

**IMPACT OF GRAPEVINE BIOCHAR ON SOME HYDRO-PHYSICAL
CHARACTERISTICS OF SILT LOAM SOIL – LABORATORY MEASUREMENTS**

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This study is focused on some hydro-physical characteristics of silt loam soil and their changes after biochar amendment. The used biochar was produced from wooden parts of grapevine (*Vitis*) in UNIPYR reactor in AgroBioTech Research Center in Nitra, Slovakia. There were established 4 sets in laboratory: pure soil and soil-biochar mixtures with 20, 40 and 80 t ha⁻¹ biochar amendment. Our results confirmed more scientific studies that adding biochar into the soil decreased soil bulk density, particle density and increased porosity. Saturated hydraulic conductivity increased only for higher biochar concentrations in our research. Based on our measurements the optimal amount of grapevine biochar for improving hydro-physical characteristics of silt loam soil was 40 t ha⁻¹.

KEY WORDS: grapevine biochar, soil characteristics, silt loam soil

Introduction

Biochar application to agricultural soils has been proposed as a way to increase crop production by improving soil chemical and physical properties. The growth of plants is determined among others by the physical state of the soil environment. Biochar may also improve soil performance by altering soil physical characteristics such as porosity, bulk density, hydraulic conductivity, and water holding capacity (Githinji, 2013; Tárník, 2019) and by changing soil chemical properties including pH, cation exchange capacity, and nutrient availability (Deal et al., 2012; Liu et al., 2012). Biochar particles can have high initial hydrophobicity if they are produced at low temperatures (<400°C) (Kinney et al., 2012). Hydrophobic biochar has positive water entry pressure (Wang et al., 2000) which means that an applied pressure is required for water to enter intrapores. If the hydrostatic pressure is less than the water entry pressure, water will not enter these intrapores, therefore reducing their effectiveness of water flow and water storage (Masiello et al., 2015).

In this paper, we focused on impact of biochar amendment on some hydro-physical characteristics described below.

Soil bulk density (BD), also known as dry bulk density, is the weight of dry soil divided by the total soil volume. The total soil volume is the combined volume of solids and pores which may contain air or water, or both. The average values of air, water and solid in soil are easily measured and are a useful indication of a soils

physical condition. Soil BD and porosity reflects the size, shape and arrangement of particles and voids (soil structure). Both BD and porosity give a good indication of the suitability for root growth and soil permeability and are vitally important for the soil-plant-atmosphere system (Cresswell and Hamilton, 2002; McKenzie et al., 2004).

Particle density (PD) of a soil indicates the mass of a soil sample in a given volume of particles (mass divided by volume). PD focuses on just the soil particles and not the total volume that the soil particles and pore spaces occupy in the soil. PD differs from BD because bulk density includes the volume of the solid (mineral and organic) portion of the soil along with the spaces where air and water are found. In general, PD represents the average density of all the minerals composing the soil. The density of the minerals depends on their elementary composition, so PD of a soil is certainly also dependent on its chemical bulk composition. In other words, density summarizes the interaction of soil chemical constituents within the environment (Di Giuseppe et al., 2016).

Hydraulic conductivity is the volume of water that flows through a unit cross-section of soil per unit time. Hydraulic conductivity plays important role in water resources development, planning and management as well as environmental protection. Saturated hydraulic conductivity (*K*) is a quantitative characteristic for the ability of porous system to transfer water in a saturated state. In soils, this characteristic depends mainly on its structure and texture. The heterogeneity of

soil significantly influences the spatial manifestation of hydraulic conductivity in both vertical and horizontal directions. On the other hand, the transformation of organic matter causes the changes of hydraulic conductivity in time (Fodor et al., 2011). K is one of the most important physical characteristics of soil that has significant effect on salt, pesticide, nutrient leaching, water infiltration and consequently, controlling surface runoff (Mohsenipour and Shahid, 2016).

