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Sunflower Husk Biochar as a Key Agrotechnical Factor Enhancing Sustainable Soybean Production

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Abstract: Climate change has a decisive impact on the physical parameters of soil. To counteract this phenomenon, the ongoing search for more effective agri-technical solutions aims at the improvement of the physical properties of soil over a short time. The study aimed to assess the effect of biochar produced from sunflower husks on soil respiration (SR), soil water flux (SWF), and soil temperature (ST), depending on its dose and different soil cover (with and without vegetation). Moreover, the seed yield was assessed depending on the biochar fertilization. Field experiments were conducted on Calcaric/Dolomitic Leptosols (Ochric soil). SR, ST, and SWT were evaluated seven times in three-week intervals during two seasons, over 2018 and 2019. It was found that the time of biochar application had a significant effect on the evaluated parameters. In the second year, the authors observed significantly ($p < 0.005$) higher soil respiration (4.38 µmol s^{-1} m^{-2}), soil temperature (21.2 °C), and the level of water net transfer in the soil (0.38 m mol s^{-1} m^{-2}), compared to the first year. The most effective biochar dose regarding SR and soybean yield was 60 t ha^{-1}. These are promising results, but a more comprehensive cost-benefit analysis is needed to recommend large-scale biochar use at this dose.

Keywords: biochar; sunflower husk; soil respiration; soybean

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1. Introduction

Soil respiration is an important indicator of soil fertility [1,2]. It includes diversified proportions of both autotrophic (root respiration) and heterotrophic components (microbial and soil fauna respiration), depending on soil type and growing season. The source of CO_2 emitted to the atmosphere from the soil surface is mainly root respiration, as well as decomposition of some root residues, soil organic matter, and plant litter [3,4]. The heterogeneity of the vegetation cover and physical properties of the soil contribute to the spatial variability of soil respiration [5,6]. Soil respiration also depends on the adopted farming system [7,8]. Many researchers argue that the farming system directly affects CO_2 emissions in soil and the content of C, and thus, the impact on global warming [9–11]. Switching from traditional to conservation tillage, including no-tillage (NT) cultivation, can reduce CO_2 emissions [12]. Soil management and changes in organic matter content are among the factors controlling CO_2 emissions [13]. Hence, it seems that determining the adaptability of the soil to the changing climatic conditions—reduced precipitation and temperature increase—would allow for safe and optimized soil management to ensure a higher yielding of plants while reducing CO_2 emissions. Kong et al. [14] proved the relationship between soil respiration, its temperature, and the amount of organic matter in the soil in the form of straw. The authors showed that straw retention in the soil is an effective method of conserving soil water and increasing carbon levels by reducing soil respiration. These studies are important in terms of the large-scale use of biochar as a source of cheap organic matter needed to improve soil retention properties. However, various scientific communities have thus far been unable to indicate the type of biomass that would indisputably and effectively, in a relatively short time, stabilize the physical parameters of the soil, as highlighted in previous studies by Liu et al. [15] and Ameloot et al. [16]. There are many sources of biomass, including wood and its waste, crops and their waste, municipal waste, food processing waste, as well as aquatic plants and algae [17–19]. Among the mentioned biomass sources, agricultural waste and energy crops are described as good precursors for the production of biogas, biofuel oil, and biodiesel [20,21]. A by-product of sunflower oil extraction from seeds demonstrates several benefits and possibilities in terms of biofuel production, especially bio-diesel [22]. In the past, the use of sunflower as a source of biomass was limited due to the unidirectional sales trend, mainly as animal feed. Recent attempts to diversify the use of sunflower in the energy industry have focused on the use of the husk as a raw material for the production of biofuels and other valuable chemical products. Sunflower husks are a promising alternative biomass source, offering numerous benefits and opportunities in biofuel research, in particular, in the production of biodiesel, biogas, and biochar [20,23]. Sunflower husks consist mainly of fibrous substances, nitrogen-free extractive proteins, oil, and ash. Its structural composition (cellulose, hemicellulose, and lignin) is diversified, impacted by environmental factors. On the other hand, according to Haykiri-Acam and Yaman [24], the sunflower husk contains 8.1% moisture, 76.4% volatile matter, 12.2% carbon, 3.3% ash, and its gross calorific value is 16.1 MJ/kg.

Biochar is produced by pyrolysis from various organic materials, including plants and organic waste. Its use on poorer or degraded soils has gained recognition as a strategic element in mitigating climate change due to its long-term and readily available carbon source [25–27]. The use of biochar on agricultural land is important for the improvement of degraded soils as it improves the physicochemical and soil properties [28–30]. According to some authors, biochar limits the absorption of heavy metals by plants, acting as a specific buffer [31]. Moreover, it is resistant to microbial degradation and remains in the soil for longer periods, thus providing a long-term benefit to soil fertility [32] and reducing the leaching of nutrients from the soil, to improve the nutrient life cycle.

Biochar made from various types of biomass sources can react in various ways depending on the type of soil to which it has been applied and broadly understood environmental conditions. This may be why, in some studies, biochar was reported to increase soil respiration and in other studies, to reduce it.

Thus far, no field studies have been conducted to assess the impact of the dosage of sunflower husk biochar on soil respiration and plant yield, although it was reported that the consequence of biochar addition on plant productivity depends on the amount added [23]. Although there is evidence on the relation between the biochar dose and its effect, the existing data gap prevents drawing general recommendations. Moreover, biochar materials can vary greatly in their characteristics; hence, the nature of the particular biochar material (e.g., pH and ash content) can also impact the application rate. Several studies have reported a positive effect of using biochar on crop yields at 5–50 tonnes per hectare with appropriate nutrient management [33]. The experiments conducted by Rondon et al. [34] resulted in a decrease in crop yield in a pot experiment with nutrient-deficient soil amended with biochar at 165 tonnes per hectare. Thus, controlling the biochar application rate is necessary to prevent its negative impact.

