

Biochar Rate Effects on Soil Water Content in Agricultural Production in the Lower Mississippi River Valley

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Abstract

In row-crop agriculture, soil water content and water retention are vital concerns for optimal crop productivity. Biochar has been reported to increase soil water-holding capacity owing to biochar's porous nature, varying particle size, and large surface area. The objective of this field study was to evaluate the effects of biochar (B) rate [*i.e.*, 0 (0B), 2000 (2B), and 4000 (4B) kg·ha⁻¹], soil depth [*i.e.*, 15, 30, and 45 cm], and their interaction on soil water content at three locations (*i.e.*, Newport in 2023 and 2024, Stuttgart from 2023-2025, and Dumas in 2024 and 2025) throughout the Lower Mississippi River Valley region of eastern Arkansas. At Newport in 2023, averaged across time, soil water contents in the 2B were 4.9% greater than the 0B treatment. At Dumas, soil water contents in the 2B/45- were 15% greater than in the 0B/15-cm combination in 2024 [cotton (*Gossypium hirsutum* L.)] and were 14% greater in the 0B/30- than in the 2B/30-cm combination in 2025 [corn (*Zea mays* L.)]. Soil water contents at Stuttgart were 8% greater in the 4B/30- than in the 0B/45-cm combination, 18% larger in the 0B/45- than in the 2B/30-cm combination, and 4% greater in the 0B/45- than in the 2B/30-cm combination in 2023, 2024, and 2025 under soybean (*Glycine max* L.), corn, and soybean, respectively. Results indicated that soil-applied biochar can conserve more soil water in water-limited environments than in agroecosystems that undergo frequent furrow-irrigation throughout a typical growing season in eastern Arkansas. Data were not collected at Dumas in 2023 and at Newport in 2025 as the result of repeated equipment malfunctions which hindered data collection.

Keywords

Biochar, Soil Water Content, Furrow Irrigation, Rainfed Irrigation

1. Introduction

Agricultural water use continues to be a serious sustainability issue for row-crop producers, particularly in eastern Arkansas where groundwater levels are declining [1]. The primary source of irrigation in eastern Arkansas is regional underground aquifers. As a result of drastically changing climactic conditions that can bring about sustained periods of drought, coupled with large groundwater withdrawals to support maximum irrigated crop production, aquifers are continually being depleted faster than their rate of recharge. The discrepancy between aquifer depletion and recharge rate can severely affect the water supply for present and future generations of Arkansas producers. In order to address the irrigation concerns, conservation practices, such as the installation of on-farm retention ponds [2] and planting cover crops [3], have been implemented as ways to alleviate aquifer reduction. However, soil amendments, such as biochar, have been viewed as options to potentially retain soil moisture and reduce irrigation-water demand.

Biochar is derived from the burning of plant biomass materials in a controlled environment of low oxygen via pyrolysis [4]. Numerous biomass sources can be used for biochar production, such as crop residues, forestry waste material, and poultry litter [5]. Increasing awareness of implementing and practicing sustainable agriculture, as well as sound environmental stewardship, has generated interest in biochar as a soil amendment. Field application of biochar is a custom that is still performed by millions of people around the world [5]. Biochar additions, over time, have made lands that were previously nutrient deficient and structurally degraded into fertile areas, conducive to agricultural production [6]. However, numerous factors, such as biochar feedstock, regional soil textures, and pre-existing soil nutrient status, all contribute to the potential efficacy of biochar as a soil amendment [7].

In response to past observations, numerous field studies have been performed to determine the effects of soil-applied biochar on various aspects of soil health [8] [9]. As a result of biochar being a porous, nutrient-rich, charcoal-like material [10], scientists have investigated the possibility of biochar as an organic amendment to improve soil tilth [11] and increase soil water content [12]. Soil applications of biochar have been reported to increase soil water-holding capacity and subsequent soil water contents [13] [14]. Soil-applied biochar has also been shown to reduce soil bulk density, along with alleviating soil compaction [15]. The primary cause of the soil health benefits has been attributed to assorted physical characteristics of biochar, which include large porosity and surface area depending on biochar particle size [16] that greatly affects soil structure and subsequent soil water retention [17].

Biochar has enhanced growth and development of various plant species, along with numerous soil parameters, either in a single application or in conjunction with commercial inorganic fertilizers and other organic resources [18] [19]. However, many aspects of biochar are still relatively unknown to agricultural producers and full-scale production systems throughout the United States with regards

to soil health and soil water content. Therefore, the objective of this multi-year field study was to quantify the effects of soil-applied biochar rates and soil depth on soil water content at three row-crop locations in eastern Arkansas. It was hypothesized that soil-applied biochar will increase soil water content at soil depths of 15, 30 and 45 cm in rainfed and furrow-irrigated production systems.

Increasing soil profile water contents in agricultural production is becoming progressively more vital during periods of sustained drought, which are intensified by climate change, to maintain optimal crop production. Consequently, the novelty of this study lies in the systematic and spatially replicated assessment of soil profile water contents across multiple row-crop systems for multiple consecutive years of consistent management in the highly agriculturally productive region of eastern Arkansas.