A soil's *porosity* and pore-size distribution characterize its pore space, that portion of the soil's volume that is not occupied by solid material. The basic character of the pore space governs critical aspects of almost everything that occurs in the soil: the movement of water, air, and other fluids; the transport and the reaction of chemicals; and the residence of roots and other biota. By convention the definition of pore space excludes fluid pockets that are totally enclosed within solid material – vesicles or vugs, for example that have no exchange with the pore space that has continuity to the boundaries of the medium. Thus we consider a single, contiguous pore space within the body of soil. In general it has fluid pathways that are tortuous, variably constricted, and usually highly connected among themselves (Nimmo, 2005).

Material and methods

Grapevine biochar production

The biochar, used in this research was obtained from wooden parts of grapevine (*Vitis*) in UNIPYR reactor by pyrolysis at 520°C. The size of biochar was 0–10 mm. This reactor is part of AgroBioTech Research Center of the Slovak University of Agriculture in Nitra and consists of set of equipment for the production of synthesis gas and biogenic fuels in liquid and solid phase. The basic principle of the plant operation is continuous thermal decomposition of biomass and dendromass, eventually other materials of organic origin (such as paper, textiles), free of inert impurities (such as metal, glass, soil, sand), with a raw material processing capacity up to 60 kg per hour. The process of biochar production is described by Gaduš and Giertl (2019). Elemental analysis of biochar carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) was performed using a CHNSO elemental analyzer (Perkin Elmer 2400 Series II CHNSO Elemental Analyzer) at Institute of Agrophysics of the Polish Academy of Sciences in Lublin (Poland). C, H, N and S results were expressed in weight percentage. Before the analysis samples were ground in a mortar and then dried at 105°C by 24 hours. Elemental composition of the biochar characteristics is listed in Table 1.

Table 1. Some chemical characteristics of biochar

	C	H	N	S
	[%]	[%]	[%]	[%]
Biochar	78.43	2.21	1.22	0.24

Soil mixtures

In this research in laboratory conditions was used the same type of soil as in our previous research in field conditions with soil particles diameter ≤ 2 mm. The soil type was classified as the Haplic Luvisol with content of sand 15.2%, silt 59.9% and clay 24.9% – silt loam (Šimanský and Klimaj, 2017). In our field research, biochar was applied into the depth of 10 cm below soil surface, that's why we considered the same depth of biochar application in laboratory measurements. The biochar was mixed to the soil at a ratio of 20, 40 and 80 t ha⁻¹ (in dry weight basis). Measurements were provided on samples with volume of 100 cm³ (Kopecky rings). Four different sets were established: a soil without biochar (soil), soil amended with biochar of 20 t/ha (G20), soil amended with biochar of 40 t ha⁻¹ (G40) and soil amended with biochar of 80 t ha⁻¹ (G80). Each set was prepared with 3 replicates.

Soil bulk density

The dry soil bulk density (ρ_d) is defined as the mass of dry soil (m_s) of the total volume (V):

$$\rho_d = \frac{m_s}{V} \text{ [g cm}^{-3}\text{]} \quad (1)$$

The soil bulk density was established based on core method (volumetric cylinder method). This method requires a volumetric cylinder. The total volume of the soil is estimated as the internal volume of the cylinder (in our measurements it was 100 cm³). Samples are dried at 105°C and then the mass of the dry soil sample is measured (Velebný, 1981).

Particle density

The particle density (ρ_s) is defined as the mass (m_s) of the unit volume of the solid soil phase (V_s):

$$\rho_s = \frac{m_s}{V_s} \text{ [g cm}^{-3}\text{]} \quad (2)$$

In this research was used pycnometric method with pycnometer volume of 100 ml. Density determination by pycnometer is a very precise method. It uses a working liquid with well-known density, such as water. We used distilled water. The pycnometer is a glass flask with a close-fitting ground glass stopper with a capillary hole through it. This fine hole releases a spare liquid after closing a top-filled pycnometer and allows for obtaining a given volume of measured and/or working liquid with a high accuracy. The laboratory measurement was described by e.g. Velebný (1981).

