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Environmental assessment of biochar application for remediation of oil-contaminated soils under various economic uses

Tatiana V. Minnikova✉, Sergey I. Kolesnikov
Southern Federal University, Rostov-on-Don, Russia

Abstract

Remediation is an important area of oil-contaminated soil restoration in Russia, since oil refining industry is the major one for Russia and neighbouring countries, and the issues of environmentally effective and economically profitable remediation of oil contamination have not yet been solved. Soils under various economic uses have different surface areas and degrees of soil particles envelopment with oil due to the presence or absence of cultivation, the amount of precipitation and plant litter. The introduction of various substances for remediation into oil-contaminated soils of steppes (arable land), forests, and semi-deserts, considering their differences, gives different results. Biochar is coal obtained by pyrolysis at high temperatures and in the absence of oxygen. The uniqueness of this coal lies in the combination of biostimulating and adsorbing properties. The purpose of the study is to conduct an environmental assessment of biochar application for remediation of oil-contaminated soils under various economic uses. The article compares the environmental assessments of biochar application in oil-contaminated soils with different particle size fraction. The following indicators of soil bioactivity were determined: enzymes, indicators of initial growth and development intensity of radish, microbiological indicators. We found that the most informative bioindicator correlating with residual oil content is the total bacteria count, and the most sensitive ones are the roots length (ordinary chernozem and brown forest soil) and the shoots length (brown semi-desert soil). The use of biochar on arable land and in forest soil (ordinary chernozem and brown forest soil) is less environmentally efficient than in semi-desert soil (brown semi-desert soil). The study results can serve to develop measures and managerial and technical solutions for remediation of oil-contaminated soils under various economic uses.

Introduction

Oil is the most common raw material for fuel production in the world [1]. Despite modern protection systems for tankers and pipelines during oil transportation, the number of accidents has increased significantly over the past couple of years both abroad[1,2] and in Russia[3]. In addition, clean

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[1] Пять крупных экологических аварий 2022 года. URL: https://www.angi.ru/news/2904237-Пять%20крупных%20экологических%20аварий%202022%20года/ (accessed 31.07.2023).

[2] 800 tons of fuel oil spilled into the sea after oil tanker MT Princess Empress sank in the Philippines. URL: https://ecosphere.press/2023/03/09/800-tonn-mazuta-okazalis-v-more-posle-krusheniya-neftyanogo-tankera-mt-princess-empress-na-filippinah (accessed 31.07.2023).

[3] Oil spill in Russian region. URL: https://lenta.ru/news/2023/01/30/razliv/ (accessed 31.07.2023).

soils without an external source of contamination also contain hydrocarbons, which are mainly of autochthonous natural origin [2]. As a result of contamination with oil and oil products, the biological condition of soils deteriorates due to the disruption of environmental and agricultural functions [3]. There are two directions for reducing the level of soil contamination with oil and oil products: 1) contamination prevention; 2) elimination of the contamination consequences with minimal damage to the environment [4-6].

In the Perm Region, monitoring of various sources of environmental pollution with oil and oil products is conducted using unmanned aerial vehicles [7]. For soil cleaning, radical sanitation methods such as removal of the contaminated layer is unacceptable, since it leads to degradation of the topsoil and its alienation. Phytoremediation is one of poorly effective but very gentle methods of restoring the soil condition [8]. The effectiveness of phytoremediation is limited by the high concentration of oil (no more than 1.5 %), soil hydrophobicity, and the need to select plants for each contamination situation [9, 10]. High soil hydrophobicity causes a decrease in plant growth and development due to disruption of water exchange in the cells of both the photosynthetic apparatus and in the stems and root system [11, 12]. Therefore, it is recommended to combine phytoremediation with other types of remediation, such as the introduction of calcium oxide or carbonate encapsulation [13].