2. Materials and Methods

2.1. Experimental Site Information

This field study was conducted at two Arkansas Discovery Farms (ADF) [20] research sites located near the cities of Dumas (33.8188, -91.3386214) in 2024 and 2025 and Stuttgart (34.3620372, -91.5213238) from 2023-2025, along with the UADA Jackson County Extension Center in Newport, Arkansas (35.5712, -91.2601) in 2023 and 2024. Soil taxonomic classifications for the study areas at each location are reported on Table 1.

Table 1. Summary of soil series, slope class, and taxonomic description of the soils mapped at the three field sites in eastern Arkansas.

Location	Soil Series, Slope Class, and Taxonomic Description
Dumas	Herbert silt loam, 0% to 1% slopes; Fine-silty, mixed, active, thermic Aeric Epiaqualfs
Newport	Dexter silt loam, undulating; Fine-silty, mixed, thermic Ultic Hapludalfs
Stuttgart	Stuttgart silt loam, 0% to 1% slopes; Fine, smectitic, thermic Albaquultic Hapludalfs

2.2. Treatments and Experimental Design

At each location, three biochar rate treatments, 0 (0B), 2000 (2B), and 4000 (4B) kg·ha⁻¹, were established in plots with dimensions of four rows that were 10-m long, with a row spacing of 96 cm at Dumas and 76 cm at Stuttgart and Newport. Plots were arranged in a randomized complete block design (RCBD), where treatments were replicated with four blocks for a total of 12 plots at each location.

2.3. Soil Sample Collection and Processing

Soil samples were collected from the 0 to 10-cm depth interval in each unamended plot at Newport on May 3 and Stuttgart on May 17 and 0 - 15 cm at Dumas on March 22 prior to the first biochar applications in 2023, sent to the Arkansas Soil

Testing Laboratory in Marianna, Arkansas, and analyzed for pH and estimated cation exchange capacity (CEC) using a 1:2 soil-water volume mixture ratio. The soil samples were then transported to the Altheimer Soil and Plant Diagnostic Laboratory in Fayetteville, Arkansas for determination of organic matter (OM) concentration by the weight-loss-on-ignition method [21] in a muffle furnace for two hours at a starting temperature of 105°C and an ending time of 360°C.

A separate set of soil samples were collected from the unamended control plots in 2024 at all three locations using a 4.8-cm-diameter soil core. Samples were dried for approximately 48 hours (h) at 70°C [22] and weighed for bulk density determinations. **Table 2** summarizes initial soil properties from the unamended control plots at the three research sites.

Table 2. Summary of initial 2023 unamended plot soil textures and mean ($\pm$ standard error) bulk density (BD) for the unamended control plots in 2024, soil pH, Mehlich-3 phosphorus (M3-P), Mehlich-3 potassium (M3-K), total nitrogen (N), estimated cation exchange capacity (CEC) and organic matter (OM) prior to the first biochar applications in 2023 for the three sites in eastern Arkansas.

Site	Sand (%)	Silt (%)	Clay (%)	BD (g·cm ⁻¹)	pH	M3-P (mg·kg ⁻¹)	M3-K (mg·kg ⁻¹)	N (%)	CEC (cmol _c ·kg ⁻¹)	OM (%)
Dumas	15	78	6	1.12 (<0.1)	6.7 (0.1)	82.5 (5.1)	170.8 (9.6)	0.11 (< 0.1)	10.5 (0.5)	2.3 (<0.1)
Newport	46	43	12	1.42 (<0.1)	6.2 (0.0)	65.5 (17)	178.8 (63)	0.08 (< 0.1)	7.3 (1.6)	1.4 (0.1)
Stuttgart	17	68	15	1.40 (<0.1)	5.5 (0.1)	115.3 (13)	200.8 (16)	0.10 (< 0.1)	8.0 (0.4)	2.2 (0.1)

2.4. Field Management

Each ADF site focused on row-crop agriculture with emphasis on cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) production in Dumas, soybean (*Glycine max* L.) and corn production in Stuttgart, and soybean production in Newport. Yearly crop production information for each research location is reported in **Table 3**.

Table 3. Summary of annual crop production information for the three sites in eastern Arkansas.

Year/Location	Crop	Cultivar	Seeding Rate (seeds·ha ⁻¹)	Planting Date
2023				
Newport	Soybean	Pioneer P46A20LX	NA ^a	May 9
Stuttgart	Soybean	Delta Soy DS577	321,326	May 17
2024				
Dumas	Cotton	Delta Pine 2127	98,840	April 25
Newport	Soybean	Pioneer P46A20LX	NA	May 31
Stuttgart	Corn	Revere 1577	84,015	April 12
2025				
Dumas	Corn	Croplan 5678	85,251	March 27
Stuttgart	Soybean	Delta Soy DS577	308,875	June 15

^aNA, not available.