Saturated hydraulic conductivity

Hydraulic methods come from supposed certain flow conditions, with boundary and initial conditions and with use of Darcy's Law (respectively Darcy-Buckingham Law in a case of unsteady state flow in unsaturated zone)

and with use of equation of continuity. Final formulas for direct calculations (approximation) of K -values were received by analytical solution of initial fundamental equations. K was measured by the falling head method in laboratory conditions based on formula (3) (Velebný, 1981):

$$K = \frac{L}{\Delta t} \ln \frac{h_1}{h_2} \quad [\text{cm day}^{-1}] \quad (3)$$

where

L – cylinder length [cm]

Δt – time elapsed [day],

h_1 – initial head from water surface to sample bottom [cm],

h_2 – final head from water surface to sample bottom [cm].

This method was described by e.g. Zvala et al. (2017).

Porosity

Porosity (P) is the fraction of pore volume (V_p) per total sample volume V (pores plus solids):

$$P = \frac{V_p}{V} \quad [-] \quad (4)$$

Using known ρ_d and ρ_s the formula (4) can be replaced with (Velebný, 1981):

$$P = 1 - \frac{\rho_d}{\rho_s} \cdot 100 \quad [\%] \quad (5)$$

Porosity of surface soil typically decreases as particle size increases and porosity of subsurface soil is lower than in surface soil due to compaction by gravity. Soil bulk density influences the soil porosity and porosity can be proportional to hydraulic conductivity. Soil porosity is

affected by soil particle texture, soil structure, soil compaction and quantity of organic material.

Results and discussion

Our measurements of soil bulk density, particle density, and porosity confirmed the scientific studies results that with higher rate of biochar the soil bulk density and particle density decrease and porosity and saturated hydraulic conductivity increased.

Average soil bulk density (Fig. 1) significantly decreased for G20, G40 and G80 about 10, 18 and 26%, respectively in comparison to pure soil. Biochar may affect soil bulk density indirectly by influencing aggregation. Increasing biochar concentration in soils resulted in decreasing soil bulk density (Verheijen et al., 2019).

Average particle density (Fig. 2) also decreased in comparison to pure soil. The smallest difference was between soil and G20, only 0.71%. For G40 and G80 it was about 4.5 and 7.4%, respectively. In general, particle density represents the average density of all the minerals composing the soil. The density of the minerals depends on their elementary composition, so particle density of a soil is certainly also dependent on its chemical bulk composition.

Average measured saturated hydraulic conductivity (Fig. 3) decreased for G20 about 49%, but for G40 and G80 increased about 25 and 195%, respectively in comparison to pure soil. These results confirmed results by Liu et al. (2016) who found that when biochar particles were finer than soil particles, K value more decreased with less biochar rate. In our case the mixtures of G20 contained smaller biochar particles than G40 and G80. Esmaeelnejad et al. (2017) founded that biochar's effect on K was mainly controlled by interpores. When fine-grained particles applied to soil, they filled interpores resulting in a creation of smaller pores and

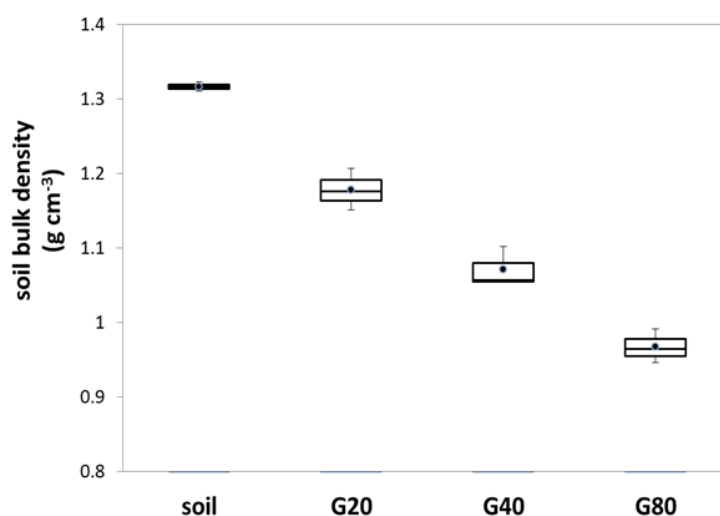


Fig. 1. Measured soil bulk density using core method at pure soil samples (soil) and mixtures soil with biochar rate of 20 t ha⁻¹ (G20), 40 t ha⁻¹ (G40) and 80 t ha⁻¹ (G80). Value range: minimum, 25th percentile, median, 75th percentile, maximum and circles represent average value.

