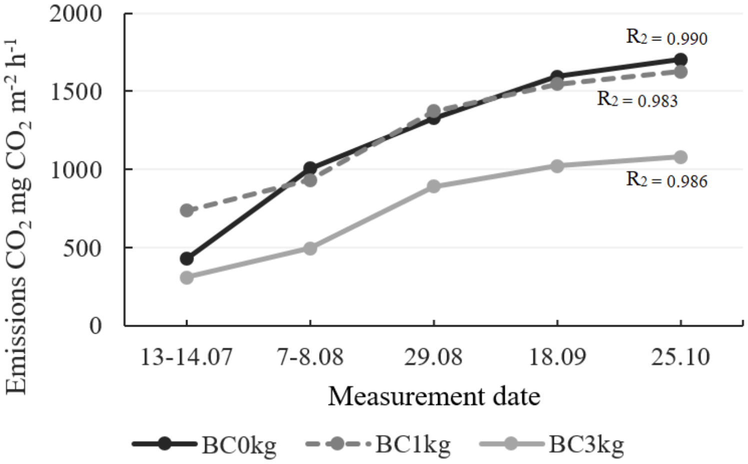

Figure 2. Cumulative CO_2 flux in the field without drainage in the area without biochar (BC0), from 1 kg·m^{-2} (BC1kg), from 3 kg·m^{-2} (BC3kg) for the growing season of 2018.

An increase in the cumulative CO_2 flux was revealed in the field with a drainage system with the application of biochar (figure 3). By the end of the growing season on the site with a biochar application rate of 1 kg·m^{-2} (DBC1kg), the cumulative CO_2 flux increased by 39.4% (1667.1 CO_2 mg m^{-2} h^{-1}) compared to the site without biochar application (DBC0), where the flow value was equal to 1009.7 CO_2 mg m^{-2} h^{-1}. At the site with a biochar application dose of 3 kg·m^{-2} (DBC3kg), the cumulative flow increased by 19.1% (1202.2 CO_2 mg m^{-2} h^{-1}).

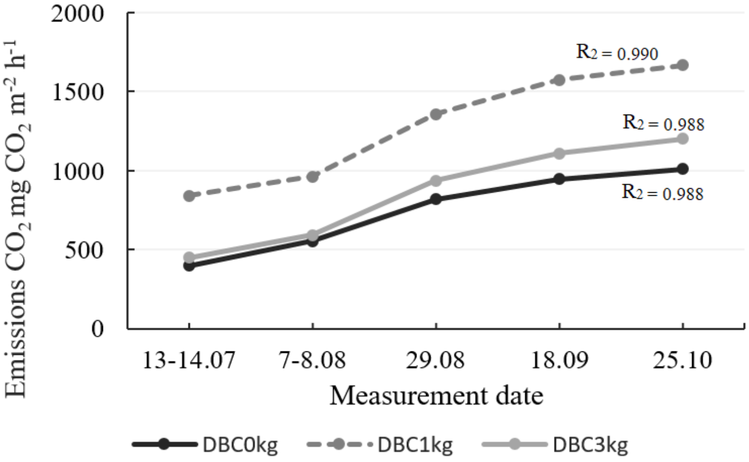

Figure 3. Cumulative CO_2 flux in the field without drainage in the area with biochar (DBC0), from 1 kg·m^{-2} (DBC1kg), from 3 kg·m^{-2} (DBC3kg) for the growing season of 2018.

The value of the cumulative CO_2 flow in the field without a drainage system with a biochar application dose of 3 kg·m^{-2} is close to the value of the cumulative flow in the area without biochar application (control plot) of the field with a drainage system (1078.6 and 1009.7 CO_2 mg m^{-2} h^{-1}, respectively). And vice versa, the value of the cumulative flow in a field with a drainage system at a biochar application dose of 1 kg·m^{-2} is close to the flow value of the control area in a field without a drainage system. It follows that, on the one hand, in a field without a drainage system, biochar affects the CO_2 emission as a drainage system and acts as a meliorant. On the other hand, the application of biochar has a negative effect on the carbon sequestration in the drainage system.