It is necessary to evaluate the modern methods of bioremediation of oil-contaminated soils without expensive removal of the upper fertile layer or the use of ineffective phytoremediants [14, 15]. Bioremediation methods involve the use of biostimulants and bioaugmenters, which reduce the oil content and return the soil to an environmental state close to that of before contamination. One of the substances often used for bioremediation of soil contaminated with oil and oil products, heavy metals is biochar [16, 17]. Biochar is mainly produced from agricultural waste (rice and wheat straw, corn and cotton stalks, other remains of grass vegetation), forest waste (wood of various tree species), livestock waste (pig, cow manure), and municipal wastewater sludge. The use of rice husk biochar together with bacterial preparations (BP) in oil-contaminated soil regulates the microbial community succession and increases the number of microorganisms associated with oil degradation at the genus level [18]. Rice husk biochar also contributes to an increase in the number of soil fungi [19]. The application of biochar with compost together with a decrease in the oil content increases the growth and development of wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), white clover (*Trifolium repens* L.), alfalfa (*Medicago sativa* L.), and ryegrass (*Lolium multiflorum* Lam.) [20]. Biochar introduced together with mycorrhiza into contaminated soil had a beneficial effect on the growth and development of clover (*Trifolium arvense* L.) and mallow (*Malva sylvestris* L.) as well as contributed to oil degradation [21]. Biochar obtained from corn was selected as a carrier to immobilize oil-degrading microorganisms: the best particle size fraction was 0.08 mm, and the best immobilization time was 18 h [22]. The application of biochar and rhamnolipid into oil-contaminated swampy soil in Louisiana wetlands (USA) allowed to increase the algae biomass, led to the growth of gram-positive bacteria, actinomycetes, arbuscular mycorrhizal fungi and to a decrease in oil concentration [23]. Despite the advantages of biochar over other substances, its application in remediation of soil contaminated with oil and oil products is not always environmentally rational [24-26]. In remediation with biochar, the soil type and the substance concentration play an important role [27-29]. The application of biochar can both promote remediation and have a toxic effect on soil biota and cause soil alienation [30-32].

The objective is to conduct an environmental assessment of biochar application for remediation of oil-contaminated soils under various economic uses. The following tasks were set: to assess the residual oil content in soils under various economic uses (arable land, forest, and semi-desert) after introducing biochar; to analyse the change in bioindicators of soil condition; to assess the environmental efficiency of biochar in soils after oil contamination.

Methods

To study the biochar efficiency in remediation of oil-contaminated soils under various economic uses (arable land, forest, and semi-desert), the following were considered: ordinary chernozem (Haplic Chernozem Loamic), brown forest (Haplic Cambisols), and brown semi-desert soils (Endosalic Calcisols Yermic) [33] (Table 1). The choice of soil types was due to the fact that in the Rostov Region (ordinary chernozem), in the beech-hornbeam forest of the Republic of Adygeya (brown forest soil), and in the steppes of the Republic of Kalmykiya (brown semi-desert soil) oil and oil products are extracted, processed, or transported [34, 35]. Soil types differ in the land type, vegetation types, particle size fraction, soil reaction (pH), cation exchange capacity (CEC), and organic matter content (C_{org}).

Air-dry soil of each type was sifted through a 2 mm sieve and moistened, and then oil was added to the vegetation vessel at a concentration of 5 % of the soil mass. After the soil was contaminated, biochar was added to it in three concentrations: recommended – 5 %; half the recommended – 2.5 %; twice the recommended – 10 % of the soil mass.

Table 1

Sampling locations and characteristics of uncontaminated soils

Soil type	Coordinates	Sampling location	Land type	pH	C_{org}, %	CEC, mEq/100 g [36]	Particle size fraction
Ordinary chernozem	47°14'17.54"N; 39°38'33.22"E	Rostov Region, Rostov-on-Don, Botanical Garden of the Southern Federal University	Arable land	7.3	7.6	33.6	Heavy loam
Brown forest	44°10'39.76"N; 40° 9'27.47"E	Republic of Adygeya, Maikop district, Nikel village	Beech-horn-beam forest	5.3	1.3	24.3	Heavy loam
Brown semi-desert	46°17'48.65"N; 46°41'40.06"E	Republic of Kalmykiya, Narimanovskii district, Drofinyi village	Semi-desert	6.7	1.0	6.5	Light loam

After incubation of contaminated soils, the residual content of oil and oil products was analysed by infrared spectroscopy using carbon tetrachloride as an extractant (PND F 16.1: 2.2.22-98).

To assess the environmental efficiency of biochar application, the residual content of oil and bioindicators characterizing the environmental state of the soil were studied (Table 2).