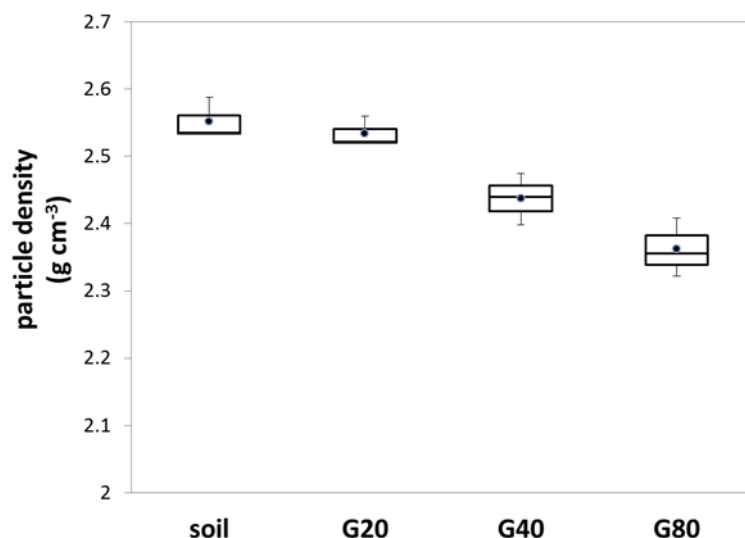


Fig. 2. Measured particle density using pycnometric method at pure soil samples (soil) and mixtures soil with biochar rate of 20 t ha^{-1} (G20), 40 t ha^{-1} (G40) and 80 t ha^{-1} (G80). Value range: minimum, 25th percentile, median, 75th percentile, maximum and circles represent average value.

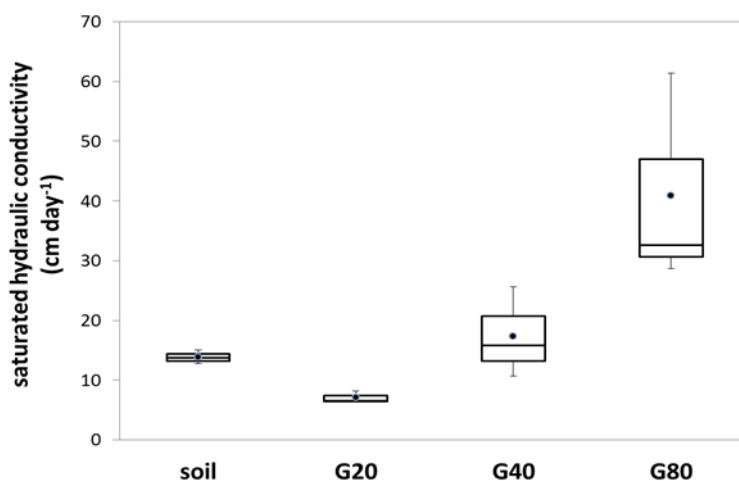


Fig. 3. Measured saturated hydraulic conductivity using falling head method at pure soil samples (soil) and mixtures soil with biochar rate of 20 t ha^{-1} (G20), 40 t ha^{-1} (G40) and 80 t ha^{-1} (G80). Value range: minimum, 25th percentile, median, 75th percentile, maximum and circles represent average value.

an increase of tortuosity, thus decreasing K . Degree of permeability for G20 was *very low* (7 cm day^{-1}) and for soil, G40 and G80 *low* (13 , 17 and 40 cm day^{-1} , respectively). The range values were higher in G40 and G80 mixtures. Previous studies showed that amending soil with biochar can either increase (Hlaváčiková et al., 2016) or decrease K (Liu et al., 2016).