The study aimed to assess the effect of biochar produced from sunflower husks on physical soil properties (soil respiration, soil water flux, and soil temperature) and seed yield, depending on its dose and different soil cover (with and without vegetation).

2. Material and Methods

2.1. Field Experiment

The experiments were conducted on the experimental field of the University of Agriculture in Krakow (50°04′ N, 19°51′ E, 211 m MSL, slope 2°). The soil was characterized as Calcaric/Dolomitic Leptosols (Ochric), according to World Reference Base for Soil Resources [35]. The soil was mostly composed of sand (56.7%), silt (32%), and clay (10.4%) with a gravel fraction (0.9%).

2.2. Experiment Design

Two field experiments were conducted in the years 2018–2019. The experiments were established in a randomized block design with four replicates.

2.2.1. Experiment-1

The single-factor experiment tested the effects of four biochar doses, i.e., 0, 20, 40, and 80 t ha^{-1} applied on bare soil in March 2018. The biochar was incorporated and mixed into the topsoil layer (30 cm depth) to obtain a uniform mass.

In the first week of March, dragging was carried out to prevent evaporation. Then, after 3 weeks, cultivation was carried out with an active rototiller aggregate up to a depth of 20 cm to loosen the topsoil before applying the biochar to the experimental plots. This was done by hand and then the biochar was mixed with a manual rotary cultivator up to a depth of 20 cm. Each treatment had four replications. Each plot's size was 3 m^2.

2.2.2. Experiment-2

In 2019, a two–factor experiment was conducted to compare the effects of four doses of biochar application (i.e., 0, 20, 40, and 80 t ha^{-1}) on two different soil covers: with and without the plants (soybean).

Each treatment had four replications. The plot size was 3 m^2 each. Soybean was sown in the second week of April at a standard planting rate (80 seeds m^{-2}), followed by standard NPK mineral fertilization (30 kg N, 70 kg P_2O_5, 100 kg K_2O). Prior to sowing, the soybean seeds were inoculated with *Bradryzobium japonicum* bacteria. No pesticides were applied during plant vegetation; weeds were controlled mechanically. In the phase of full maturity, the soybean yield and the height of the first pod deposition were assessed based on the yield structures, as an important parameter of the plants' adaptation to the habitat conditions.

2.3. Biochar Characterization

The biochar was produced from sunflower husks by pyrolysis, at 450–550 °C [36,37]. It was prepared for scanning electron microscope (SEM) by thorough crumbling. Next, the sample was transferred under vacuum and imaged using SEM (Zeiss Ultra Plus, Microscopy GmbH, Potsdam, Germany) at 5 kV.

The obtained biochar's water content is 0.49%, ash 8.08%, volatile particles 11.56%, and fixed carbon 79.87%. Its elemental composition is as follows: C—85.32%; H—2.99%; N—1.06%; S—0.058%; O—2.01%; pHKCl—9.2.

The biochar is characterized by specific porosity (Figure 1): average pore radius is 0.24 µm, the total pore area is 19.01 m^2 g^{-1}, and the total porosity is 75.92%.

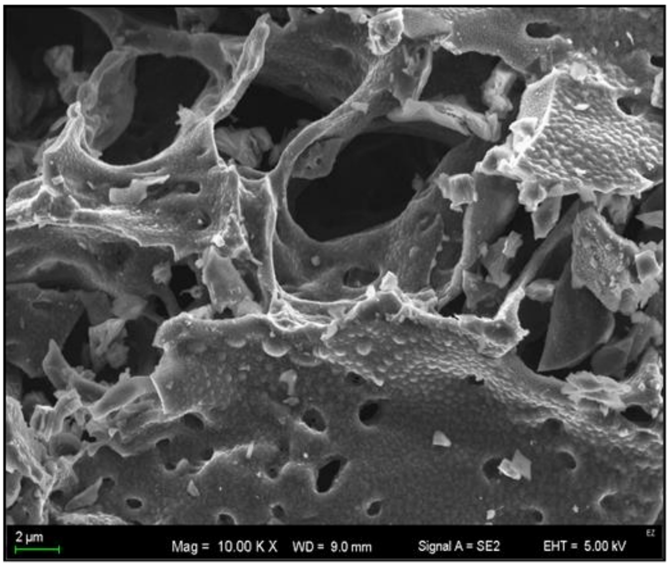


Figure 1. SEM image of the biochar porosity.

2.4. Soil Analysis

The chemical properties of soil were determined by standard methods and conducted in the second year of the study. The pH was measured potentiometrically in 1 M KCl after 24 h in the liquid/soil ratio of 10. Total organic carbon (TOC) was determined by TOC-VCSH (Shimadzu) with Solid Sample Module SSM-5000.

Measurements of soil respiration were conducted with the SRS-SD 1000 m (by ADC BioScientific Ltd., Hoddesdon, UK). Due to the specificity of the SRS-SD device (by ADC BioScientific Ltd., Hoddesdon, UK), CO_2 readouts in the soil were registered and recorded after 15 min from the moment the measurement was started. To reduce the measurement errors, readouts were made at the same time of day with similar atmospheric conditions. Measurements were not carried out during or shortly after precipitation. Prior to the measurements, the speed of gas flow was determined at 200 µmol s^{-1}, which guaranteed that the balance inside a measurement chamber was achieved after 15 min of active operation of the meter (SRS-SD 1000). The soil respiration, soil temperature, and water flux were measured 7 times during each season in three-week intervals during the two seasons.