Table 2

Methods for assessing the environmental state of oil-contaminated soils after remediation

Bioindicator	Measurement method	Source
Catalase activity (H_2O_2: H_2O_2 – oxidoreductase, EC 1.11.1.6)	Volumetric, assessing the volume of water displaced by oxygen as a result of hydrogen peroxide decomposition upon contact with soil, ml O_2/1 g of soil in 1 min	[37]
Dehydrogenase activity (substrate: NAD(P) – oxidoreductase, EC 1.1.1)	Reduction of triphenyltetrazolium chloride (TTC) to triphenylformazans (TPF) under anaerobic conditions with spectrophotometric termination, mg TPF/10 g of soil in 24 h	[38]
Total bacteria count	Fluorescence microscopy using acridine orange dye at ×40 magnification. Bacterial count, billion bacteria/1 g of soil	[39]
Radish shoots length	After 7 days from the start of the phytotoxic experiment, radish (*Raphanus sativus* L.) shoots length was measured, mm	[40]
Radish roots length	After 7 days from the start of the phytotoxic experiment, radish (*Raphanus sativus* L.) roots length was measured, mm	[40]
Radish germination	Evaluation of radish (*Raphanus sativus* L.) germination after 7 days of the experiment, %	[40]

Based on the results of bioindicator determination, the integral indicator of the biological state of soils (IIBS) was estimated [41]. For the IIBS of ordinary chernozem, the relative values of each indicator were estimated in comparison with uncontaminated soil (control – 100 %). Relative values of this indicator for other experimental variants:

$$B_1 = \frac{B_x}{B_{max}} \cdot 100 \ \%,$$

where B_1 is the relative score of the indicator; B_x is the actual value of the bioindicator; B_{max} is the maximum value of the indicator in the control.

The next stage of estimating the IIBS is summing up the relative values of bioindicators and estimating the average scores:

$$B_{avg} = \frac{B_1 + B_2 + ... + B_n}{N},$$

where B_{avg} is the average assessment score of the indicators; N is the number of indicators.

Final stage of estimation:

$$IIBS = \frac{B_{avg}}{B_{ref}} \cdot 100 \ \%,$$
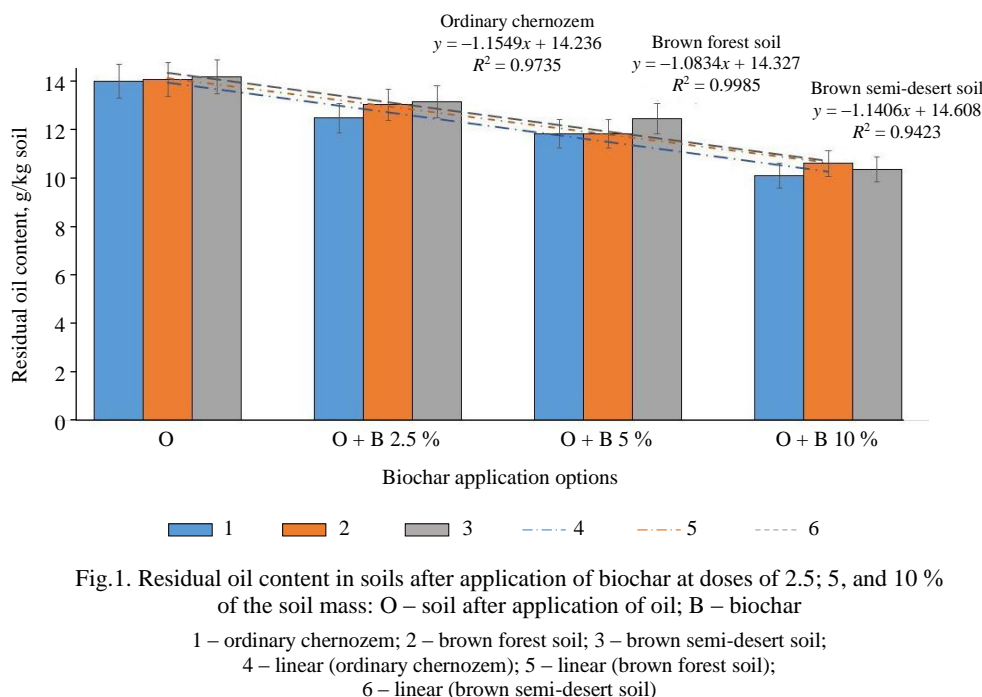
where B_{ref} is the control value averaged over all biological indicators.

Statistical processing of the results was performed in the Statistica 12.0 software. Mean values and variance were determined using variance analysis (Student's t-test).