Due to the relatively small plot dimensions, field applications of biochar were broadcast by hand at a walking speed of approximately $4.8 \text{ km}\cdot\text{hr}^{-1}$. Biochar was applied each project year, shortly before each location's planting. The mechanical soil manipulations from planting lightly incorporated the biochar to a depth of ~5 to 10 cm. Pre-plant and in-season fertilizer applications were made for each location according to soil-test results and UADA fertilizer recommendations for cotton [23], corn [24], and soybean [25]. Estimated crop yields were determined from hand-harvested samples collected at Dumas on September 4, 2024, and August 12, 2025; at Newport on October 3, 2023, and September 30, 2024; and at Stuttgart on October 12, 2023, August 12, 2024, and October 14, 2025. Cumulative biochar applications for each site and project year were as follows: biochar treatments 2B and 4B at Dumas in 2024 received 7.76 and $15.52 \text{ kg}\cdot\text{plot}^{-1}$ respectively and in 2025, the cumulative applications were 15.52 and $31.04 \text{ kg}\cdot\text{plot}^{-1}$ respectively; treatments 2B and 4B at Newport in 2023 received 6.08 and $12.16 \text{ kg}\cdot\text{plot}^{-1}$ respectively and in 2024, cumulative rates were 12.16 and $24.32 \text{ kg}\cdot\text{plot}^{-1}$ respectively; treatments 2B and 4B for Stuttgart in 2023 received 6.08 and $12.16 \text{ kg}\cdot\text{plot}^{-1}$ respectively and cumulative rates rose to 12.16 and $24.32 \text{ kg}\cdot\text{plot}^{-1}$ in 2024 and 18.24 and $36.48 \text{ kg}\cdot\text{plot}^{-1}$ for treatments 2B and 4B respectively.

The Dumas and Stuttgart sites were managed using furrow irrigation according to producer-standard practices. Irrigation water was supplied using two irrigation sets with an approximate capacity of 4921 liters per minute (LPM). Irrigation was typically applied at 7- to 8-day intervals depending on rainfall and crop water demand during the various stages of crop development throughout a growing season. Cumulative rainfall totals at each site during each project year's data range were as follows: Dumas in 2024 and 2025 had cumulative rainfall totals of 39.9 cm and 39.2 cm respectively (University of Arkansas at Monticello, AR US USC00037315), Newport in 2023 and 2024 had cumulative rainfall amounts of 25.3 cm and 41.5 cm respectively (Newport Army Air Field, AR US USC00035189), and Stuttgart in 2023, 2024, and 2025 had cumulative rainfall totals of 18.8 cm, 36.5 cm, and 22.8 cm respectively (Stuttgart Municipal Airport, AR US USW00013925).

2.5. Biochar Properties

The biochar used in this study was produced by enviraPAC (Monticello, Arkansas) from short-leaf pine (*Pinus echinata*), a species the company recommended for agricultural usage, and was produced at temperatures $> 600^{\circ}\text{C}$. The resulting particle-size distribution of the biochar was mixed, ranging from fine to 1.6 cm in characteristic dimension. The biochar was not inoculated prior to field application. Biochar sub-samples were sent to the Alzheimer Soil and Plant Diagnostic Laboratory in Fayetteville, Arkansas and evaluated for various initial chemical characteristics (Table 4).

2.6. Soil Water Pressure Monitoring and Data Processing

Evaluation of biochar rates on soil water content was made by installing three soil

water pressure sensors (200SS-15, IRROMETER Company Inc., Riverside, CA) in each plot by excavating holes with a slide hammer and soil probe to depths of 15, 30, and 45 cm to continuously monitor soil water pressure throughout the calendar year. Soil water pressure sensors were connected to data loggers (900 M, IRROMETER Company Inc.) placed within the 3-m wide alleys between treatment blocks for continuous data recording and exporting. Soil water pressure sensors recorded data every 12 hours (hr), but averaged at 12-hr intervals for statistical analyses.

Table 4. Chemical analyses of enviraPAC (Monticello, AR) biochar for total nitrogen (TN), total phosphorus (TP), total potassium (TK), total calcium (TCa), pH, and electrical conductivity (EC) along with N, P₂O₅, K₂O, and Ca.

Biochar Property	Mean	Sample Basis
TN (%)	0.18	Dry basis
TP (%)	0.03	Dry basis
TK (%)	0.28	Dry basis
TCa (%)	0.14	Dry basis
pH	9.5	Dry basis
EC (dS·m ⁻¹)	0.47	Dry basis
N (kg·Mg ⁻¹)	1.40	As-is basis
P ₂ O ₅ (kg·Mg ⁻¹)	0.58	As-is basis
K ₂ O (kg·Mg ⁻¹)	2.73	As-is basis
Ca (kg·Mg ⁻¹)	1.10	As-is basis

Measured soil water pressures were converted to soil water contents using the Soil-Plant-Air-Water (SPAW) computer tool [26] using initial sand and clay percentages and average OM concentration data from the unamended control plots at each location from the 0 - 10 cm at Newport and Stuttgart and 0 - 15 cm at Dumas to reflect the appropriate soil sample depth according to UADA recommendations for soybeans [25] and cotton [23], respectively. Soil texture data used were as follows: 15% sand and 6% clay at Dumas, 46% sand and 12% clay at Newport, and 17% sand and 15% clay at Stuttgart based on on-house measurements using the 12-hr hydrometer method [27]. Soil OM concentrations were averaged from soil samples collected from unamended control plots in 2023 (*i.e.*, 2.3% for Dumas, 1.4% for Newport, and 2.2% for Stuttgart). Conversion of measured soil water pressures to soil water contents allowed for a clearer inference in determining differences between the three biochar treatments and soil depths by project year along with any observed statistical interactions.