Soil respiration (net molar flow of CO_2 in/out of the soil; µmol mol^{-1}) is:

$$Ce = u\ (-\Delta c), \tag{1}$$

where u is the molar air flow in mol s^{-1}; Δc is the difference in CO_2 concentration throughout the soil chamber, µmol mol^{-1}; $\Delta c = C_{ref}$—Can, where C_{ref} is the CO_2 flowing into the soil chamber, µmol mol^{-1}; and C_{an} is CO_2 flowing out from the soil chamber, µmol mol^{-1}.

The net H_2O Exchange Rate (Soil Flux) W_{flux} (m mol s^{-1} m^{-2}) is:

$$W_{flux} = \Delta eus/p, \tag{2}$$

where us is the molar flow of air per square meter of soil, m mol m^{-2} s^{-1}; Δe is the differential water vapor concentration, m Bar; and p is the atmospheric pressure, mBar.

2.5. Statistical Analyses

Results were statistically analyzed. The assumption of normality was checked and based on it, the statistical analysis was conducted. The one- and two-way analysis of variance (ANOVA) tests were performed at $\alpha = 0.05$, followed by an HSD Tukey's test. The Pearson coefficient of correlation between traits was calculated.

3. Results

3.1. Meteorological Conditions

The course of the weather was similar in the studied growing seasons; however, the distribution of rainfall changed in time (Figure 2). In 2018, heavy rainfall (over 59 mm) occurred in July, while in 2019, it occurred in April, May, and September (Figure 2A). In the analyzed period, there were periods without rainfall (June), but also numerous periods of drought (Figure 2B). More rainfall occurred in 2019; most days with rainfall occurred in May, and the least in June.

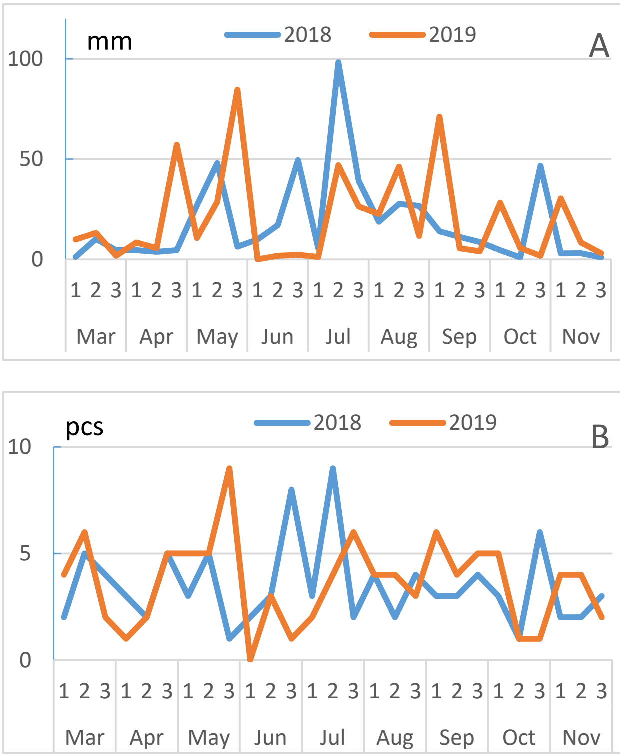


Figure 2. Rainfall distribution (**A**) and the number of days with rainfall (**B**) in 10-day intervals during the vegetation seasons.

3.2. Impact of Biochar Application on Selected Soil Parameters in the Year of Application and after One Year

The significantly positive conditional correlation obtained between soil water flux (SWF), soil respiration (SR), and soil temperature (ST) was related to the date of application of biochar (Table 1). Smaller correlations of other factors of parameters were visible in the first year of the study, which was impacted by the physical properties of the soil, e.g., looseness due to recent biochar application. In the first year of the study, the most significant relationship was found between SR and SWF. As the flow of water between the soil and the atmosphere increased, an increase in soil respiration was observed. In the second year after biochar application, the relationship between SR and SWF increased to ultimately prove the strongest mean correlation (r = 0.76) over the years. Along with the increase in respiration, the water flow in the soil increased significantly. On the other hand, a weaker correlation was found between soil respiration and temperature (r = 0.55) and between temperature and water flow in the soil (r = 0.44).

3.3. Impact of Biochar Application on Selected Soil Parameters in the First and in the Second Year on Bare Soil

The biochar-amended soil was characterized by higher pH and TOC compared to control soil. The pH increased proportionally to the biochar rate (Table 1). The TOC increase was proportional to the increase of biochar rate mainly in treatments of bare soil. No significant differences of TOC were revealed (Table 2).

Without the use of a protective plant, the analyzed soil parameters significantly varied between seasons (Table 3). The lower efficiency of the respiration process identified in the first year of the study was due to the physical properties of the soil, probably related to the lack of compactness resulting from the timing of biochar application. The water content in the soil was the result of the amount of rainfall and the number of days with rainfall. Higher precipitation was recorded in 2019, as confirmed by the significantly higher values of the obtained soil water flux index. The amount of biochar used significantly impacted the soil respiration process. The best effects were observed in the test objects with 60 t ha^{-1} biochar applied compared to control. Moreover, the use of biochar significantly improves the water flow in the soil compared to the control object.

Table 1. Pearson coefficient of correlation between soil water flux (SWF), soil respiration (SR), and soil temperature (ST).

