Enhancing Sandy Soil Resilience to Drought through Biochar

AUTHORS

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INTRODUCTION

Sandy soils are globally significant in agricultural areas but are inherently vulnerable to drought due to their low water retention capacity and high saturated hydraulic conductivity (Ks). This vulnerability is compounded by Soil Water Repellency (SWR), a condition where hydrophobic organic compounds on soil particles resist wetting, severely limiting water infiltration and plant water availability.

To build climate resilience and sustain agricultural productivity, innovative soil management strategies are critically needed. Biochar (BC), a porous, carbon-rich soil amendment, offers a promising adaptation solution. This study investigates the potential of biochar addition to sandy soils to improve key hydrophysical properties, thereby enhancing the soil's capacity to withstand drought and climate variability.

METHODOLOGY

A. Soil and Biochar Materials:

- **Soil**: Sandy soil (Aeolic Arenosol) with very low organic carbon content (≈0.04%), collected from Plavecký Štvrtok, Slovakia.
- **Biochars:** Two studies utilized biochars produced under different conditions to assess key factors:
  - **Study 1 (Surda et al., 2025):** Compared the effect of water-repellent willow biochar produced from the Swedish biomass willow variety - *Salix viminalis x schwerinii* var. Tordis (B300 at 300°C, B520 at 520°C) and a wettable fiber sludge/grain husk biochar (B550 at 550°C). All were applied at a 1% w/w rate with a 125 μm–2 mm particle size.
  - **Study 2 (Vitková et al., 2024):** Used willow biochar produced at 300°C and 520°C to test the influence of application rate (20 and 40 Mg ha−1) and particle size (<125 μm and 125 μm–2 mm).

B. Measured Hydrophysical Parameters:

- **Porosity (P):** Calculated from bulk and particle density.
- **Available Water Content (AWC):** Determined as the difference between field capacity (10 kPa) and permanent wilting point (1500 kPa) from Soil Water Retention Curves (SWRC).
- **Saturated Hydraulic Conductivity (K_S):** Measured using the modified falling-head method.
- **Soil Water Repellency (SWR):** Assessed by Contact Angle (CA) (severity) using the sessile drop method, and Water Drop Penetration Time (WDPT) (persistence).

OBJECTIVE

To systematically assess how biochar application rate, particle size, and pyrolysis temperature influence soil water retention, hydraulic conductivity, and water repellency in sandy substrates.

RESULTS AND DISCUSSION

The addition of biochar to sandy soil significantly improved key parameters related to drought resilience across both studies, although with strong dependence on the biochar's properties.

Table 1 Characteristics of biochar (C– carbon content, H– hydrogen content, N– nitrogen content, WDPT– water drop penetration time, CA– contact angle). (Source: Šurda et al., 2025)

Biochar	Product of origin	C [%] NR=3	H [%] NR=3	N[%] NR=3	WDPT [s] NR=5	CA [°] NR=5
B300	willow	82.2	2.74	0.86	12609.5^{a}	115.56^{a}
B520	willow	83.1	2.21	1.19	12613.8^{a}	128.30^{b}
B550	fiber sludge and grain husks	53.1	1.84	1.4	1.75^{b}	27.77^{c}

Sl.No.	Parameter	Biochar Effect	Key Findings (Vitková et al., 2024)	Key Findings (Surda et al., 2025)
1.	Available Water Content (AWC)	**Significant Increase** (up to 168% higher than control).	AWC was significantly affected by rate, size, and temperature. The highest increase was seen at the **40 Mg ha−1 rate** and with **smaller BC particles** (<125 μm).	AWC significantly increased in **all** BC treatments, nearly doubling the control value. No significant difference was found between hydrophobic (SB300, SB520) and wettable (SB550) types.
2.	Saturated Hydraulic Conductivity (K_S)	**Significant Decrease** (up to 90% reduction).	K_S was significantly decreased by all factors (rate, size, temperature). The **smallest BC particle size** (<125 μm) caused the greatest reduction, likely by clogging large pores.	**Hydrophobic** BCs (SB300, SB520) caused a **statistically significant K_S decrease**. **Wettable** BC (SB550) caused an insignificant K_S decrease.
3.	Porosity (P)	Increase.	P was significantly increased, but the effect depended on interactions between temperature and rate, and size and rate. The **large-sized BC** (125 μm–2 mm) caused the greatest increase.	P significantly increased in **all** BC treatments.
4.	**Contact Angle (CA)**	Increase.	CA was significantly affected by **rate and particle size**, but not pyrolysis temperature. The **small-sized BC** (<125 μm) and **higher application rate** (40 Mg ha−1) increased CA the most.	The **Hydrophobic** BCs (SB300, SB520) induced a **slight severity** of water repellency (40°≤CA<90°) in the soil mixture, while the **wettable** BC (SB550) mixture remained wettable (CA<40°).

