Effect of various doses of birch-derived biochar on the growth of *Helianthus annuus* L.

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Abstract. Although biochar (BC) is expected to improve soil properties and plant growth, few studies have confirmed its effect on *Helianthus annuus* L. (sunflower). The effects of four different concentrations of birch-derived BC (2.5, 5, 7.5, and 10%) on the biometric growth parameters of sunflower were studied in a 60-day pot-scale experiment. In addition, the physicochemical properties and elemental composition of the birch-derived BC and peat substrates were examined. It is noted that birch-derived BC was characterized by a slightly acidic pH (about 6.4), lower electrical conductivity and 3.4 times higher water-holding capacity compared to the control substrate. Moreover, the percentage of carbon in BC was 1.4 times higher, while the content of hydrogen and oxygen, on the contrary, was lower in 1.5 and 2.0 times than in the control substrate. In most cases, adding BC to the peat substrate improved *H. annuus* growth parameters such as shoot height, root length, leaf area, as well as total fresh and dry biomass. The best results were obtained by adding 5% BC, which had a positive effect on all biometric parameters of *H. annuus* plants, while 10% BC had the least impact.

1 Introduction

The demand for food increases as the world's population grows. Experts predict that the world's population will grow to 50% by 2050. Therefore, increased food production is required to meet the growing demand of the population [1, 2]. However, rapid climate change, including global warming and the emergence of hazardous environmental factors both abiotic and biotic, is severely limiting global crop production [3, 4]. As a result, increasing production per unit area and gradually improving agricultural productivity are two promising approaches to ensuring food security for the world's expanding population. In this regard, the search for natural components for the development of environmentally friendly biological fertilizers is relevant [5]. The use of biochar obtained from various plant wastes in the agricultural sector opens broad prospects [6, 7].

Biochar (BC) is a carbon-rich, porous material formed through the thermal decomposition of biomass, such as plant residues, agricultural waste, or wood, under controlled oxygen-

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limiting conditions. As a result, this method is referred to as the pyrolysis technique, and it works by heating biomass to high temperatures while excluding or removing almost all oxygen. The end result is stable charcoal with a well-structured network of pores, also known as BC [8].

At present, global research is being conducted to determine the potential benefits of using BC to increase crop productivity and, thus, food security [6, 7, 9]. Besides, BC is consistent with modern green development concepts because it promotes agricultural sustainability, helps to maintain ecosystem balance, and reduces soil pollution [10]. It has been demonstrated that applying BC made from birch to arable soil impacts the pH as well as its capacity to retain moisture and nutrients. Because of its high porous ratio, high functional group, and high surface area, birch wood-cleaved biochar can greatly increase plant yields even at low dosages [11].

The sunflower (*Helianthus annuus* L.) is a significant and third-largest oilseed crop after soybean and rapeseed, grown in many parts of the world [12, 13]. Sunflower achenes contain 38–68% oil, ready for human consumption as food. Sunflower oil is used in the food and soap industries and for the production of varnish and paint. Sunflower oilcakes and oilseed meal provide concentrated livestock fodder. Livestock is fed with thrashed sunflower anthodia and with the silage from sunflower plants harvested while they were blossoming [12]. Sunflower productivity has been declining globally over the last decade, owing primarily to lower resource use efficiency, extreme climatic conditions, and increased pest infestations and diseases caused by imbalanced (N) fertilizer application [14]. Sunflowers are usually tall plants; the height of some cultivated varieties reaches 150–200 cm. Climate and soil conditions have a significant impact on plant height, as do biotic and abiotic stress and poor soil nutrition. As with plant height, the primary yield trait, head diameter, is highly dependent on environmental factors [15]. Cultivated sunflowers typically take 60–70 days to flower and 80–100 days to reach physiological maturity [16]. Sunflowers tolerate biotic and abiotic stresses such as drought, salinity, low temperatures, frost, poor soil conditions, etc. This is due to its extensive root system as well as the high succulence of its leaves, which results in sodium sequestration, especially during salt stress [15].