Discussion of results

The residual oil content (Fig.1) after 30 days of the experiment and biochar application decreased by 10-27 % (ordinary chernozem), 7-24 % (brown forest), and 7-27 % (brown semi-desert). The higher the dose of biochar, the more effective the oil decomposition in the soil.

According to the regression equations and determination coefficients, the closest relationship between oil decomposition and the effect of biochar in different doses corresponds to brown forest soil ($R^2 = 0.9985$), the least close to brown semi-desert ($R^2 = 0.9423$), and ordinary chernozem corresponds to an intermediate value ($R^2 = 0.9735$). The difference in oil decomposition in soils is associated

Fig.1. Residual oil content in soils after application of biochar at doses of 2.5; 5, and 10 %
of the soil mass: O – soil after application of oil; B – biochar

1 – ordinary chernozem; 2 – brown forest soil; 3 – brown semi-desert soil;
4 – linear (ordinary chernozem); 5 – linear (brown forest soil);
6 – linear (brown semi-desert soil)

with the particle size fraction, organic matter content, and reaction of the soil environment [32]. In heavy loamy soils, such as brown forest soil and ordinary chernozem, the biochar application reduces the oil content to a greater extent than in brown semi-desert soil, which has a sandy loam particle size fraction. Thus, the series of biochar efficiency for oil decomposition in soils is as follows: brown forest soil > ordinary chernozem > brown semi-desert soil.

The biological parameters of the studied soils after the biochar application are given in Table 3. After the introduction of oil into ordinary chernozem, the decrease in biological parameters relative to the control was from 34 % (catalase activity) to 99 % (radish shoots and roots length). During the remediation of oil-contaminated brown forest soil, the bioactivity varied from 12 % (dehydrogenase activity) to 74 and 87 % (shoots length and roots length, respectively) relative to the control. In brown semi-desert soil, oil inhibited bioactivity in the range from 11 % (dehydrogenase activity) to 44 % (shoots length). The difference in the bioindicator sensitivity is due to the soil structure: in heavy loamy soils, a significant decrease in the radish shoots and roots length was observed, while in light loamy soil, a decrease was found in the bacteria count and the radish shoots length.

When adding biochar at 2.5, 5 and 10 % of the ordinary chernozem mass, it was noted that with an increase in the biochar concentration, bioactivity increases: catalase activity by 5-19 %; dehydro-genase activity by 0.5-9 %; total bacteria count by 17-50 %; germination by 33-600 %; shoots length by 2-39 times; roots length by 2-54 times compared to the oil-contaminated background.

In brown forest soil, biochar, just like in chernozem, stimulated biological parameters with concentration increase: catalase activity by 8-20 %; dehydrogenase activity by 10-203 %; total bacteria count by 84-133 %; radish germination by 72-105 %; shoots length by 43-156 %; roots length by 73-274 % compared to oil-polluted background. In brown semi-desert soil, biochar stimulated catalase activity by 7-31 %; dehydrogenase activity by 3-8 %; total bacteria count by 11-18 %; germination by 15-28 %; shoots length by 20-31 %; roots length by 5-18 % compared to oil-polluted background.