	2018			2019			Mean		
	SWF	**SR**	**ST**	**SWF**	**SR**	**ST**	**SWF**	**SR**	**ST**
SWF	1	0.76 *	0.14	1	0.82 *	0.71 *	1	0.76 *	0.40
SR	0.76 *	1	0.42 *	0.82 *	1	0.73 *	0.76 *	1	0.55
ST	0.14	0.42 *	1	0.71 *	0.73 *	1	0.40 *	0.55 *	1

* Significant at the 0.05 probability level.

Table 2. Soil pH and total organic carbon (TOC) in soil after the second year from biochar incorporation.

Dose of Biochar (t ha^{-1})	pH $_{KCl}$		Total Organic Carbon (TOC) %	
	Bare Soil	**Soybean**	**Bare Soil**	**Soybean**
0	6.3	6.3	0.9	0.9
40	7.4	8.0	1.3	1.3
60	7.5	8.3	1.4	1.3
80	7.6	8.1	2.0	1.3
p-value	ns	ns	ns	ns

N = 4. Means labelled with different letters were significantly different for Tukey's as per test at $p < 0.05$, ns—not significant at the 0.05 probability level.

Table 3. Soil respiration, average soil temperature, and water vapor flow in the soil in the studied years (2018–2019), in plots without plants (bare soil).

Factor	Soil Respiration—SR (μmol s^{-1} m^{-2})	Soil Surface Temperature—ST (°C)	H_2O Exchange Rate (Soil Water Flux) = SWF (m mol s^{-1} m^{-2})
Year (Y)			
2018	2.94 b	22.2 a	0.36 b
2019	4.38 a	21.2 b	0.38 a
p-value	0.002	0.04	ns
Biochar dose t ha^{-1} (B)			
0	1.55 b	20.3 b	0.31 b
40	4.25 a	21.4 ab	0.38 a
60	4.99 a	22.3 a	0.39 a
80	3.87 a	22.7 a	0.40 a
p-value	<0.001	<0.002	<0.001
p-value Y × B	ns	ns	ns

N = 4. Means labelled with different letters were significantly different for Tukey's as per test at $p < 0.05$. ns—not significant at the 0.05 probability level.

Upon analyzing the soil respiration process throughout the growing season, significant object-related differentiation was found, depending on the dose of biochar used (Figure 3). The respiration process fluctuated depending on temperature and humidity. The significantly higher soil temperature in the summer months significantly increased soil respiration. The highest activity of soil respiration, irrespective of the dose of biochar used, was found in August. Biochar had a significant impact on the soil respiration process, which resulted in high readings in objects with a dose of 60 t ha^{-1} (18 µmol s^{-1} m^{-2}).

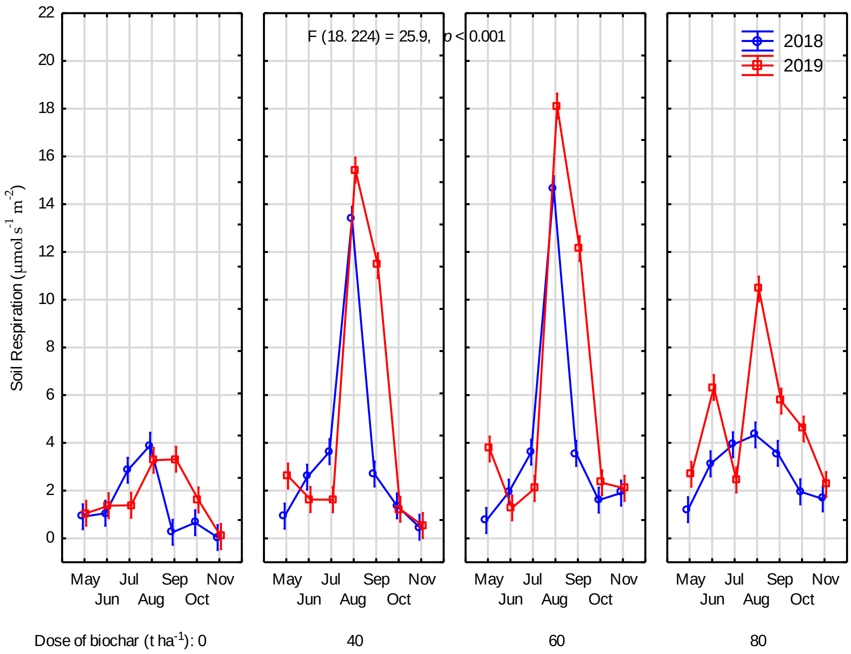


Figure 3. Distribution of soil respiration throughout the growing seasons in objects fertilized with biocarbon, without a protective plant (bare soil).

3.4. Impact of Biochar Application on Selected Soil Parameters in the Second Year Depending on the Soil Protection Variant

The use of a protective plant in the second year of the study had no significant effect on the soil respiration process and water flow in the soil (Table 4). However, a significant impact of the applied biochar dose on the soil respiration process and soil temperature was observed. Application of an average dose of biochar (60 t ha^{-1}) resulted in a significant increase in soil respiration compared to the control. This test object also obtained a slightly higher soil temperature and an increased water flow rate in the soil. The in-depth statistical analysis showed a significant convergence of the analyzed factors on the soil respiration process (Table 3, Figure 4). The use of biochar significantly decreased the respiratory activity of the soil, especially in the 40 t ha^{-1} dose. However, applying a higher dose did not increase soil respiration.