Dataloggers and sensors were removed from each field plot prior to each location's primary harvesting event and reinstalled shortly thereafter. The dataloggers and sensors were then removed prior to the planting of next year's crop at each location and subsequently reinstalled. Data was not collected at Dumas in 2023

and at Newport in 2025 due to repeated equipment malfunctions that impeded effective data collection.

2.7. Statistical Analyses

The effects of biochar rate, soil depth, and their interaction on soil water contents were evaluated by a two-factor ANOVA, separately by location and separately by year, using a generalized linear mixed model with a lognormal distribution in JMP Student Edition 18 and SAS Version 9.4 (SAS Institute, Inc.). Biochar rate and soil depth were fixed effects, while datalogger measurement date in each project year was a random effect, used as a term of repeated measures and not officially tested as a fixed effect in all analyses. Soil water content values for each biochar rate and soil depth treatment combination were calculated by averaging soil water contents from individual biochar treatment plots across all four blocks at each location. The 12-hour sampling intervals for each site were included in each sampling date random effect and subsequently incorporated into the covariance structure. Means for all analyses were determined by a protected least significant difference (LSD) procedure at $P < 0.05$.

3. Results

Agricultural productivity is contingent on adequate soil moisture for optimum crop growth. Soil water contents differed among biochar treatments, soil depths, and/or both across all three study locations and within study years at a location (Table 5).

Table 5. Analysis of variance summary of the effects of biochar treatment, soil depth, and their interaction on soil water contents at three locations in the Lower Mississippi River Valley in 2023, 2024, and/or 2025.

Location/Year	Biochar	Soil Depth	Biochar × Soil Depth
P			
Dumas			
2024	<0.001	<0.001	<0.001
2025	<0.001	<0.001	<0.001
Newport			
2023	<0.001	<0.001	0.139
2024	<0.001	<0.001	<0.001
Stuttgart			
2023	<0.001	<0.001	<0.001
2024	<0.001	<0.001	<0.001
2025	0.001	0.001	<0.001

3.1. Dumas

Soil water contents over time for Dumas in 2024 were generally consistent among

the three biochar treatments at the 15- and 30-cm depths for each instance of low and large soil water contents throughout that soybean growing season (**Figure 1**). The only inconsistency between biochar rates at 45 cm occurred between days of year 160 - 180 when soil water contents in the 2B treatment were visually greater when compared to the other two treatments (**Figure 1**). In contrast to 2024, soil water contents over time for 2025 showed inconsistencies between biochar treatments throughout the corn growing season. Soil water contents for all biochar rate/soil depth combinations in 2025 varied for most of the measurement period, with days of year 100 - 120 providing the largest variation in soil water contents among treatment combinations (**Figure 1**).

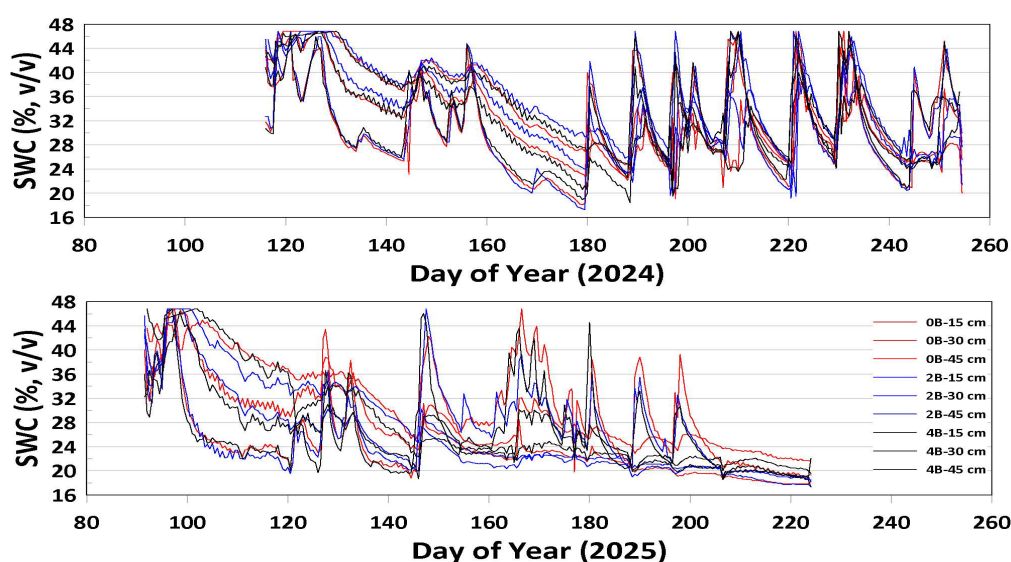


Figure 1. Soil water contents over time throughout the 2024 (top) and 2025 (bottom) growing seasons at the Dumas, AR site by biochar (B) treatment (0, 2, and 4 Mg-ha⁻¹) and soil sensor depth combination. Cotton was grown in 2024 and corn in 2025.