The principle of effect of biochar on the respiratory activity of the soil is based on its pore structure. Many researchers indicate that biochar has a special pore structure (figure 1) [23–24]. Due to the pore structure, biochar sorbs soil moisture [25–26], increases the pore space of the soil and, accordingly, the specific soil surface [1, 27]. An increase in the pore space enhances the microbiological activity [28–29]. An increase in the specific surface area and microbiological activity of the soil leads to an increase in the sequestration capacity of soils, that is, to an increase in the process of carbon fixation in the soil space, which leads to a decrease in the CO_2 flux [13, 22].

The described principle of effect of biochar probably occurs in both experimental fields, however, a strong difference in the initial water-air properties leads to the opposite final effect. In a field without a drainage system, biochar absorbs moisture and releases an equivalent volume of pore space in the soil and thus increases the sequestration capacity of the soil. The drainage system has a good sequestration effect (figure 3). Biochar, which sorbs soil moisture, resists the effect of the drainage system. It tries to retain moisture in the soil space.

The stored moisture tends to flow back into the free pore space of the soil. It is logical that more biochar absorbs more moisture due to the larger number of introduced pores. Therefore, the application of 3 $kg·m^{-2}$ of biochar significantly reduces the sequestration activity in comparison with the application of a dose of 1 $kg·m^{-2}$. However, figure 3 shows that the application of biochar at a dose of 3 $kg·m^{-2}$ significantly less disrupts the action of the drainage system, compared to a dose of 1 $kg·m^{-2}$. Probably, due to the initial identical soil porosity, the reverse redistribution of moisture is not the same when 1 and 3 $kg·m^{-2}$ of biochar are applied. The number of free soil pores surrounding a biochar particle when applying 1 $kg·m^{-2}$ is greater than the number of pores surrounding a biochar particle when applying 3 $kg·m^{-2}$. A large number of surrounding pores have a large specific surface area. The larger the specific surface, the stronger the binding of water and the more it remains in the soil space, respectively, the smaller the specific surface, the more free the bound moisture and more vulnerable to physical and biological processes. In other words, the loss of free soil pore space in a field with a drainage system at a dose of 3 $kg·m^{-2}$ of biochar is less than at a dose of 1 $kg·m^{-2}$. Thus, the increase in the CO_2 flux with the application of 1 $kg·m^{-2}$ of biochar is less than with the application of 3 $kg·m^{-2}$.

It is logical that in order to maintain the carbon balance in the soil, with a decrease in the CO_2 flux, soil carbon should be conserved; accordingly, with an increase in the CO_2 flux, there should be a loss of soil carbon. Thus, the sequestered carbon must either remain in the soil or go into biomass. Therefore, the results of the cumulative flow with the data on plant biomass for the 2018 growing season were compared (during the period, cabbage was grown in the fields with and without a drainage system). It is assumed that an increase in the CO_2 flux would lead to a lower CO_2 content of the biomass and vice versa. Based on the comparison results, the assumption was confirmed (table 4). In the field without drainage system in the area with the biochar application at a dose of 3 $kg·m^{-2}$, the highest average value of plant biomass was recorded as compared to the area without biochar application and the lowest value of the cumulative flow. In a field with a drainage system, at a site with a biochar application at dose of 1 $kg·m^{-2}$, the lowest average value of plant biomass and the highest value of the cumulative CO_2 flux were recorded.

Table 4. Average vegetative biomass (cabbage) for the growing season of 2018 from the experimental plots on the territory of the Primorskaya vegetable experimental station.