The positive effect of BC on the growth characteristics of plants was shown by different researchers [11, 17]. However, it has been noted that the effects of BC can vary depending on the dose, soil type, granulometric composition, pH value, and other factors [18].

This study aims to evaluate the effects of four different concentrations of birch-derived biochar (2.5, 5, 7.5, and 10%) on the biometric growth parameters of *H. annuus*, such as the number and area of leaves, shoot height, root length, as well as fresh and dry biomass, in order to determine the optimal doses of BC for this important sunflower crop.

2 Materials and methods

2.1 Materials

Sunflower plants (*H. annuus* variety Yenisei) were selected as the subject of study. The ultra-early ripening large-fruited sunflower variety Yenisei for oilseed and confectionery purposes was created at the Krasnoyarsk Research Institute of Agriculture (Krasnoyarsk, Russia) by the method of individual selection against a harsh background infected with broomrape, using the source material from the lines of the Federal Scientific Centre “All-Russian Research Institute of Oilseeds named after V. S. Pustovoit” and local populations of sunflower varieties, with subsequent selection of selected plants for certain economic traits and their directed cross-pollination and evaluation of their offspring. Ecotype: Central Russian. It is distinguished by its consistent yield and increased manufacturability, as well as resistance to drought, spring frosts, lodging, shedding, broomrape, and rust. Distributed throughout Siberia, the Urals, and Russia's Volga region. It matures biologically in 76–78 days and harvests in 90–95 days. The plant grows to a height of 130–150 cm, with medium-sized stems that are resistant to lodging and excellent foliage. The basket is thin and has a diameter of 20–25 cm. The weight of 1000 seeds is 90–100 g, with 25–28% husk and 46–48% oil. The achenes are black-and-grey striped, elongated, and large. According to the State Commission for Variety Testing, the Yenisei variety ranks first in terms of clean kernel yield during hulling (90%), ensuring high quality oil and cake production while also expanding the possibilities of using sunflower in the confectionery industry [19, 20]. The tested BC was made of birch wood by a domestic manufacturer (Novosibirsk, Russia).

2.2 Methods

A pot-scale experiment was conducted on growing sunflower plants from seed on a peat substrate supplemented with different doses of BC over two spring months (April and May). Sunflower seeds of the same shape and size were soaked for 24 hours before being planted in 0.5 L pots with peat-containing soil (PS) supplemented with 2.5, 5, 7.5, and 10% BC (*v/v*), which had previously been homogenised to powder with a mortar and pestle. The pots were initially covered with film to create a warm environment for germination; however, the cover was removed once germination had occurred. Plants were grown in natural light and at room temperature (24 ± 3°C) for 60 days. The experiment was carried out in six biological replicates. Standard methods were used to measure biometric characteristics such as average shoot height, leaf number, root length, and fresh and dry biomass in aboveground and underground plant organs. Shoot length and leaf area changes were monitored on a regular basis throughout the plant's life cycle. To measure leaf area during growth dynamics, 5–8 leaves from each plant were photographed with a ruler as a marker and processed using the JMicroVision 1.2.7 software. The physicochemical parameters and elemental composition of homogenised BC and peat substrates were determined. The pH and electrical conductivity (EC) were measured using a pH meter/conductometer ("Hanna Instruments", Germany). The water-holding capacity (WHC), moisture content, and ash content of BC and the control substrate were measured using standard methods [21]. Elemental composition (CHN/O) was determined using the elemental analysers CHN PE 2400 (Perkin Elmer Instruments, USA) and EA3000 (Euro Vector Instruments, Italy). The total nitrogen content was determined with the Kjeldahl method [22]. Following wet digestion with 70% nitric acid, the calcium content was measured using a Varian AA240FS atomic absorption spectrometer (Varian Australia Pty Ltd, Australia).

