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Studying the Effectiveness of Biochar Suspension in Improving the Physicochemical Characteristics of Soil Sensitive to Erosion

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ABSTRACT

Due to the modifying properties of biochar, in recent years, the use of this substance has been considered with the aim of reducing soil erosion. The purpose of this study was to investigate the effects of biochar injection in the form of suspension on the chemical and physical characteristics of two types of soil sensitive to erosion. For this purpose, first, two types of biochar were produced and characterized, and then it was added to two types of soil prone to erosion in two levels in the form of aqueous suspension. The effect of adding biochar on the chemical and physical characteristics of loam, sand, and loam was investigated. The results obtained from this study showed that the addition of biochar in the form of an aqueous suspension can, in addition to preventing erosion-sensitive soil from touching, when adding biochar to the soil, improve the water permeability coefficient, and increase organic carbon, and soil granulation. So the use of both types of biochar increased the organic carbon of the studied soils. However, wood biochar showed a greater effect in this regard due to its higher carbon content. The use of both types of biochar in soil with a coarser texture (sandy loam) and higher water permeability decreased the soil water permeability. While the biochar obtained from wood increased the permeability coefficient of loam soil. In addition, the effect of biochar on increasing soil grain stability in loam soil was significant. In general, the effect of biochar addition on soil characteristics varies depending on the type of biochar used, the level of biochar addition, and the type of soil.

Keywords: *Soil, Erosion, Biochar, Physicochemical characteristics*

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INTRODUCTION

Soil erosion is one of the most important environmental problems in the world, because it not only causes soil degradation and decreases land fertility, but also has side effects such as increased floods, siltification, and water pollution (Zhuang *et al*., 2015; Zhai *et al*., 2024). Recent studies have shown that soil erosion through the loss of soil organic carbon can even exacerbate climate change and global warming (Li *et al*., 2019; Li *et al*., 2021). Therefore, to restore the fertility of the land and preserve the ecological environment, soil protection against Erosion is very important.

The addition of biochar to the soil is a promising method to achieve the aforementioned goals. The presence of oxygen is produced (Tripathi *et al*., 2016). At first, the use of biochar in soil was considered as a solution for long-term carbon sequestration and to deal with climate change, because the stable aromatic structure and resistance of biochar in soil (Xia *et al*., 2016) causes long-term carbon retention in the soil (Amini *et al*., 2016). Biochar is also known as an important soil conditioner due to its multiple positive effects in improving physical (Mangrich *et al*., 2015), chemical (Uzoma *et al*., 2011), and biological (Lehmann *et al*., 2011) properties. Biochar can impact soil organic matter content and soil grain stability (Obia *et al*., 2016).

Reducing soil erosion through maintaining soil organic matter, increasing soil stability of seeds (Doan *et al*., 2015), improving the water permeability coefficient, and increasing the moisture retention capacity in the soil as a result of the use of biochar has caused this amendment to reduce edibility, and improving the conditions of soils prone to erosion should be taken into consideration.

Xiu *et al*. (2019) studied the effect of biochar produced from corn straw in Planosol soil. The results of that research showed that the application of two and three percent levels of biochar increased organic carbon, stability of soil grains, and also improved water holding capacity. They concluded that the loss of volatile and volatile components during the pyrolysis process increases the amount of porosity in the raw material used (corn straw) to produce biochar and the formation of fine pores on the biochar, which changes the structure and increases the surface area. Somerville *et al*. (2020) investigated the effect of biochar produced from eucalyptus wood at a pyrolysis temperature of

550 °C on two soils. The results of their research showed that the biochar used in the soil can significantly increase the water permeability coefficient and decrease the apparent specific mass after 27 months in both tested soils. However, the addition of biochar did not have a significant impact on the stability of soil grains in both soils.