Average porosity, calculated based on formula (5), increased with biochar rate (Fig. 4). For G20 was higher at 10%, for G40 at 15% and for G80 at 22% in comparison to pure soil. When pores are connected, water moves faster in larger pores than in smaller pores and

thus larger pores dominate water flow through porous media. Amending soil with biochar will likely change porosity, pore size, pore connectivity, and hydrophobicity of soil because of the dual porosity of the system, changes in the particle size distribution, and hydrophobicity of biochar (Liu et al., 2016).

Soil samples and mixtures prepared in laboratory conditions, had similar compaction as this type of soil in field conditions, as well as mixture of this type of soil and biochar in rate of 20 t ha^{-1} in field conditions, applied in Malanta area, where our previous research was done. Differences between samples in the same type of set were

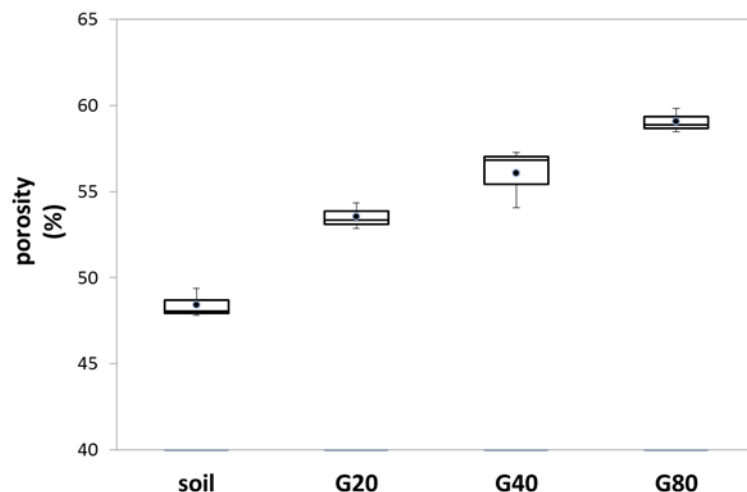


Fig. 4. Calculated porosity at pure soil samples (soil) and mixtures soil with biochar rate of 20 t ha^{-1} (G20), 40 t ha^{-1} (G40) and 80 t ha^{-1} (G80). Value range: minimum, 25th percentile, median, 75th percentile, maximum and circles represent average value.

insignificant during measurements.

Results of soil bulk density and porosity measurements were significant between pure soil and G20. Conversely, by particle density were insignificant and by saturated hydraulic conductivity were opposite than other measurements, in this content it means negative. There were measured big differences in all analyzed characteristics between pure soil and G80. The question now is, how much organic matter, in this case the biochar, is needed add into the silt loam soil to prepare its optimal hydro-physical conditions for vegetation root system. Based on results in our study, the biochar amendment in rate of 80 t ha^{-1} is too much and differences between G40 and G80 were small. Amount of 20 t ha^{-1} of biochar had a negative effect on saturated hydraulic conductivity, so the optimal amount of grapevine biochar for improving hydro-physical characteristics of silt loam soil was 40 t ha^{-1} .

Conclusions

In this study we tried to analyze some hydro-physical characteristics after biochar application on samples prepared in laboratory conditions. We measured soil bulk density, particle density, and calculated porosity to help understand the physical mechanisms that may cause changes in saturated hydraulic conductivity. The results in all studied characteristics varied with biochar concentration. Adding biochar decreased soil bulk density, particle density and increased porosity. Depending on the soil type and particle size of biochar, results are more or less similar in many scientific studies and our study confirmed these conclusions. Measurements of saturated hydraulic conductivity were different, because adding biochar into soil may affect saturated hydraulic conductivity of soil by changing pore characteristics. Past studies have reported that biochar

addition increases saturated hydraulic conductivity as a result of its high surface area and large internal pore volume. We confirm it only for higher biochar concentrations. Decreasing of saturated hydraulic conductivity for G20 was caused by big count of very small particles of biochar. This type of grapevine biochar in amount of 40 t ha^{-1} is enough to improve hydro-physical characteristics of silt loam soil.

Acknowledgement

This work was supported by Scientific Grant Agency No. VEGA 2/0053/18 and by AgroBioTech Research Centre built in accordance with the project Building „AgroBioTech“ Research Centre ITMS 26220220180.

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