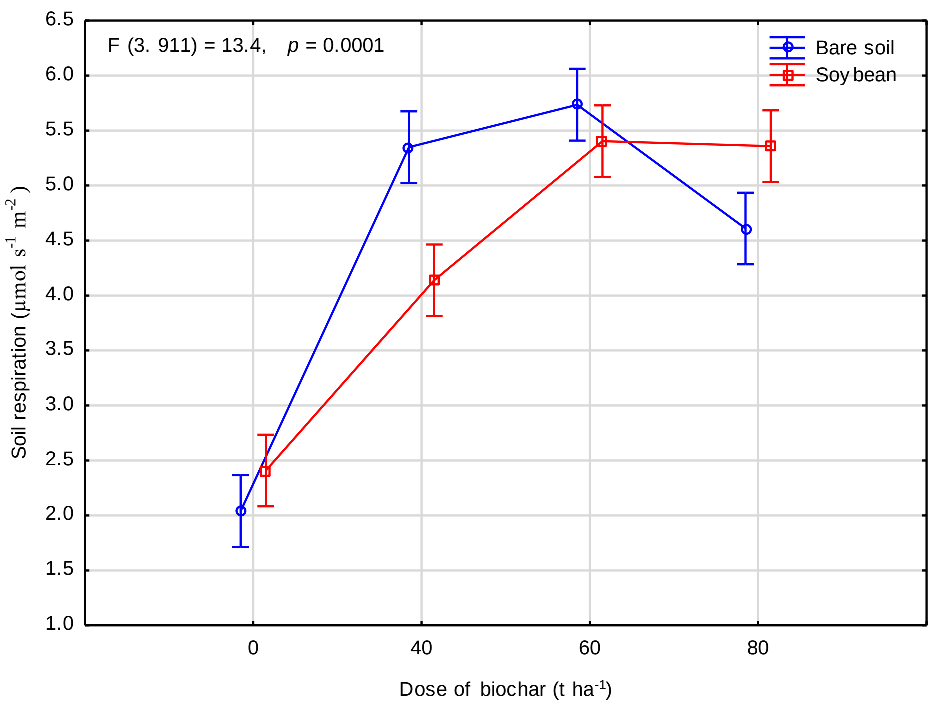
The course of soil respiration in the analyzed period (May–October) depended on the adopted soil cover variant (Figure 5). The lack of plant cover slightly increased the respiratory activity of the soil in May–July, but it significantly increased it in the summer months, i.e., August–September. Application of an average dose of biochar (60 t ha^{-1}) resulted in a significant increase in soil respiration compared to the control.

The minimal soil cover and characteristic of plants in the juvenile phase (June) resulted in a slight increase in soil respiration after the use of biochar (Figure 5b). A significant observation in soil respiration was found in August and September (during the period of intensive growth of plant biomass and roots) in objects with a high dose of biochar. The biochar used had a significant impact on the soybean yield (Figure 6). Soybean yields were significantly higher in the object where the average dose of biochar was applied (60 t ha^{-1}) compared to the control. However, no significant variation in the plant morphotype was found. The height of the first fruiting node on plants was similar regardless of the biochar dose used (Figure 7).

Table 4. Soil respiration activity, average soil temperature, and water vapor flow in the soil in the second year after biochar application, depending on the soil protection variant.

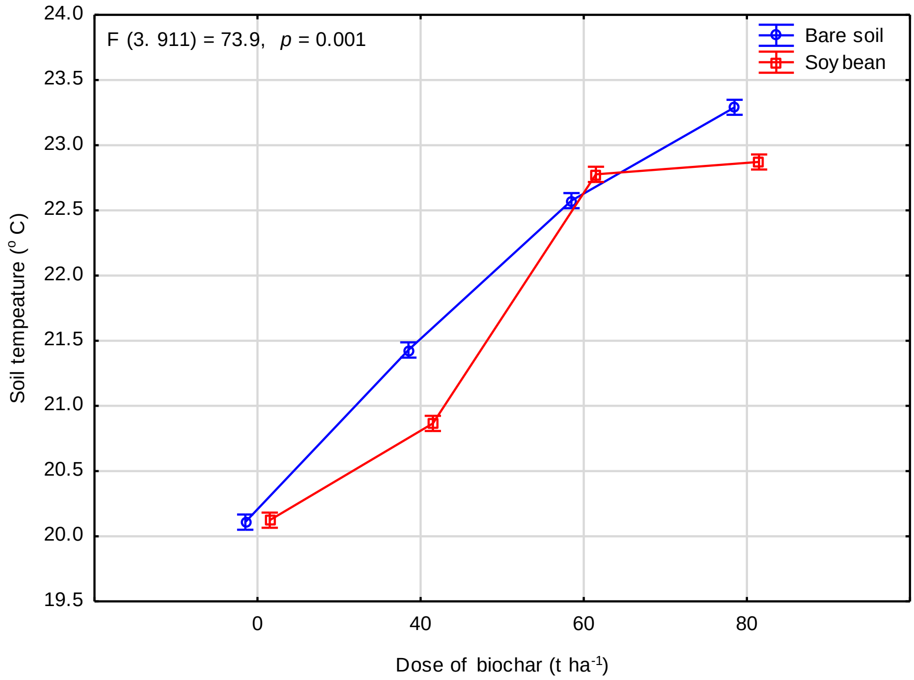
Factor	Soil Respiration—SR ($\mu mol\ s^{-1}\ m^{-2}$)	Soil Surface Temperature—ST (°C)	H_2O Exchange Rate (Soil Water Flux) = SWF ($m\ mol\ s^{-1}\ m^{-2}$)
Soil protection variant (SV)			
Bare soil	4.43 a	21.8 a	0.39 a
Soybean	4.32 a	21.6 b	0.59 a
p-value	ns	<0.05	ns
Biochar dose t ha^{-1} (B)			
0	2.21 c	20.1 c	0.32
40	4.74 b	21.1 b	0.37
60	5.56 a	22.7 a	0.84
80	4.98 b	23.1 a	0.43
p-value	<0.001	<0.001	ns
p-value SV × B	<0.001	<0.001	ns

N = 4. Means labelled with different letters were significantly different for Tukey's as per test at $p < 0.05$; ns—not significant at the 0.05 probability level.