In addition to the positive effects of biochar in the mentioned cases, stopping carbon and fighting global warming, improving soil quality and plant growth, producing biochar from agricultural and garden residues can be a suitable method for managing these residues. For example, rice paddy husk is considered a by-product of rice mills, and also pruned tree branches, which are found in abundance, can be used as carbon-rich biochar (Kuhlbusch & Crutzen, 1996). The primary characteristics of biochar depend on the type of raw material used and the thermal chemical conditions of biochar production (Lehmann, 2007). But like any additional treatment to the soil, including organic and inorganic treatments, the method of biochar application, such as the level of application and the method of adding to the soil, is very important and probably affects the efficiency of biochar.

The effect of biochar application levels and size has been considered in various studies. But what is important is to investigate the impact of different methods of adding biochar to the soil, including mixing it uniformly with the soil, sprinkling it on the soil surface, mixing it with solid or liquid fertilizer, using strips and pits, etc. The method of uniformly mixing biochar with surface soil, which has been utilized in most studies, can cause the collapse of the natural structure and soil degradation. Thus, it is very important to introduce an application method that is related to minimal soil disturbance, especially in soils sensitive to erosion. This research was conducted to study the effect of adding various levels of biochar produced from two different types of raw materials of garden and agricultural waste in the form of biochar aqueous solution on the physical and chemical characteristics of two erosion-prone soils with different textures.

MATERIALS AND METHODS

Production of biochars and determination of their characteristics

Two types of biochar were provided from different raw materials, including the wood of the pruned branches of the Fraxinus excelsior tree and rice paddy husk, by slow pyrolysis method and at a temperature of 550 degrees Celsius in an electric induction furnace. Then, the efficiency of biochar production was calculated based on the weight of biochar produced per unit weight of the raw material. The ash amount in biochar was also calculated by heating five grams of biochar at 500 degrees Celsius for more than 8 hours and weighing it again (ASTM D1762-84). Chemical reaction and electrical conductivity were measured according to the method of Rajkovich *et al.* (2012) and in a mixture of deionized water and biochar with a weight ratio of 20:1 (biochar: water). Determination of the total amount of hydrogen, carbon, and nitrogen in biomass was done by dry combustion using a Perkin Elmer 2400 elemental analysis device (ASTM D4373-02). Using the KYKY EM3200 electron microscope, the morphological structure of biochars was revealed.

Sampling and determination of soil characteristics

To preserve the natural structure, the soil samples were prepared intact from a depth of 0 to 10 cm. In this way, metal cylinders with a diameter of 25 cm and a height of 15 cm were slowly inserted into one of the cylinders with a sledgehammer to a depth of 10 cm from the soil around and below them using a spatula, and to prevent the soil from falling and to preserve its structure, a sub-pot was immediately placed at the bottom of each cylinder. In addition to the soil columns, other damaged and untouched samples were also prepared to determine the basic physical and chemical characteristics. Electrical conductivity and chemical reaction in 1:1 water-to-soil suspension, the size distribution of primary soil particles (texture) by hydrometric method (Gee & Bauder, 1986), and soil organic carbon by more oxidation method (Nelson & Sommers, 1996) were determined. In this study, two types of soil with different textures were used, SL soil (with sandy loam texture) and L soil (with loam texture). Preliminary investigations showed that L soil has chemical reactivity, higher electrical conductivity, and lower organic carbon compared to SL soil.

Applying treatments and incubation of soil columns

Two types of produced biochar, milled and with a particle size of 63-250 microns, were added to the cylinders containing intact soil at the levels of 0.7 and 1.4% by weight and three repetitions as aqueous suspensions. Three soil cylinders without biochar were also introduced as a control treatment. The soil cylinders were kept for six months (180 days) in the greenhouse at a temperature range of 20-25 degrees Celsius and subjected to multiple drying and wetting cycles. At the end of the six-month incubation time, disturbed and undisturbed soil samples were prepared from cylinders and chemical reaction, electrical conductivity, and organic carbon of the soil was measured by the method mentioned in the determination of basic soil characteristics. The apparent specific gravity was measured by the cylinder method (Grossman & Reinsch, 2002), the saturated water permeability of the soil SL by the constant load method, and the soil by the precipitation method (Reynolds, 2002). To perform micromorphological studies, clumps were selected and thin sections were prepared from them and studied by polarizing microscope. To evaluate the wet soil grain size distribution, the sieve method was used (Nimmo & Perkins, 2002). In this way, after drying and passing the soil through a 4 mm sieve, 50 grams of soil was soaked for 24 hours by water spray and then The soil was placed in a container containing water and on a series of sieves with pore diameters of 2, 1, 0.5, 0.25, 0.125, and sieving continued at 35 rpm for 10 minutes. The remaining soil on each sieve was carefully removed and dried at 105 degrees Celsius.