Table 3

Change in biological parameters after adding biochar, abs. units

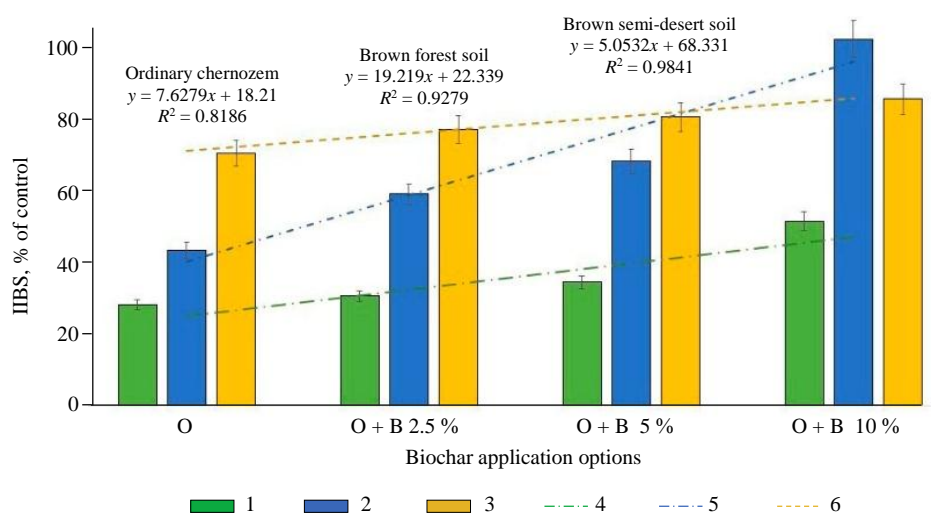| Variants	Catalase activity, ml O_2/1 g per 1 min	Dehydrogenase activity, mg TPP/10 g per 24 h	Radish (*Raphanus sativus* L.) germination, %	Radish (*Raphanus sativus* L.) shoots length, mm	Radish (*Raphanus sativus* L.) roots length, mm	Total bacteria count, billion/1 g of soil
Ordinary chernozem						
Control	7.4	29.9	84	24.7	50.7	1.60
O	4.9	18.6	6	0.2	0.3	0.60
O + B 2.5 %	5.1	18.7	8	0.5	0.9	0.70
O + B 5 %	5.6	20.1	12	1.5	1.4	0.75
O + B 10 %	5.8	20.3	42	8.2	16.6	0.90
Brown forest soil						
Control	6.4	9.8	90	27.1	44.2	1.20
O	3.8	8.7	36	7.0	5.8	0.48
O + B 2.5 %	4.1	9.6	62	10.1	10.2	0.89
O + B 5 %	4.3	10.7	70	13.1	13.8	1.08
O + B 10 %	4.6	26.5	74	18.1	21.9	1.13
Brown semi-desert soil						
Control	2.1	18.9	86	25.0	27.4	1.00
O	1.3	16.9	66	14.0	24.2	0.62
O + B 2.5 %	1.4	17.4	76	16.8	25.4	0.69
O + B 5 %	1.52	17.8	78	18.3	26.9	0.70
O + B 10 %	1.77	18.3	85	18.4	28.5	0.73

Fig.2. Change in the integral indicator of the biological state of soils
after the biochar application in different doses

1 – ordinary chernozem; 2 – brown forest soil; 3 – brown semi-desert soil;
4 – linear (ordinary chernozem); 5 – linear (brown forest soil);
6 – linear (brown semi-desert soil)

During remediation of ordinary chernozem and brown forest soil, a decrease in soil phytotoxicity was observed due to an increase in the length of radish shoots and roots by 15-399 and 27-543 times, respectively, compared to the oil-contaminated background. This effect is probably due to the porous structure of biochar, which allows partial adsorption of oil and stimulation of its decomposition, as well as improvement of the soil structure, which is important for the growth and development of the root system of plants [17, 31]. However, stimulation of phytotoxic indicators relative to oil-contaminated soils did not allow achieving the control level, which is an indicator of the state of soils with a heavy loamy composition under oil contamination. In brown semi-desert soil, control values were achieved already at a biochar dose of 5 % for germination and roots length of radish.

According to Table 3, the integral indicator of the biological state was determined for each soil type after biochar application (Fig.2). According to estimations, in the soil without remediants, the IIBS of ordinary chernozem, brown forest, and brown semi-desert soils is 70, 55 and 27 % relative to the control. With the application of 2.5, 5, and 10 % biochar, the IIBS of ordinary chernozem changed by 46-68 % relative to the control. After applying biochar, the IIBS value of chernozem close to the control was not observed. The IIBS of brown forest soil increased at biochar doses of 2.5 and 5 % by 16 and 25 % relative to the oil-contaminated background (39 and 29 % lower than the control, respectively). At a biochar dose of 10 %, the IIBS of brown forest soil reached the control. In brown semi-desert soil, the IIBS value increased proportionally to the increase in the biochar dose of 2.5, 5, and 10 % by 20, 16, and 11 % below the control, respectively.

According to the regression equations presented in Fig.2, it is obvious that the change in the IIBS of each soil after remediation correlated differently with the oil content: from the highest correlation degree for brown semi-desert soil ($R^2 = -0.98$) to the lowest one among the three soils for ordinary chernozem ($R^2 = -0.82$). According to the efficiency of biochar application taken from the IIBS value, a series of soils was compiled: brown semi-desert soil > brown forest soil > ordinary chernozem.

The information content of each indicator and each soil type was assessed based on the strength of the correlation between the residual oil content and the value of all bioindicators (Table 4).