At Dumas, in southeast Arkansas, soil water contents differed among biochar treatments by soil depth ($P < 0.001$) in 2024 and 2025 (**Table 6**). In 2024, soil water content in the 2B/45- was greater than all other biochar-depth treatment combinations. Soil water contents in the 2B/30-, 4B/45-, and 0B/45- were greater than in the 0B/30- and 4B/30-cm biochar-depth treatment combinations, which, in turn, had greater soil water contents than in the 4B/15-, 2B/15-, and 0B/15-cm biochar-depth treatment combinations.

In 2025, in contrast to 2024, soil water contents in the 0B/30- were greater than in all other biochar-depth treatment combinations. Slightly similar to 2024, soil water contents were also greater in the 0B/15-, 0B/45-, and 2B/45- than in the 4B/30- and 4B/45-, which were, in turn, greater than in the 2B/15-, 4B/15-, and 2B/30-cm biochar-depth treatment combinations. Data for Dumas in 2023 was not reported due to repeated equipment malfunctions which deterred data collection.

Table 6. Soil water contents at Dumas, Newport, and Stuttgart in percent by volume (%Vol.) for biochar treatments equivalent to 0 (0B), 2000 (2B), and 4000 (4B) kg·ha⁻¹ in 2023, 2024, and 2025 at the 15-, 30-, and 45-cm soil depths.

Biochar Treatment	Soil Depth (cm)	Soil Water Content (% v/v)						
		Dumas			Newport		Stuttgart	
		2023	2024	2025	2024	2023	2024	2025
0B	15	-	29.2 e ^a	26.7 b	21.4 f	35.9 bc	32.5 d	31.3 de
	30	-	31.5 c	28.2 a	22.8 e	36.7 a	35.4 b	33.3 b
	45	-	32.8 b	26.3 b	26.1 b	34.3 e	37.1 a	34.6 a
2B	15	-	29.5 e	25.1 d	20.3 g	35.3 d	32.5 d	33.0 b
	30	-	33.1 b	24.1 e	25.0 c	35.7 c	30.7 f	31.2 e
	45	-	34.5 a	26.3 b	27.1 a	35.3 d	31.7 e	32.4 bc
4B	15	-	30.2 d	24.8 d	22.8 e	35.9 bc	31.3 e	32.0 cd
	30	-	31.3 c	25.6 c	24.7 cd	36.8 a	34.7 c	33.1 b
	45	-	32.9 b	25.8 c	24.3 d	36.1 b	34.6 c	32.3 c

^aColumns not sharing the same letter are significantly different ($P < 0.05$).

3.2. Newport

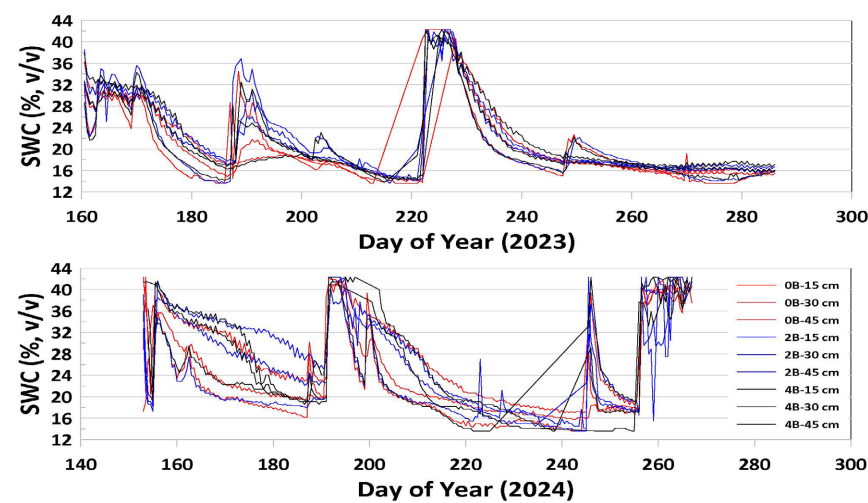


Figure 2. Soil water contents over time throughout the 2023 (top) and 2024 (bottom) growing seasons at the Newport, AR site by biochar (B) treatment (0, 2, and 4 Mg·ha⁻¹) and soil sensor depth combination. Soybeans were grown in both years.