Statistical analysis

The impact of two factors, including the biochar type and the biochar application level, was analyzed as a factorial experiment in the completely randomized design form in three replications by SAS statistical software. The means comparison was also done by Duncan's test at the 5% probability level.

RESULTS AND DISCUSSION

Characteristics of biochars

The results of the studies showed that although the performance of both biochars is almost the same with 58.6% for Fraxinus excelsior wood and 51.3% for rice paddy husk, the results of elemental analysis indicate a different chemical composition of these two biochars. The characteristics of the produced biochars are listed in **Table 1**.

Table 1. Chemical characteristics of two types of biochar used.

Parameter	Unit	WB	RB
Production efficiency	%	58.6	51.3
Ash	%	9.22	40.13
Chemical reaction	-	9.5	9.7
Electrical conductivity	Microms per centimeter	63	512
Carbon	%	75.20	45.40
Hydrogen	%	2.69	2.43
Nitrogen	%	0.94	0.47
Oxygen	%	11.95	11.57
The molar ratio of hydrogen to carbon	Molar ratio	0.43	0.64
The molar ratio of oxygen to carbon	%	0.12	0.19

WB: wood biochar from the pruned branches of Fraxinus excelsior tree, and RB: rice paddy husk biochar.

Biochar obtained from rice paddy husk had more ash and electrical conductivity compared to wood biochar. More mineral ash in biochar probably results in higher electrical conductivity. Both biochars had alkaline chemical reactions (more than 7). Biochar used in previous research was usually alkaline, however, biochar can be produced by any chemical reaction in the range of 4-12 (Lehmann, 2007), and the molar ratio of hydrogen to carbon in wood and shell biochar was 0.43 and 0.64, respectively. A lower molar ratio of hydrogen to carbon indicates the presence of more aromatic carbon and, as a result, greater resistance to decomposition (Schmidt & Noack, 2000).

Biomass raw materials have a molar ratio of hydrogen to carbon of about 1.5, but With the thermal decomposition of biomass, this ratio decreases, for this reason, wood biochar has more aromatic carbon and is more resistant to decomposition, and as a result, it will probably be a more effective tool to stop carbon in the soil. The molar ratio of hydrogen to carbon and oxygen to carbon, are useful indicators for evaluating biochar properties. Li *et al*. (2019) stated that higher oxygen-to-carbon molar ratios indicate the presence of more hydroxyl, carboxyl, and carbonyl groups in biochar.

Biochars have less H/C of 0.7, which confirms the definition of biochar. The molar ratio of oxygen to carbon (O/C) and hydrogen to carbon (H/C) of biochars was also used to prepare the van Krevillen diagram that HC and OC have decreased compared to biomass in both wood biochar and rice paddy husk, and these ratios were in the range of charcoal in both biochars. Spokas (2010) stated that the minimum half-life of biochars with an oxygen-to-carbon ratio of less than 0.2 is 1,000 years. Therefore, both wood biochar and rice paddy husk with O/C >0.2 probably have a long life in the soil, and wood biochar due to its lower O/C ratio compared to rice paddy husk biochar, has a greater ability to stop carbon in the soil.

Microscopic images of both types of biochar showed that many pores were formed on their surface. The diameter and number of pores in Fraxinus excelsior wood biochar were greater than that of rice paddy husk biochar, and therefore this biochar had more porosity than rice paddy husk biochar. Biochar macropores affect vital soil functions such as hydrology and aeration (Troeh & Thompson, 2005). Coarse pores are important for the movement of roots in the soil and also as a habitat for a wide variety of soil microbes. Microbial cells are typically 0.5-5 microns in size. Therefore, the large pores of biochar provide suitable dimensions for the life of microorganisms. In addition, the porous and regular structure of biochars causes a high specific surface area and high absorption capacity.