All bioindicators in the remediation of ordinary chernozem are informative ($r > 0.90$), but the most informative is the total bacteria count ($r = -1.00$). In the remediation of brown forest soil, the most informative indicator is the catalase activity ($r = -1.00$), and the least informative is the dehydrogenases activity ($r = 0.04$). For brown semi-desert soil, the most informative bioindicator is the total bacteria count ($r = -0.99$), and the least informative is the radish roots length ($r = -0.51$).

Table 4

Coefficient *r* of correlation between the bioindicator value and the residual oil content

Catalase activity	Dehydrogenase activity	Radish germination	Radish shoots length	Radish roots length	Total bacteria count
Ordinary chernozem					
–0.98**	–0.99**	–0.97**	–0.99**	–0.99**	–1.00**
Brown forest soil					
–1.00**	0.04	–0.80*	–0.95**	–0.98**	–0.64*
Brown semi-desert soil					
–0.96**	–0.88**	–0.72*	–0.96**	–0.51	–0.99**

Notes:
Significance of difference from control: * *p* < 0.05; ** *p* < 0.001.
■ The most informative indicator.
■ The least informative indicator.

For remediation of oil-contaminated ordinary chernozem and brown semi-desert soil with biochar, the most informative indicator is the total bacteria count, and for brown forest soil, the most informative indicator is catalase activity. Differences in the informativeness of the indicators for each soil type are due not only to their structure, but also to the content of organic matter and the soil environment reaction [42]. Among the studied samples, only in brown forest soil the soil environment reaction is acid (pH = 5.7), while in brown semi-desert soil (pH = 6.7) and ordinary chernozem (pH = 7.3) it is alkaline (see Table 1). The soil bacteria count is an informative bioindicator of oil-contaminated soil remediation [43].

The sensitivity of bioindicators was assessed by the difference with the control: the higher the value is than the control, the more sensitive the soil is to remediation (Table 5). The greater the difference from oil-contaminated soil without remediants, the more sensitive the indicator. Thus, for remediation of ordinary chernozem and brown forest soil with biochar, the most sensitive bioindicator is the roots length, and the least sensitive is the dehydrogenases and catalase activity.

Table 5

**Relative values of bioindicators for each soil type (averaged by biochar doses),
% of oil-contaminated soil without remediants**

Catalase activity	Dehydrogenase activity	Radish germination	Radish shoots length	Radish roots length	Total bacteria count
Ordinary chernozem					
113	106	344	1,697	2,104	131
Brown forest soil					
113	179	191	195	261	214
Brown semi-desert soil					
117	106	121	127	111	114

Notes:
■ The most informative indicator.
■ The least informative indicator.

For remediation of brown semi-desert soil, the most sensitive bioindicator is shoots length, and the least sensitive is dehydrogenase activity. Brown semi-desert soil of the Chernozemel'skii district of the Republic of Kalmykiya, when contaminated with fuel oil and kerosene at a rate of 2.5 % of the soil mass, stimulated the growth of radish shoots and roots [44]. It was also previously determined that the combined treatment with biochar and rhamnolipid has the lowest ecotoxicity for plants and algae when used for remediation of oil-polluted wetlands [23].

The most sensitive indicator in the remediation of oil-contaminated ordinary chernozem (arable land, steppe soil) and brown forest soil (forest soil) with biochar is the radish roots length, and in brown semi-desert soil (semi-desert) – the radish shoots length.

The study results are important since thousands of hectares of soil are contaminated with oil and oil products every year due to various economic uses. The application of a single concentration of biochar for all types of soil is environmentally ineffective. The use of biochar for cleaning oil-contaminated soil depends on the soil type, the natural material from which the biochar is made, and the contamination level [45]. When remediating oil-contaminated soils with biochar, in addition to oil concentration, it is necessary to consider the agroclimatic (air temperature, amount of precipitation, wind speed), agrochemical (N content), and physicochemical parameters of the soil (humus, pH, particle size fraction, BOD, COD, easily soluble salt content). Biochar, due to the adsorbent properties, can be used in any climatic zone, since the adsorption rate does not depend on the temperature and moisture content of the soil [46-48]. Biochar as a biostimulant is more effective in soils formed in climatic conditions with a sufficient number of sunny days and precipitation, such as in soils of the steppe and forest zones.