Biochar enhances drought resilience primarily by increasing AWC and reducing K_S.

- The increased Available Water Content is crucial for drought mitigation, confirming biochar's role as a climate-smart amendment. This is attributed to the BC's porous structure increasing soil micro-porosity.
- The significant reduction in K_S is beneficial for sandy soils, as it slows water movement and reduces deep drainage losses, making more water available to plants. The finest BC fraction was most effective at reducing K_S, likely by filling large conductive pores.

KEY CLIMATE ADAPTATION STRATEGY:

To maximize soil water resilience in drought-prone areas, a climate-smart biochar strategy should focus on:

1. **High Application Rates** (40 Mg ha−1 demonstrated better AWC).
2. **Smaller Particle Sizes** (<125 μm) to maximize water retention (AWC) and reduce deep drainage (K_S).
3. **Hydrophobicity Assessment** is mandatory, as even slightly water-repellent BC can hinder water movement.

This research provides experimental evidence that optimized biochar application is a viable, climate-smart strategy for improving soil hydrophysical dynamics and securing productivity in sandy, drought-vulnerable landscapes.

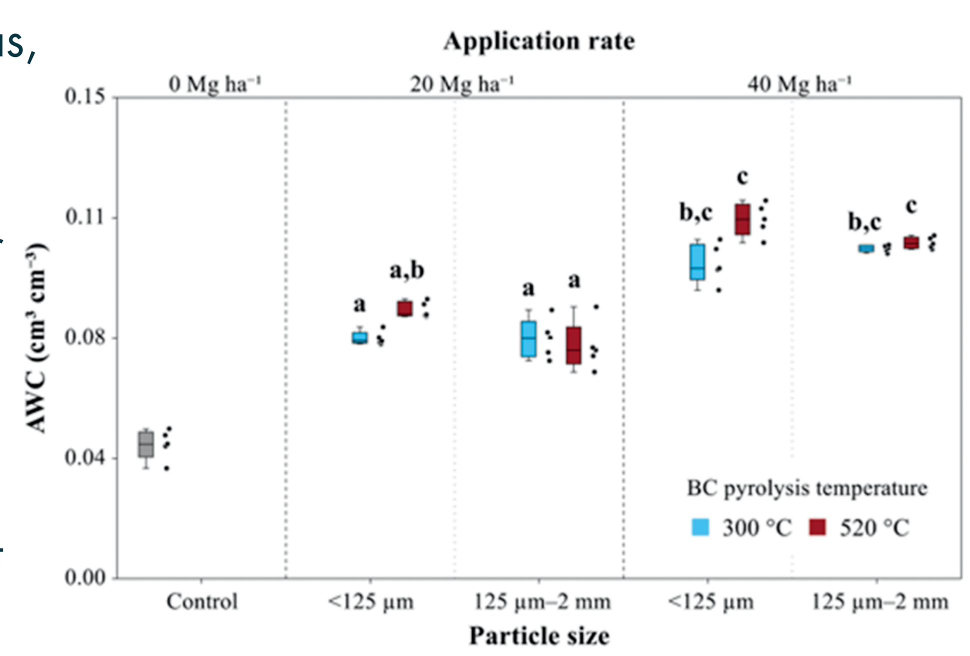

Figure 1: Measured values of the available water content for plants (AWC) for all experiment treatments. (Source: Vitková et al., 2024)