Soil water contents at Newport in 2023 were generally similar between biochar treatments at all depths, except for two periods: between days of year 170 - 180 and 185 - 200 (Figure 2). Soil water contents in the 2B treatment were consistently larger at all depths during these intervals. In contrast to 2023, soil water contents in 2024 showed inconsistencies between biochar treatments at all depths (Figure 2). The inconsistencies were more pronounced in the intervals between peaks representing periods of large soil water contents, with soil water contents in the 2B and 4B treatments greater than in the 0B treatment at the 15- and 30-cm depths through-

out the 2024 soybean growing season (**Figure 2**). At the 45-cm soil depth, soil water content inconsistencies among biochar treatments occurred again during peak intervals, however the inconsistencies fluctuated between treatments (**Figure 2**).

At Newport, in northeast Arkansas, soil water contents differed among biochar treatments ($P < 0.001$) and differed among soil depths ($P < 0.001$) in 2023 (**Table 7**). Soil water contents, averaged across soil depths, was greater in the 2B than in the 4B treatment and soil water contents in both biochar treatments were greater than in the 0B treatment (**Table 7**). Averaged across biochar treatments, soil water contents at the 45-cm depth were greater than at the 30-cm depth, which was, in turn, greater than at the 15-cm depth (**Table 7**).

Table 7. Soil water contents at Newport in percent by volume (%Vol.) for biochar treatments equivalent to 0 (0B), 2000 (2B), and 4000 (4B) kg·ha⁻¹ and for the 15-, 30-, and 45-cm soil depths in 2023.

Treatment	Soil Water Content (% v/v)
Biochar	
0B	19.3 c ^a
2B	20.3 a
4B	20.0 b
Soil Depth (cm)	
15	19.3 c
30	19.9 b
45	20.4 a

^aColumns not sharing the same letter are significantly different ($P < 0.05$).

In contrast to 2023, in 2024, soil water contents differed among biochar treatments by soil depth ($P < 0.001$) (**Table 5**). Soil water contents in the 2B/45- was greater than in all other biochar-depth treatment combinations (**Table 6**). Soil water contents in the 0B/45- was greater than in the 2B/30- and 4B/45-cm combinations, with the 4B/30-cm combination intermediate (**Table 6**). Soil water contents decreased in the following order 0B/30- = 4B/15- > 0B/15- > 2B/15-cm for the remaining biochar depth combinations (**Table 6**). Data for Newport in 2025 was not reported due to consistent equipment breakdowns which impeded data collection.

3.3. Stuttgart

Soil water contents for Stuttgart in 2023 were generally consistent among biochar treatments at all soil depths throughout the soybean growing season (**Figure 3**). However, in contrast to 2023, there were visible differences in soil water contents in the intervals between peak water contents in 2024, with soil water contents in the 0B treatment consistently greater at 45 cm than for all other treatment combinations from days of year 130 - 160 (**Figure 3**). From day of year 160 to 220,

little soil water content consistency occurred, where soil water contents in the 0B and 4B treatments were consistently greater than the 2B treatment at all soil depths (**Figure 3**).

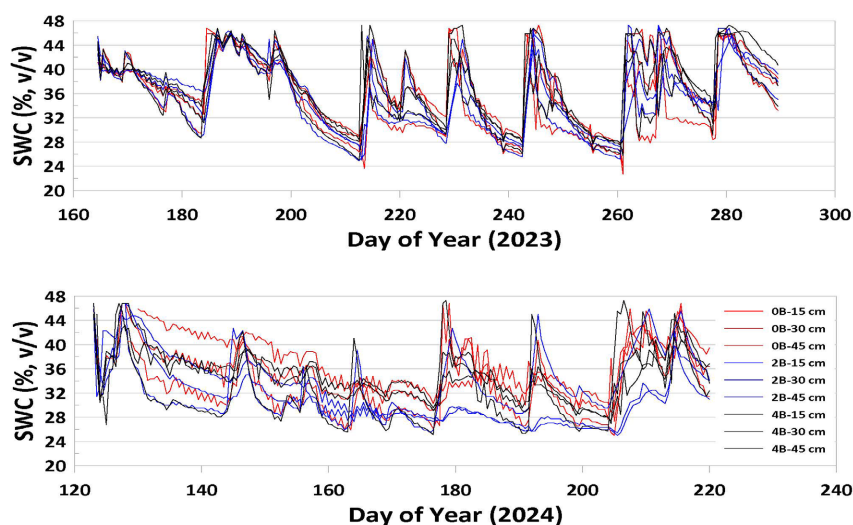


Figure 3. Soil water contents over time throughout the 2023 (top) and 2024 (bottom) growing seasons at the Stuttgart, AR site by biochar (B) treatment (0, 2, and 4 Mg·ha⁻¹) and soil sensor depth combination. Differences in x-axes values on both graphs are the result of different planting/harvesting dates and growing season durations for soybean (2023) and corn (2024).

Similar to Dumas, but in contrast to Newport, soil water contents at Stuttgart, in east-central Arkansas, differed among biochar treatments by soil depth ($P < 0.001$) in 2023, 2024, and 2025 (**Table 6**). In 2023, soil water contents in the 4B/30- and 0B/30- were greater than in all other biochar-depth treatment combinations (**Table 6**). Soil water contents in the 4B/45- were also greater than in the 2B/30-, with soil water contents in the 4B/15- and 0B/45-cm combinations intermediate (**Table 6**). Soil water contents in the 2B/45- and 2B/15- were greater than in the 0B/45-cm combination (**Table 6**).