The use of biochar is inextricably linked with the soil type (ordinary chernozem, brown forest, chestnut, brown semi-desert, solonchak, etc.) and the type of agricultural use (steppe, forest, and semi-desert). In the steppe zone of Russia (for example, in the Rostov Region and Krasnodar Territory), arable and virgin soils predominate, represented by various chernozems and chestnut soil subtypes, with a heavy loamy particle size fraction, high and medium humus and nitrogen content in the soil, and high soil buffering. As a result, in case of oil contamination of such soils, biochar application is effective, and the efficiency increases in combination with microbial preparations and humic substances [49-53]. The degradation of petroleum hydrocarbons in forest soils is influenced by the carbon and nitrogen ratio, which promotes the development of native microbiota, including oil-degrading bacteria [54-56]. The use of biochar for the remediation of forests and forest-steppes, as in the Republic of Adygeya, allows stimulating native microbiota due to the carbon introduced into the soil. The application of biochar in semi-desert soils, for example, in the Republic of Kalmykiya and the Astrakhan Region, is less effective, since it is directly related to the light particle size fraction of the soils, the virtual absence of vegetation in the soil cover, and the low content of humus and nitrogen. Therefore, the most sensitive bioindicator in the remediation of brown semi-desert soil is not the roots length, as in steppe and forest soils, but the radish shoots length. The greater sensitivity of shoots length is associated with the greater number of sunny days in the region. Thus, the application of biochar for oil contamination remediation and environmental restoration of the soil helps to reduce the pollutant concentration and is of great importance for the sustainable development of plants.

The informativeness of the bioindicator in case of contamination by oil and oil products is important first of all, since the connection between the amount of decomposed oil and the response of the bioindicator is considered [53, 57, 58]. The activity of microorganisms (fungi and bacteria) is one of the most informative, but not the most sensitive indicators [59]. The bioindicator sensitivity is determined by the indicator stimulation relative to the control. In case of oil contamination, the sensitivity is judged by the ratio of the bioindicator and the oil-polluted background, as well as the control. The use of microbiological preparations containing bacteria, fungi, and algae, i.e. microbial consortia, is most effective [60]. In case of oil contamination of sod-podzolic, light-gray, sod-carbonate, dark-gray, and floodplain soils, phytotesting methods (garden cress (*Lepidium sativum* L.), soft wheat (*Triticum aestivum* L.), Siberian spruce (*Picea obovata* Ledeb.), and Scots pine (*Pinus sylvestris* L.) observed the greatest resistance to oil contamination in floodplain soil, and the greatest vulnerability in sod-carbonate and light-gray soils [61]. In some cases, despite the set of measures such as collection and removal of spilled oil, the use of specialized oil extraction units, the application of nitrogen fertilizers, loosening and phytoremediation, the oil content in peat-gley soil is not reduced sufficiently and is dangerous for the surrounding ecosystem [62]. The application of biochar inoculated with

Bacillus and *Paenibacillus* microorganisms is also effective with preliminary BP inoculation in biochar – stimulation of dehydrogenase activity by 27 % of the background value. The most informative bioindicators of the soil are obtained when biochar is applied with *Bacillus* and *Paenibacillus*. Their application stimulates catalase activity, the total bacteria count in oil-contaminated chernozem, and increases the barley roots length, showing the greatest sensitivity [63].

Conclusion

The application of biochar for remediation of oil contaminated soils under various economic uses has different environmental efficiency. The oil content after biochar application decreases in all soils, regardless of the type of economic use. The most sensitive bioindicators for biochar remediation of arable land and forest soil are the roots length, and for semi-deserts, the shoots length. The most informative indicators for biochar remediation of oil-contaminated ordinary chernozem and brown semi-desert soil are the total bacteria count, and for brown forest soil, the catalase activity. From the point of view of environmental efficiency assessed by the integral indicator of the biological state of soils, the application of biochar on arable land and in forest soil (ordinary chernozem and brown forest soil) is less environmentally efficient than in semi-deserts (brown semi-desert soil). The obtained results serve to develop measures and managerial and technical solutions for the remediation of oil-contaminated soils under various economic uses.

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Authors: **Tatiana V. Minnikova,** *Candidate of Biological Sciences, Leading Researcher, loko261008@yandex.ru, https://orcid.org/0000-0002-9453-7137* (*Southern Federal University, Rostov-on-Don, Russia*), **Sergey I. Kolesnikov,** *Doctor of Agricultural Sciences, Head of Department, https://orcid.org/0000-0001-5860-8420* (*Southern Federal University, Rostov-on-Don, Russia*).

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