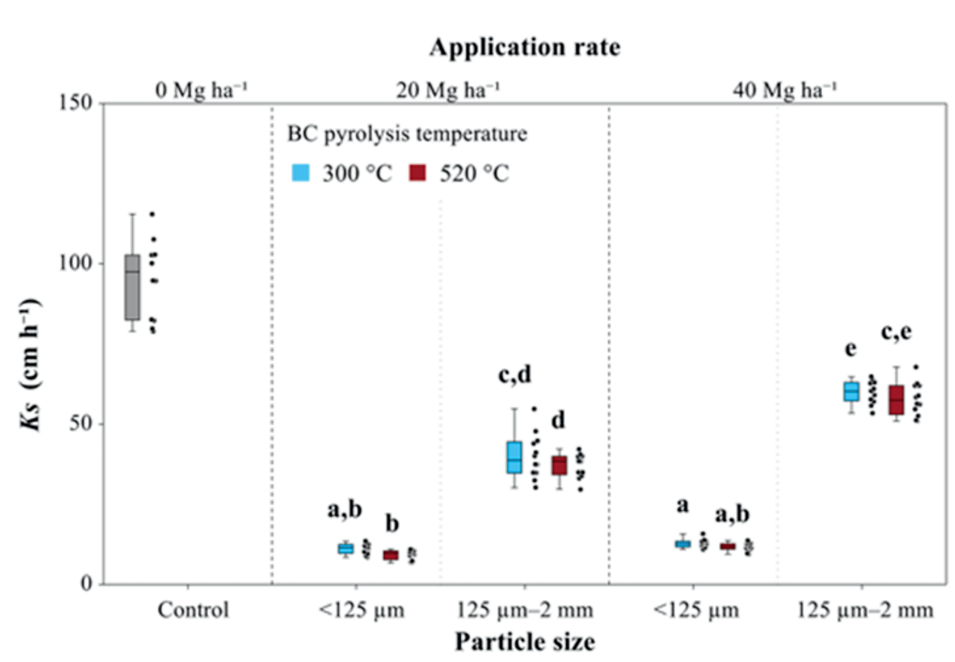

Figure 2: Measured values of the saturated hydraulic conductivity (K_S) for all treatments of the experiment. (Source: Vitková et al., 2024)

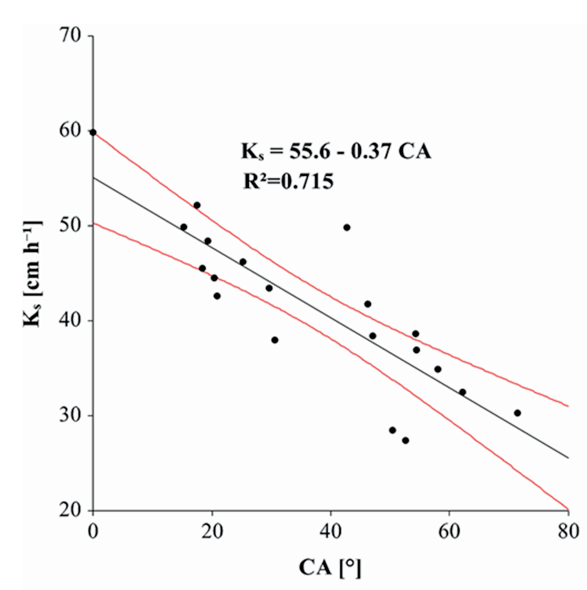

Figure 3: The relation between the saturated hydraulic conductivity (K_S) and contact angle (CA), in sandy soil amended with wettable and hydrophobic biochars. (Source: Šurda et al., 2025).

CONCLUSION

Biochar, a highly porous carbon-rich amendment, possesses desirable soil amendment properties due to its inherent structural characteristics; however, its influence on Soil Water Repellency (SWR) requires critical evaluation. A subtle, biochar-induced elevation in the contact angle (CA) was found to be inversely and highly correlated with the soil's saturated hydraulic conductivity (K_S). This implies that a marginal increase in soil hydrophobicity can significantly impair the hydrologic efficiency and transmissivity of the soil matrix.

References: 1. Šurda, P., Vitková, J., Lichner, L., Botková, N., & Toková, L. (2025). Effect of wettable and hydrophobic biochar addition on properties of sandy soil. Biologia, 80, 1247–1258. https://doi.org/10.1007/s11756-024-01702-9
2. Vitková, J., Šurda, P., Lichner, L., & Výleta, R. (2024). Influence of biochar application rate, particle size, and pyrolysis temperature on hydrophysical parameters of sandy soil. Applied Sciences, 14(8), 3472. https://doi.org/10.3390/app14083472

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