In contrast to 2023, soil water contents in the 0B/45- were greater than in all other biochar-depth combinations (**Table 6**) in 2024. Soil water contents in the 0B/30- were also greater than in the 4B/30- and 4B/45-, which, in turn, had greater soil water contents than in the 2B/15- and 0B/15-cm combinations (**Table 6**). Soil water contents in the 2B/45- and 4B/15- were both greater than in the 2B/30-cm combination (**Table 6**).

In 2025, similar to 2024, soil water contents in the 0B/45- were again greater than in all other biochar-depth treatment combinations (**Table 6**). In contrast to 2023/2024, soil water contents in the 0B/30-, 4B/30-, and 2B/15- were greater than in the 4B/45-cm combination, with soil water contents in the 2B/45-cm combination intermediate (**Table 6**). Soil water contents in the 4B/45- were greater than in the 0B/15-cm combination, with soil water contents in the 4B/15- intermediate followed by the 2B/30-cm combination (**Table 6**).

4. Discussion

Soil water contents frequently differed among biochar rates by soil depth at the two ADF experimental locations and at the UADA research center in Newport throughout this study, although the differences were more pronounced at Newport than at Dumas and Stuttgart. At first glance, the differences appear to be the result of different irrigation regimes, with both Dumas and Stuttgart relying heavily on furrow irrigation during the growing season from both groundwater and aboveground tail water-ditch reservoir recovery sources, respectively [2], while Newport only relied on rainfall as the crop water source. However, since all three locations differed somewhat regarding the extent to which soil water contents were affected by biochar-depth treatment combinations, the variations in soil texture at each site may have played a role in the differences among locations [13].

Although the soils at all three locations shared the same soil order classification (*i.e.*, Alfisols), the soil at Dumas had a lower clay content (Table 2), thus making the soil incorporation of surface-applied biochar by the mechanical planter more efficient than at Newport and Stuttgart. The soils at Newport and Stuttgart had greater clay contents (Table 2), thus likely impeded biochar incorporation via mechanical planting to some degree within their respective soil profiles, leaving a sizeable portion of biochar on the soil surface. In addition to soil texture, other soil property differences may have contributed to differential soil water content behavior among the three study locations. Despite the soil at Dumas had greater initial CEC than Stuttgart (10.5 to 8.0 cmolc·kg⁻¹; Table 2), the lower bulk density at Dumas (1.12 g·cm⁻³ in 2024) suggested increased porosity, thus perhaps increased water infiltration resulted in more even water redistribution throughout the soil profile in both the control and biochar-amended treatments. An enhanced infiltration capacity would have almost certainly masked the effect of biochar on soil water content, especially during irrigation events when water was uniformly applied. Conversely, the larger bulk density at Stuttgart (1.40 g·cm⁻³ in 2024) signified a greater degree of soil compaction, hence lower porosity, which could have somewhat impeded water from percolating downward in the soil [28] even though Stuttgart relied on furrow irrigation throughout this study, which also likely served to mask the effect of biochar on soil water content.

The masking effect of furrow-irrigation on soil water contents at Dumas and Stuttgart was evident in the temporal soil water content patterns (Figure 1 and Figure 3) that showed the soil water contents for all three biochar treatments being somewhat similar and aligned during instances of low and large soil water contents, especially when cotton and soybeans were grown compared to corn. In addition, the temporal soil water content patterns also indicated that frequent furrow irrigation likely reduced treatment differences by repeatedly replenishing soil water throughout the growing season, thereby masking potential biochar effects on soil moisture dynamics contrasted to the Newport site, which was managed under dryland crop production without irrigation (Figure 2).

Soil water contents were consistently affected by biochar treatment and/or soil

depths or their combination both years at the Newport study location. Throughout this study, the only contribution of water to the Newport study location was via rainfall. The lack of consistent water inputs facilitated the differences among biochar treatment and among soil depths in 2023 along with differences among biochar-soil depth combinations in 2024. The temporally soil water content patterns for Newport in 2023 and 2024 (**Figure 2**) showed fewer instances of peak soil water contents, allowing for additional drying periods relative to the Dumas (**Figure 1**) and Stuttgart (**Figure 3**) study locations.

Factoring in intermittent durations of rainfall, the majority of water received at the Newport location would be subject to evaporation due to increased warming that would contribute to the loss of soil water [29]. Therefore, the effects of biochar on soil water content would likely have been detected as a result of reductions in soil evaporation and solar radiation reflectance from plots that had broadcast biochar remaining on the soil surface [30]. Furthermore, [31] reported that soil surface applications of a biochar derived from pine (*Pinus* spp.) feedstock decreased soil albedo, which, in turn, decreased soil water evaporation at rates ranging from 0.9 to 181 Mg·ha⁻¹.