The results of analysis of variance of the effect of biochar on the physicochemical properties of soils

The results of the analysis of variance to investigate the effect of biochar type and level on soil physical and chemical characteristics for SL and L soil showed that the effect of biochar type on chemical reaction, water permeability coefficient ($p>0.01$), and organic carbon ($p>0.05$) in SL soil It was meaningful. The level of biochar application and the interaction effect of the type and level of biochar application also had a significant effect on the soil permeability coefficient ($p<0.01$). This means that in other cases, the two types of biochar or the levels of 0.7 and 1.4% of biochar were not significantly different from each other ($p>0.05$). In soil L, the results of the analysis of variance indicating the effect of biochar type on chemical reaction, water permeability coefficient ($p>0.01$), and organic carbon ($p>0.05$) were significant. The level of biochar application had a significant effect on organic carbon, weighted average soil grain diameter ($p>0.01$), and water permeability coefficient ($p>0.05$). The interaction effect of type and level of biochar application on the chemical reaction of organic carbon, the weighted average diameter of soil grain ($p<0.01$), electrical conductivity, water permeability coefficient, geometric mean diameter, and fractal dimension of soil grain ($p>0.05$) was significant.

The effect of biochar on the chemical properties of soils

Effect of biochar on chemical reaction and electrical conductivity

The chemical reaction of SL soil in the wood biochar treatment was significantly higher than the rice husk biochar treatment, but none of these two treatments, as well as the biochar application levels, were significantly different from the control treatment **(Table 2)**. The results of the analysis of variance showed that the effect of none of the type, level, application, and interaction effects of type and level of biochar application on the electrical conductivity of SL soil was not significant. The mean comparison also showed no significant difference in biochar treatments compared to the control **(Table 2)**.

In soil L, the chemical reaction of the soil at all levels of biochar application except for the 1.4% level, biochar of wood was significantly lower than the control treatment (without biochar). At the level of 1.4% wood biochar, the chemical reaction was significantly higher than the control treatment and the corresponding level of rice paddy husk biochar. The comparison of electrical conductivity in any of the application levels of wood biochar and rice paddy husk did not show any significant difference with the control treatment. However, the 0.7% level of wood biochar had more electrical conductivity compared to its 1.4% level and both levels of rice paddy husk biochar application. In soil L, the level of 1.4% biochar from the pruned branches of the Fraxinus excelsior tree caused a significant increase in chemical reaction. But in other cases, the application of biochar caused a significant reduction in soil chemical reactions.

The results of previous studies indicate an increase in the chemical reaction of the soil due to the use of biochar (Wang *et al*., 2017a) and most of these studies have been conducted on acidic soils with low chemical reactions (Dai *et al*., 2017; Liu *et al*., 2017). Some mechanisms can increase the chemical reaction of the soil due to the use of biochar. In many cases, this increase is due to the presence of some alkaline substances in biochar (Cui *et al*., 2019). The proliferation of microorganisms that produce acidic substances in soils modified with biochar (Kim *et al*., 2016) and the increase of acidic functional groups on the oxidation effect of biochar (Serkalem, 2015) can be one of the reasons for reducing the chemical reaction of soils treated with biochar.

The effect of biochar on the amount of organic carbon

The comparison of means showed that SL soil organic carbon in wood biochar treatment was significantly higher than that of rice paddy husk biochar. In both biochar treatments and application levels, biochar had significantly higher organic carbon content than the control soil (without biochar) **(Table 2)**. The amount of soil organic carbon L was significantly higher than the control treatment at all levels of wood biochar and rice paddy husk application, and this increase was higher at the level of 1.4% of wood biochar than in other cases. The biochar obtained from the wood of Fraxinus excelsior tree branches had more organic carbon than the biochar from rice paddy husks, and as a result, it had a greater effect in increasing the organic carbon of both studied soils.