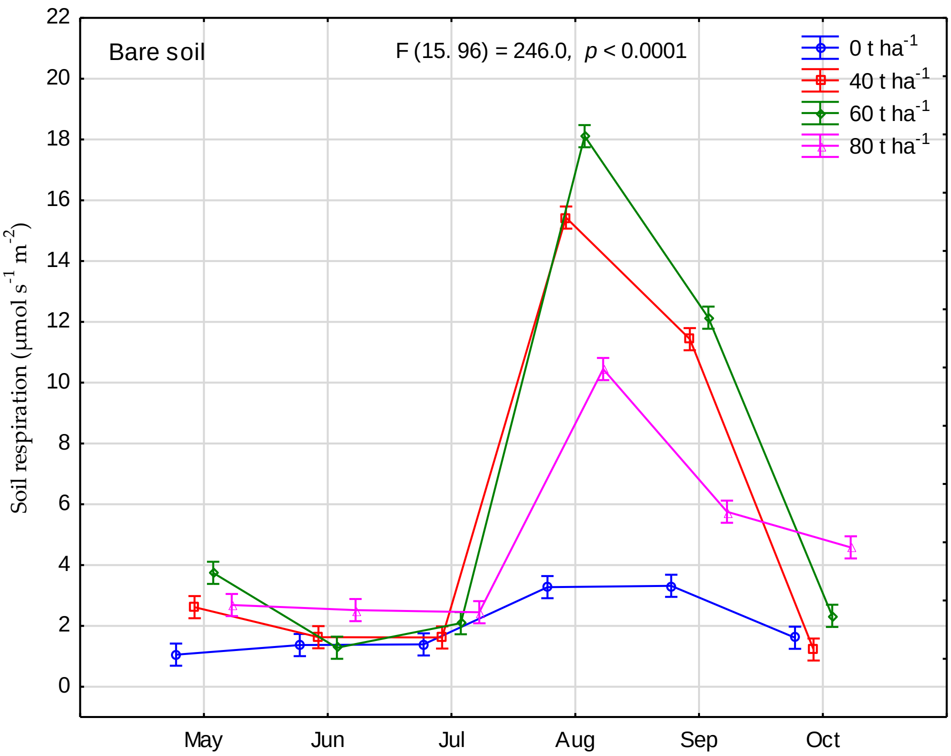
(**a**)

Figure 4. *Cont.*



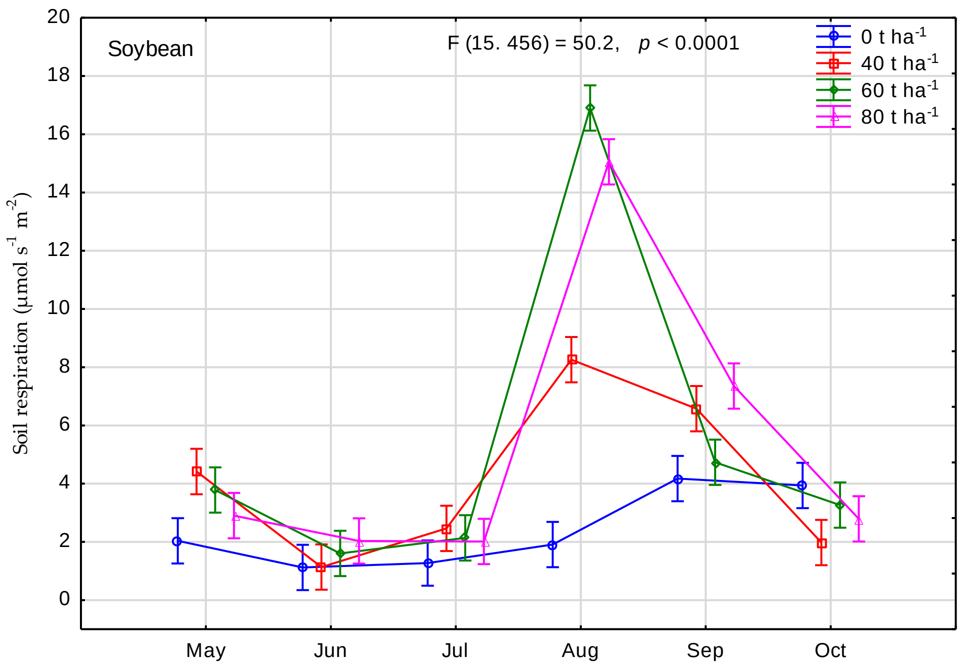
(**b**)

Figure 4. Effect of factor convergence on (**a**) soil respiration and (**b**) soil temperature.



(**a**)

Figure 5. *Cont.*



(**b**)

Figure 5. Soil respiration as a convergent effect of the dates of measurements and the dose of biochar in the objects measured: (**a**) without a protective plant, and (**b**) with a protective plant.