All statistical analyses were executed using MS Excel 2016 and Statistical 13.0. The data presented in the table and figures are the mean values (Means) and standard errors (SE) from four replicates for physicochemical parameters and six replicates for biometrical measurements. The significant difference between the treatments was determined using a one-way ANOVA, followed by Tukey's test. Different letters indicate a significant difference between treatments at $p < 0.05$.

3 Results and discussion

Birch-derived BC had a slightly acidic pH (around 6.4) and a lower electrical conductivity than the control PS (Table). BC had a water-holding capacity 3.4 times that of PS and 6–10 times that of most known soils [23]. Furthermore, large pores and internal surface areas aid in the absorption and adsorption of plant-beneficial minerals and nutrients from the soil [24]. Before being used in the experiment, the BC had 47 times less moisture content than the PS. BC is well known for having a very large surface area, which helps in absorbing nutrients and toxic components such as heavy metals and some organic pollutants from soil [25, 26]. Because of its high-water holding capacity, optimal pH, and large surface area, BC is commonly used as a carrier material for biofertilizer production [26]. The percentage of carbon in BC used in the experiment was 1.4 times higher than in the PS, while the content of hydrogen and oxygen, on the contrary, was lower in 1.5 and 2.0 times, respectively. The C/H ratio was 18.8 and 9.1, while the C/O ratio was 4.3 and 1.6, respectively, according to BC and PS. Total nitrogen concentrations in BC and PS were relatively low, while calcium concentrations were quite high (Table).

Table. 1. The physicochemical parameters and elemental composition of birch-derived biochar (BC) and peat-containing substrate (PS) used in a pot-scale experiment with *H. annuus* plants.

Parameter	**BC**	**PS**	**Elemental composition (%)**	**BC**	**PS**
pH (H_2O, 1:5)	6.38 ± 0.09	6.65 ± 0.06	Carbon	76.92 ± 2.87	56.50 ± 2.13
EC (μS/cm)	273.79 ± 1.21	714.52 ± 1.32	Hydrogen	4.10 ± 0.31	6.18 ± 0.17
WHC (%)	265.4 ± 4.27	78.70 ± 3.12	Oxygen	17.95 ± 2.66	36.43 ± 0.87
Moisture content (%)	2.46 ± 0.21	115.72 ± 1.04	Nitrogen	0.15 ± 0.03	0.31 ± 0.01
Ash content (%)	0.91 ± 0.12	19.80 ± 0.45	Calcium	6.27 ± 0.24	3.96 ± 0.14

The pot-scale study found that the addition of birch-derived BC accelerated seed germination compared to PS. The application of BC had no significant effect on the shoot height of *H. annuus* in the early stages of growth (Fig. 1A). However, after 25 days of plant vegetation, BC significantly increased the shoot height of sunflowers. Plants at 7.5% BC treatment had the greatest height, reaching a peak (71 cm) after 60 days of growth (1.4 times higher compared to control, Fig. 1A).