The percentage of soil organic carbon increase due to the application of Fraxinus excelsior wood and rice paddy husk biochar was about 81 and 43 in SL soil and 141 and 100 in L soil, respectively. Therefore, both biochars in L soil caused a greater increase in soil organic carbon compared to SL soil. The change in the amount of soil organic carbon due to the addition of biochar has been seen in several studies (Munda *et al*., 2018; Abbas *et al*., 2019). Increasing soil organic matter can have beneficial effects. Increasing soil organic carbon and applying organic amendments, especially in semi-arid areas, can improve degraded soils. In addition, organic matter plays an important role in the stability of soil grains.

Table 2. Effect of type and level of biochar application on some SL soil characteristics.

	Electrical conductivity (dSm^{-1})	Chemical reaction	Organic carbon (%)
Control group (without biochar)	1463.7[a]	7.45[ab]	0.21[c]
Wood biochar	1266.8[a]	7.53[a]	0.38[a]
Rice husk biochar	1233.5[a]	7.40[b]	0.30[b]

	Electrical conductivity (dSm^{-1})	Chemical reaction	Organic carbon (%)
Control group (without biochar)	1463.7[a]	7.45[a]	0.21[b]
0.7	1273.8[a]	7.42[a]	0.32[a]
1.4	1226.5[a]	7.51[a]	0.36[a]

The same letters indicate no significant difference in means at the five percent probability level.

The effect of biochar on the physical properties of soils

The effect of biochar on water permeability coefficient

Based on the results obtained in this research, the water permeability coefficient in SL soil was significantly lower than the control treatment at both levels of wood biochar and rice paddy husk application. In soil L, the water permeability coefficient was significantly higher than the control treatment at both levels of wood biochar application, however, the level of 1.4% rice paddy husk biochar caused a significant decrease in the soil water permeability coefficient compared to the control treatment. The use of both biochars decreased the permeability coefficient of SL soil. The levels of 0.7 and 1.4% biochar from the top branches of the Fraxinus excelsior tree caused a 68% reduction in soil water permeability, while this reduction was 33% and 59% in the case of 0.7% and 1.4% biochar from rice paddy husk, respectively. However, in soil L, the application of 0.7 and 1.4% levels of wood biochar from the pruned branches of Fraxinus excelsior tree caused a significant increase of 70 and 115% in the water permeability coefficient, while the levels of 0.7 and 1.4% biochar from rice paddy hulls decreased the water permeability coefficient. The soil became L. although the difference in the level of 70% biochar of rice paddy husk with the control treatment was not significant.

Barnes *et al.* (2014) reported that the use of biochar produced from mesquite wood in both sandy and clay soils increased the water permeability coefficient of clay soil by 300%, but in contrast, the use of biochar in sandy soil decreased the water permeability coefficient by 92%. became dust Based on the results of other studies, the addition of biochar may significantly reduce or not affect the permeability coefficient in soils with a coarse texture such as sandy loam or sand (Barnes *et al*., 2014; Githinji, 2014). SL soil has a very high water permeability coefficient, which can be an obstacle to maintaining moisture in the soil, and therefore its reduction due to the application of biochar can be an important achievement. On the contrary, the soil permeability coefficient L was relatively low, and its increase due to the use of biochar from the branches of Fraxinus excelsior tree can cause a significant decrease in runoff production.

The results of the meta-analysis study on the effects of biochar on soil water characteristics showed that the application of biochar in coarse-textured soils by converting large pores (water passage pores) into medium and fine pores (water storage pores) reduces the water permeability coefficient and increases the moisture retention capacity. It becomes dust. The application of biochar in fine-textured soils can open up the passage of water increase the coefficient of water passage and reduce runoff by converting very fine pores into fine and coarse pores and increasing the formation of coarse soil grains (Edeh *et al*., 2020).