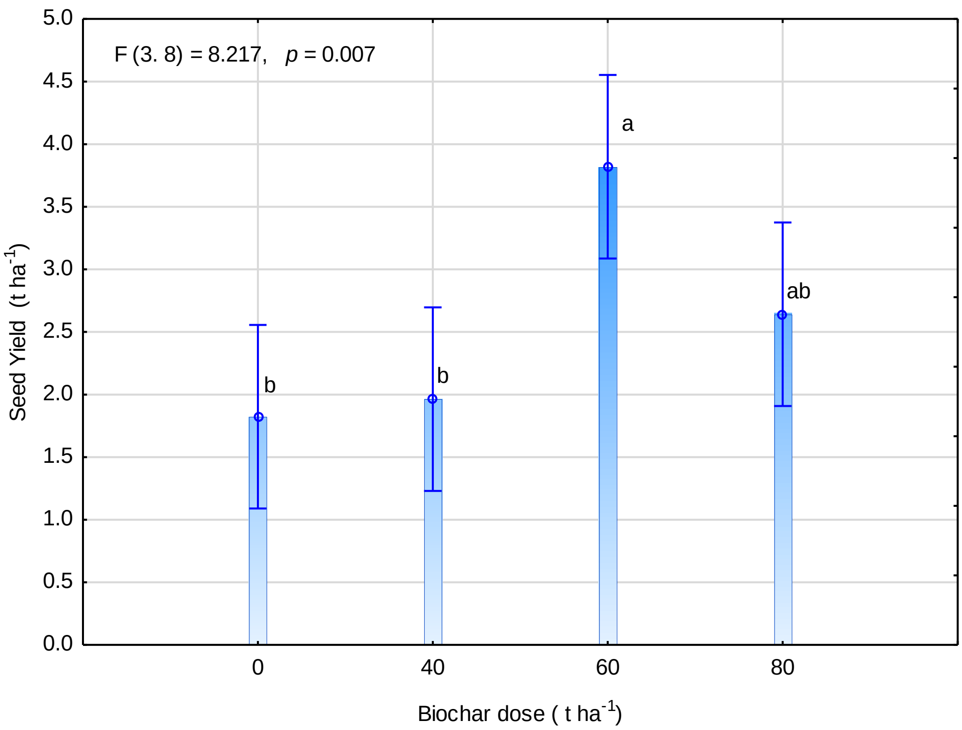


Figure 6. Soybean yield (t ha^{-1}) depending on the level of biochar fertilization. Means labelled with different letters were significantly different for Tukey's as per test at $p < 0.05$. Error bars indicate one standard error.

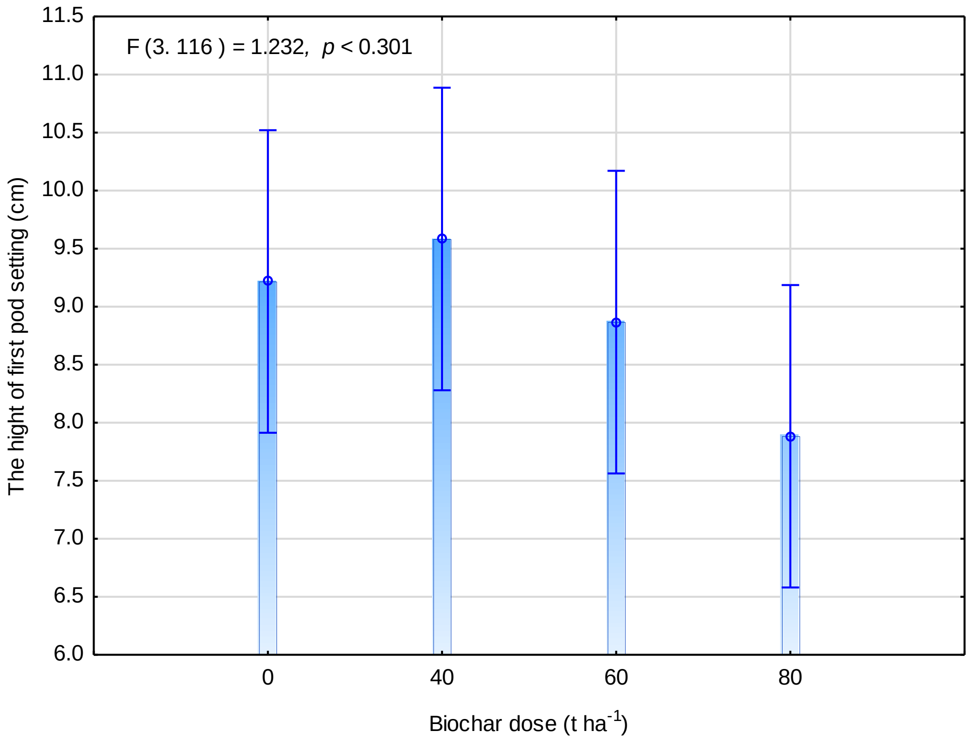


Figure 7. Height of the first pod setting depending on the level of biochar fertilization.

4. Discussion

Our results showed that biochar application increased soil respiration compared with the control treatment, which is in contradiction with several studies based on short-term incubation [1,37,38]. According to Lu et al. [25], the effects of biochar on soil respiration are varied because of differences in biochar type, soil type, soil moisture and temperature conditions, and crop planting. There was a significant negative correlation between soil respiration and soil moisture [25]. Their results indicated that rainfall during the maize-growing season suppressed soil respiration and limited the effects of biochar. The effect of soil temperature on soil respiration was greater than that of soil moisture, and soil respiration due to biochar incorporation was more sensitive to the soil temperature than that of control treatments. The research confirmed the above results since seasonal variations in soil respiratory activity, conditioned by the course of the weather, were shown. The lower efficiency of the respiration process was found in the first year of the study, which was impacted by the physical properties of the soil, e.g., lack of compactness due to recent biochar application. Moreover, the soil respiration activity was found to be highly dependent on the water flow rate and temperature. The significantly higher soil temperature in the summer months significantly increased soil respiration. The highest activity of soil respiration, irrespective of the dose of biochar used, was found in August. The presented results have been partially supported by the research of Rutigliano et al. [32], who observed that the speed of respiration was growing within the first 3 months and was statistically higher than the control, but after 14 months, there was no difference between the samples.