Plot	BC0	BC1kg	BC3kg	DBC0	DBC1kg	DBC3kg
Average biomass cabbage, kg	0.520	1.100	1.487	2.473	2.260	2.414

4. Conclusion

The effect of biochar on CO_2 emissions showed a significant decrease in the cumulative CO_2 flux in a field without a drainage system. The biochar application at a dose of 1 $kg·m^{-2}$ decreased the cumulative flow by 4.5% while the dose of 3 kg·m^{-2} decreased it by 36.6% as compared to the site without the biochar application.

A decrease in the CO_2 flux indicates a reclamation effect of biochar. The reason for the reclamation action is the high sorption properties, which affect the sequestration capacity of the soil. In a field with a drainage system, the application of biochar had a negative effect on CO_2 emissions and led to an increase in the value of the cumulative flow by 39.4% in the area with an application dose of 1 kg·m^{-2} and by 16% with an application dose of 3 kg·m^{-2}. It is assumed that the negative effect of biochar is associated with the impossibility of removing moisture from the soil space by the drainage system due to its partial sorption by biochar, which causes deterioration in the water-air state of the soil.

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References

[1]. Sohi S, Lopez-Capel E, Krull E and Bol R 2009 Biochar, climate change and soil: a review to guide future research *CSIRO L. Water Rep*. (Australia: Australia's national science agency) p 64

[2]. Lehmann J, Kuzyakov Y, Pan G and Ok Y S 2015 Biochar and the plant-soil interface *Plant Soil.* **395** 1–5

[3]. Wang C, Shen J, Liu J, Qin H, Yuan Q, Fan F, Hu Y, Wang J, Wei W, Li Y and Wu J 2019 Microbial mechanisms in the reduction of CH_4 emission from double rice cropping system amended by biochar: A four-year study *Biol. Biochem.* **135** 25–63

[4]. Wu Z, Zhang X, Dong Y, Li B and Xiong Z 2019 Biochar amendment reduced greenhouse gas intensities in the rice-wheat rotation system: six-year field observation and meta-analysis *Agr. Forest Meteorol.* **278**

[5]. Wu D, Senbayram M, Zang H, Ugurlar F, Aydemir S, Bruggemann N, Kuzyakov Y, Bol R and Blagodatskaya E 2018 Effect of biochar origin and soil pH on greenhouse gas emissions from sandy and clay soils *Appl. Soil Ecol.* **129** 12–27

[6]. Liu X, Li P and Ma J 2019 Impact of biochar application on yield-scaled greenhouse gas intensity: A meta-analysis *Sci. Total Environ.* **656** 960–76

[7]. Dong X, Singh B P, Li G, Lin Q and Zhao X 2019 Biochar increased field soil inorganic carbon content five years after application *Soil Till. Res.* **186** 36–41

[8]. Hawthorme L, Johnson M S, Jassal R S, Black T A, Grant N J and Smukler S M 2017 Application of biochar and nitrogen influences fluxes of CO_2, CH_4 and N_2O in a forest soil *J. Environ. Manage.* **192** 208–14

[9]. Czekala W, Malinska K, Caceres R, Janczak D, Dach J and Lewici A 2016 Co-composting of poultry manure mixtures amended with biochar – The effect of biochar on temperature and C-CO_2 emission *Bioresour. Technol.* **200** 921–7

[10]. Yang X, Meng J, Lan Y, Chen W, Yang T, Yuan J, Liu S and Han J 2017 Effects of maize stover and its biochar on soil CO_2 emissions and labile organic carbon fractions in Northeast China *Environ. Sci. Pollut. Res.* **24** 8200–9

[11]. Sial T A, Lan Z, Khan M N, Zhao Y, Kumbhar F, Liu J, Zhang A, Hill R L, Lahori A H and Memon M 2019 Evaluation of orange peel waste and its biochar on greenhouse gas emissions and soil biochemical properties within a loess soil *Waste Manage.* **87** 125–34

[12]. Lin Z, Liu G, Cowie A L, Bei Q, Liu B, Wang X, Ma J, Zhu J and Xie Z 2017 Impact of biochar application on yield-scaled greenhouse gas intensity: a meta-analysis *Pedosphere* **27** 248–61