The effect of biochar on soil stability profiles

Based on the obtained results, none of the biochars had any effect on the grain stability in SL soil, but the average weight of the grain diameter was significantly higher than the control treatment at all levels of wood biochar and rice paddy husk application. The geometric mean of the soil grain diameter of all levels of wood biochar application and the level of 1.4% rice paddy husk biochar was significantly higher than the control treatment. Even though the geometric mean diameter of the soil grain was greater in the 0.7% treatment, this difference was not significant in paddy husk biochar compared to the control treatment. The fractal dimension was significantly lower than the control treatment at all levels of wood biochar and rice paddy husk application. In surface soil, 0.7% and 1.4% wood biochar of pruned tree branches caused an increase of 29% and 27%, respectively, in the weighted average of soil grain diameter, while in the case of rice paddy husk biochar, this increase was 15% and 44%. In addition to the weighted mean diameter of the soil grain, an increase in the geometric mean diameter and a decrease in the fractal dimension of the soil grain were observed in biochar treatments. The fractal dimension of soil grains is an important factor in the size distribution of soil grains. The more stable the soil grains are, the smaller the fractal dimension is. In contrast, unstable soil grains are crushed more and have a larger fractal dimension, which reflects the unfavorable soil structure (Caruso *et al*., 2011). The application of biochar, especially the level of 1.4% rice paddy husk biochar, increased the stability of soil grains in L soil with loam texture, but it had no significant effect on SL soil with sandy loam texture. This can be caused by the fact that particles with a diameter smaller than 0.05 mm are rarely seen in sandy loam soil.

The effect of biochar on apparent and real specific gravity

In none of the soils, the effect of sources of changes, including type, level, and the interaction effect of type and level of biochar application on apparent and real specific mass was not significant. However, the average comparison showed that the apparent specific gravity in soil L in wood biochar treatment and rice paddy husk treatment was significantly lower than the control treatment. Biochar in soil L, which has a smaller particle size and less organic matter, has performed better in reducing apparent specific gravity. The apparent specific gravity of the soil was reduced by 9 and 12%, respectively, due to the use of chopped tree branches and rice paddy husk biochar. A reduction in the apparent specific mass of soil due to the application of biochar has been reported in different studies (Pereira *et al*., 2012; Trifunovic *et al*., 2018).

The effect of biochar on the micromorphological characteristics of soils

The comparison of morphological characteristics of the soil, including the presence of voids and soil structure and its development status, shows the improvement of the above due to the use of both biochar produced from the wood of pruned tree branches and rice paddy husk.

CONCLUSION

The results of this research showed that biochar produced from the wood of the pruned branches of Fraxinus excelsior (WB) and rice paddy husk (RB) is likely to have long-term durability in the soil. Since carbon sequestration in the soil is considered an effective way to reduce greenhouse gas emissions, so biochar production from agricultural and garden wastes such as rice paddy husks and pruned tree branches can be a suitable management measure to combat the phenomenon of global warming.

Regarding the effects of biochar application of Fraxinus excelsior tree branches (WB) and rice paddy husk (RB) in the form of aqueous suspension on the two studied soils, the findings of this research showed that the soil grain stability and apparent specific gravity profiles in the soil SL did not change but improved in L soil. Although the microscopic examination of thin sections of both SL and L soil showed a relative improvement in soil structure. The soil in the SL soil was not enough. The use of both biochars in both soils improved the amount of soil organic carbon. The water permeability coefficient in SL and L soil decreased and increased, respectively, and the effectiveness of biochars in improving the amount of organic carbon and soil water permeability coefficient was RB<WB.

In general, it can be said that different types of biochar do not have the same impact on a specific soil, and similarly, one type of biochar cannot have the same impact on various types of soil. This happens because of the significant effect of the type of raw materials and pyrolysis conditions on the properties of biochar and the difference between the basic properties of different soils. However, the results of the studies showed that with the use of biochar in the form of aqueous suspension, in addition to avoiding damage and destruction of the soil, especially soils sensitive to erosion, it is possible to cause a long-term stoppage of carbon in the soil and improve important characteristics affecting the quality of the soil. And also the sustainable use of agricultural and garden residues.

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