Lu et al. [25] analyzed soil respiratory activity in the following four years of consecutive application of straw biochar. The authors highlighted that application of straw biochar neither increased nor inhibited soil respiration throughout the entire maize-growing season compared to the control. In our own research, the authors showed that the use of biochar has a positive effect on the soil respiration process, but it depends on the soil protection variant. In the case of biochar application without soil protection, the positive effect of soil respiration was noticed regardless of biochar dose differentiation, compared to control. The differences in soil respiration between biochar treatments were significant in the experiment with soil protection. The use of biochar (up to 60 t ha^{-1}) in the experiment with soybean as a soil protector significantly increased the respiratory activity of soil compared to the control.

Zhang et al. [39] proved that the soil respiration of fields treated with returned wheat straw was 547 kg C ha^{-1} year^{-1} higher than in fields without residue in the same region. In the experiment, the authors proved relevant differences in respiration of soil conditioned by biochar compared to control conditions. However, the biochar application in different doses did not change soil respiration significantly. Shah et al. [38] tested the effect of different doses of biochar (5, 10, 20 t ha^{-1}) on soil respiration. The authors showed that with the increase in the dose of biochar, the soil respiratory activity increased. Similar conclusions were presented by Kubaczyński et al. [37], who stated that in short-term incubations, soil respiration was positively correlated with increasing biochar dose, while during long-term (several years) observation, the impact of biochar dose on the amount of emitted CO_2 was not so significant. It is worthwhile to conduct short- and long-term field studies in this area. In our own research, the authors showed that the soil respiratory activity increased proportionally to biocarbon fertilization. The best results were obtained in an object with 60 t ha^{-1} biochar, beyond which the soil respiratory activity slightly decreased.

Seremesic et al. [40] tested the effect of biochar at various doses (12.5, 25.75, 125 t ha^{-1}) and different soil types (Alluvium (A), Chernozem (C), and Humogley) on the biometric parameters of soybeans. The authors showed that soybean shoot biomass was significantly affected by soil type and biochar level. Soil types had less effect on morphological trait manifestation in soybeans. Sun et al. [41] suggested that biochar incorporation to brown soil can benefit soybean production by N retention in the soil and enhanced microbial turnover that resulted in P and K feedback. Results obtained by Seremesic et al. [40] correspond with a study of Yin et al. [42] on acid black soil, in which soybean yield increased by 35.97% compared to the control. Significant effects of biochar application on the soybean shoot were observed on Humogley soil compared to soybean height that was observed on Chernozem. Regarding shoot biomass, Humogley significantly influenced its formation compared to Alluvial soil. The obtained result could be explained with an improved water retention capacity of Humogley.

The obtained results of the soil tests for Calcaric/Dolomitic Leptosols prove that high soybean yields can be obtained with appropriate biocarbon fertilization. The authors showed that the soybean yield was significantly differentiated as impacted by the applied doses of biochar. Significantly higher soybean yields were obtained in the object with a dose of 60 t ha^{-1} biochar compared to control. However, the biochar application resulted in no significant difference in the formation of the first fruiting node on plants. Only slightly lower-placed pods were observed in test objects with a high dose of biochar. Upon analyzing the impact of biochar application on the soil respiration process throughout the growing season of soybean, the authors showed a significant difference between the objects. A significant observation in soil respiration was found in August and September (during the period of intensive growth of plant biomass and roots) in objects with a high dose of biochar.

Yooyen et al. [43] compared the effects of different doses of *Blachia siamensis Gagnep.* biochar (10, 20, 30 t ha^{-1}) on soybean yield. Growth and yields of soybean, including stem height, number of nodes, dry matter of stems, dry matter of leaves, dry matter of pods, and dry matter of seeds in the biochar treatments, show statistically significant differences at $p < 0.05$ compared to control (BC 0). The most significant result obtained in this study was the statistically significant increase of pods and seeds ($p < 0.05$). Moreover, according to the results, treatments with 20 t ha^{-1} and 30 t ha^{-1} of biochar yielded seeds 28.0 percent and 36.8 percent heavier, respectively, compared to the untreated control. In our own research, the authors showed that the biochar application increased the seed yield of the soybean, but the impact on the height of the first pod was not relevant. The highest yield (3.8 t ha^{-1}) was obtained in an object with 60 t ha^{-1} biochar, and with a higher dose, the yield slightly decreased.

5. Conclusions

The respiration process fluctuated depending on temperature and humidity. The significantly higher soil temperature in the summer months significantly increased soil respiration. The highest activity of soil respiration, irrespective of the dose of biochar used, was found in August. Biochar had a significant impact on the soil respiration process, which resulted in high readings in objects with a dose of 60 t ha^{-1} (18 μmol s^{-1} m^{-2}). The use of a protective plant in the second year of biochar application had no significant effect on the soil respiration process and water flow in the soil. However, a significant impact of the applied biochar dose was observed on the correlation between soybean cultivation on the soil respiration process and soil temperature. Among the compared treatments, a significantly higher soil respiration activity was found in the object after the application of 60 t ha^{-1} biochar, which increased soybean yield by an average of 2 t ha^{-1} compared to the control. The dose of 60 t ha^{-1} of biochar from the sunflower husk can be recommended for soybean cultivation since it increases the physical properties of sandy soil.

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