[13]. Rittl T F, Butterbach-Bahl K, Basile C M, Pereira L A, Alms V, Dannenmann M, E Couto G and Cerri C E 2018 Greenhouse gas emissions from soil amended with agricultural residue biochars: Effects of feedstock type, production temperature and soil moisture *Biomass Bioenergy* **117** 1–9

[14]. Mechler M A A, Jiang R W, Silverthorn T K and Oelbermann M 2018 Impact of biochar on soil characteristics and temporal greenhouse gas emissions: A field study from southern Canada *Biomass Bioenergy* **118** 154–62

[15]. Zhang A, Cheng C, Hussain Q, Zhang M, Feng H, Dyck M, Sun B, Zhao Y, Chen H and Wang X Contrasting effects of straw and straw-derived biochar application on net global warming potential in the Loess Plateau of China *Field Crop Res.* **205** 45–54

[16]. Bovsun M, Nesterova O, Semal V, Khokhlova A and Sakara N 2020 Changes in the composition and properties of biochar after one-year application *E3S Web Conf.* **217** 1–9

[17]. *Standardized product definition and product testing guidelines for biochar that is used in soil version 2.1* 2015 (USA: IBI International Standard) p 61

[18]. Rajkovich S, Enders A, Hanley K, Hyland C, Zimmerman A R and Lehmann J 2011 Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil *Biol. Fertil. Soils* **48** 271–84

[19]. *Standard test method for chemical analysis of wood charcoal: ASTM D1762-84* 2007 (United States: ASTM International) p 2

[20]. Liu J, Shen J, Su Y, Ge T, Jones D L and Wu J 2014 Effects of biochar amendment on the net greenhouse gas emission and greenhouse gas intensity in a Chinese double rice cropping system *Eur. J. Soil Boil.* **65** 30–9

[21]. Cui Y, Meng J, Wang Q, Zhang W, Cheng X and Chen W 2017 Effect of straw and biochar addition on soil nitrogen, carbon, and super rice yield in cold waterlogged paddy soils of North China *J. Integr. Agr.* **16** 1064–74

[22]. Mukherjee A, Lai R and Zimmerman A R 2014 Effects of biochar and other amendments on the physical properties and greenhouse gas emissions of an artificially degraded soil *Sci. Total Environ.* **487** 26–36

[23]. Downie A, Crosky A and Munroe P 2009 *Physical properties of biochar* (London: Earthscan Publications Ltd) pp 13–32

[24]. Litvinovich A V, Hammam A M and Bure V M 2016 Empirical models of water-retention capacity of sandy soil, reclaimed by different size fractions of biochar *Agr. Veterin. Animal Sci.* 107–13 (in Russian)

[25]. Asai H, Samson B K, Stephan H M, Songyikhangsuthor K, Homma K, Kiyon Y, Inoue Y, Shiraiwa T and Horie T 2009 Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield *Field Crop Res*. **111** 81–4

[26]. Lehmann J and Joseph S 2009 Biochar for environmental management *Biochar effects on soil nutrient transformations* (London: Earthscan Publications Ltd) pp 251–265

[27]. Van Zwieten L, Singh B, Joseph S, Kimber S, Cowie A and Chan K Y, 2009 Biochar and emissions of non-CO_2 greenhouse gases from soil *Sci. Technol.* 227–49

[28]. Mukhina I M 2017 *Influence of carbonized biomass on fertility parameters of sod-podzolic soils and greenhouse gas emissions* (St. Petersburg: Agrophysical Res. Institute) p 187 (in Russian)

[29]. Grigorian B R, Grigorian A N, Grigorian A N, Kulagina V I, Sungatullina L M, Koltsova T G and Ryazanov S S 2016 Influence of biochar on plant growth, microbiological and physicochemical indicators of low-humus soil under the conditions of a vegetation experiment *Bull. Technol. Univer.* **11** 185–9 (in Russian)