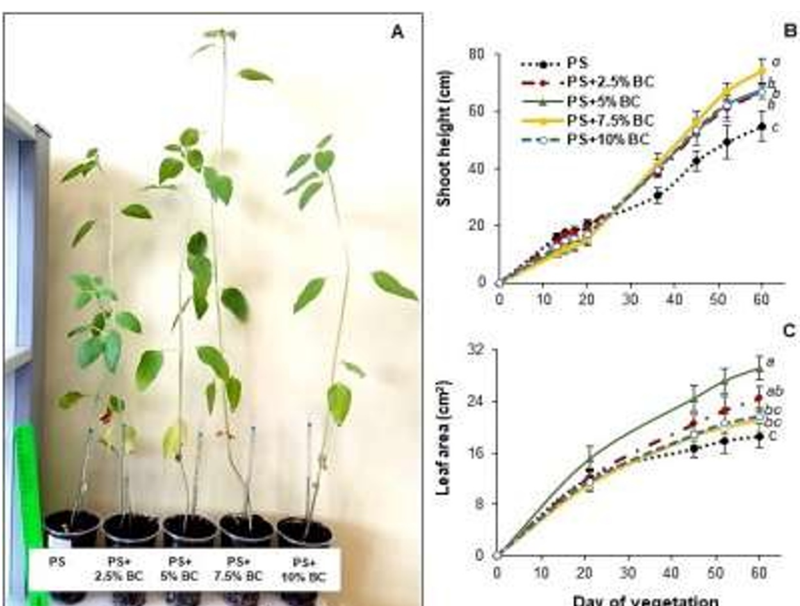

Fig. 1. Sunflower (*H. annuus* ver. Enisey) appearance (A), shoot height (B) and leaf area (C) after 60 days of growing at different concentrations of birch-derived biochar (BC). PS – peat substrate. The presented data are Means ± SE. Different letters indicate significant difference between treatments at $p < 0.05$ according to Tukey's test.

As for the sunflower leaf number, there was no significant effect when BC was added. The number of leaves was almost equal to 12.3 ± 0.22, with slight differences at 5% and 7.5% BC concentrations, as shown in Fig. 2A. For the roots of *H. annuus* plants, the application of BC resulted in a significant increase in their length, especially when applying biochar at a concentration of 5%, as the root length reached approximately 49 cm after 60 days of growth (Fig. 2B). This value exceeded the length of the roots in PS by 2.3 times.

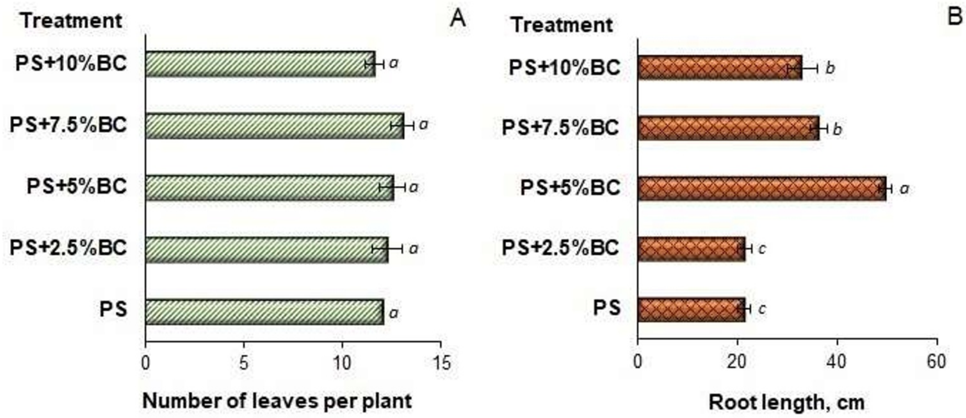

Fig. 2. The leaf number (A) and root length (B) of *H. annuus* after 60 days of growing at different concentrations of birch-derived biochar (BC). PS – peat substrate. The presented data are Means ± SE. Different letters indicate significant difference between treatments at $p < 0.05$ according to Tukey's test.

The addition of 5% BC resulted in significantly increased total biomass in roots and shoots, followed by 7.5% BC > 2.5% BC > 10% BC ≥ Control (Fig. 3). The fresh biomass of *H. annuus* at 5% BC was 1.2 times greater compared to the control (Fig. 3A). A similar pattern was observed for the total dry biomass of shoots, with only slight variations in the total dry root biomass (Fig. 3B). Obviously, the use of BC at a concentration of 5% improved the physicochemical properties of the soil and promoted plant growth, providing a favourable water-air and nutrient regime. Previously, when studying the effects of different concentrations (2.5, 5, 7.5, and 10%) of birch-derived BC on the growth parameters of *Phacelia tanacetifolia* in pot experiment, it was shown that the addition of BC to the soil in most cases had a positive effect on root and shoot length and biomass, as well as leaf area [24]. The best results were observed when BC was added at concentrations of 7.5%, whereas the least effect was observed at 2.5%.