Soil bulk densities at Newport were large (1.42 g·cm⁻³ in 2024), implying possible soil compaction. However, the soil water content variations at Newport can possibly be explained by biochar application, which was consistent with [32] who noted significant increases in soil water content, 1.4 to 18.4% increase for biochar-amended soils to a no-biochar-applied control, via the application of a crop straw-based biochar in a predominantly clay-textured soil at rates of 20 to 60 g·kg⁻¹ soil in a glasshouse experiment. [32] based observations on the alteration of total soil porosity, which increased by 29%, and soil aggregate formation, which increased by 115% in biochar-amended soils. Furthermore, [33] reported improvements in soil aggregation, 2.8% to 24.6% increase compared to control soils, and soil moisture retention, 1 to 1.04-fold over the no-biochar-applied control, in a sandy-clay-loam soil using biochar created from Oleaster (*Elaeagnus angustifolia*) residues that were proportional to biochar application rates at a ratio of 1, 2 and 4 weight percentages (wt·wt⁻¹) of biochar to 3 kg of dried soil per pot.

Given that the significant results for Newport seem stimulated by amounts of sporadic rainfall that would accelerate prolonged periods of dry-soil conditions, the effects of soil-applied biochar on soil water contents at Newport would appear to be magnified compared to the Dumas and Stuttgart locations. Dry-soil conditions factored into a study by [34], who reported that softwood and walnut (*Juglans regia* L.) shell-based biochars having a large volume of pores (0.35 to 40 nm) momentarily increased soil water content in sandy-textured soils while having a minimal effect in clay-dominated soils during a drought-induced laboratory experiment at biochar application rates of 9 and 18 Mg·ha⁻¹. Since the biochar used in the current study primarily consisted of large fragments, observations would indicate that the greater pore abundance in the enviraPAC biochar facilitated soil water infiltration, movement, and subsequent storage in the biochar-amended

plots at Newport. In addition, [35] reported that biochars derived from beechwood (*Fagus sylvatica* L.) increased soil water content by 3.1% compared to an unamended control in temperate silt- and clay-loam soils in Austria throughout a protracted period of drought. However, [35] attributed the effect to a large biochar application rate of 65 Mg·ha⁻¹ rather than biochar particle size. The possible increase in soil water storage for areas that experience constant low soil moisture while relying on rainfall irrigation through applications of soil-applied biochar can be advantageous to crop growth and development in the short term, as well as instances where drought-like conditions persist between rainfall events. However, to experience possible increases in crop yields and other crop development parameters, blending biochar with an inoculant such as animal manures is highly recommended to encourage microbial activity and the mineralization of nutrients within the biochar (J. Reese, enviraPAC LLC, personal communication).

5. Conclusions

The objective of this project was to determine if soil-applied biochar would significantly increase soil water content at various soil depths from furrow and rainfed irrigation programs. Although significant increases in soil water content were observed at all three ADFP locations, the effect of biochar rate was more prevalent at Newport using rainfed irrigation while the effect was more sporadic and inconsistent at Dumas and Stuttgart which employed furrow irrigation throughout this study. Therefore, we reject part of the original hypothesis which stated that soil applied biochar would significantly increase soil water content in furrow irrigated production systems.

Throughout this study, the effects of biochar on soil water contents were more evident at Newport than at Dumas and Stuttgart, which was attributed to differences in irrigation strategies (*i.e.*, dryland at Newport, and furrow irrigation at Stuttgart and Dumas). Biochar particles left on the soil surface at Newport likely decreased soil water evaporation and solar reflectance, which are two main drivers of soil water loss. Conversely, biochar's influence on soil water contents at Dumas and Stuttgart was somewhat negligible due to constant irrigation throughout their respective growing seasons despite variations in crop selection.

Although significant differences in soil water contents occurred in this field study regarding biochar's capacity to retain soil water, there are limitations to biochar's widespread use in eastern Arkansas agriculture. In eastern Arkansas, there are few production facilities currently producing biochar. Factoring in purchasing costs (*i.e.*, ~ \$1190 per 1000 kg biochar; enviraPAC, LLC, Monticello, AR) and transport coordination, producers may be hesitant to buy and apply biochar to large areas of their respective farms. Additionally, if producers are seeking crop yield benefits of soil-applied biochar, it is recommended that the biochar be inoculated with poultry manure prior to field application, thereby representing another farm-related expense. Additional research is needed to ascertain the effect of biochar on soil water content in eastern Arkansas regarding different agricul-

tural production systems along with varying soil textures.

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Author Contributions

James M. Burke: Report writing and preparation, data management, experimental design, statistical analysis, graphic creation, soil sample collection, equipment installation. Kristofor R. Brye: Contributing text, graphics and edits. Mike Hamilton: Contributing text and edits. Mike B. Daniels: Contributing text and edits. Lee Riley: Acquiring project materials/equipment, equipment installation, on-site equipment maintenance. Brett Cooper: Downloading and exporting soil water pressure data, equipment installation, on-site equipment maintenance. Eric Simon: equipment installation and on-site equipment maintenance.

Conflicts of Interest

The authors declare no conflicts of interest concerning the publication of this paper.

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