Adding BC to agricultural soil improves its structure. As a result, the physiological, chemical, and biological characteristics of the soil are enhanced, which helps to enhance its capacity to absorb nutrients [17, 18]. An increase in crop yield or overall productivity of different plant species at BC application by improving the physical, chemical, and biological properties of the soil was also reported by other authors [11, 17, 18, 27]. When BC is added to the soil, it stimulates microbial activity, soil agglomeration, and fungal growth. This was confirmed by Jones et al. [28], who noted that using a higher concentration of BC led to an increase and improvement in the growth of *H. annuus*. These results found that using birch-derived BC improved the physical and chemical properties of the soil while also assisting *H. annuus* in their biometric growth parameters by retaining more water and nutrients from the soil.

In general, increasing the amount of birch wood-derived BC from 2.5% to 7.5% improved the growth parameters of H. annuus, which then stabilised. The use of 5% birch wood-derived

BC most likely improved the physical and chemical properties of the soil while also encouraging plant growth by providing adequate water, air, and nutrients (NPK).

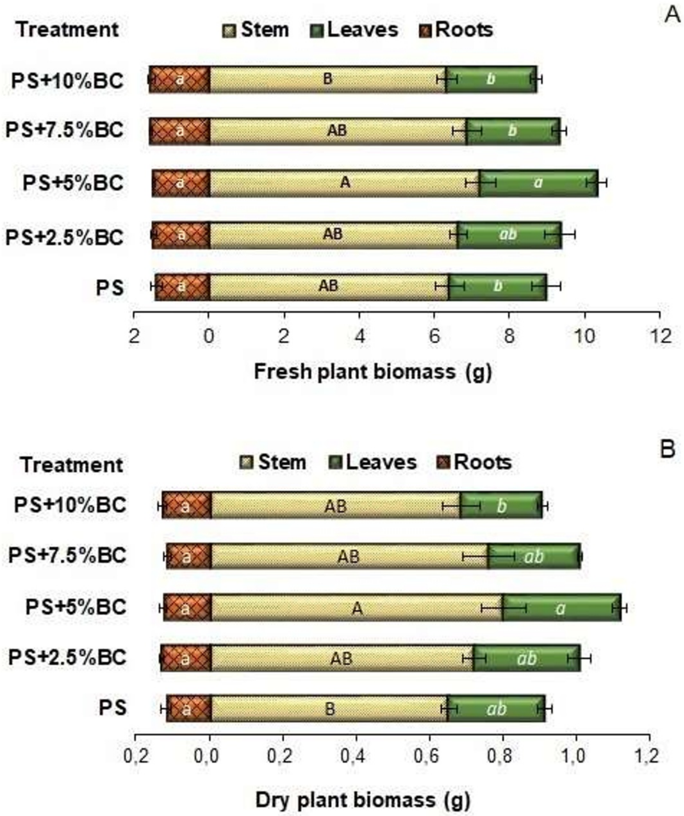

Fig. 3. Fresh (A) and dry (B) biomass of *H. annuus* organs after 60 days of growing at different concentrations of birch-derived biochar (BC). PS – peat substrate. The presented data are Means ± SE. Different letters indicate significant difference between treatments at $p < 0.05$ according to Tukey's test.

4 Conclusion

This study concludes that adding birch wood-derived biochar (BC) to the soil improved all *Helianthus annuus* growth parameters, such as shoot height, root length, leaf area, as well as total fresh and dry biomass of the plant's organs. The best results were obtained by adding 5% BC, which had a positive effect on all biometric parameters of sunflower plants, whereas 10% concentration had the least impact. However, more in-depth research is needed to understand the *H. annuus* plant's response to different types and concentrations of BC, as well as the rate of use, which must be thoroughly evaluated in order to better understand the mechanisms of BC action on all growth parameters of the sunflower. Besides, the future research should focus on optimizing BC preparation conditions based on soil type and crop types. It might also make it easier to apply BC widely and in various environmental settings.

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