

CHANGES IN SOIL HYDRAULIC CONDUCTIVITY OF AN ULTISOL IN RESPONSE TO BIOCHAR APPLICATION IN ILE-IFE, NIGERIA.

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ABSTRACT

This study determined effects of wood biochar on soil hydraulic conductivity (k) of two soil series classified as Ultisol. The experiments were conducted at the Screenhouse of Obafemi Awolowo University (OAU), Ile-Ife, Osun State, Nigeria. The treatments consisted of four rates of milled local biochar (0, 450, 900 and 1344 kg/ha) arranged in a Randomized Complete Block Design with four replicates. Surface (0-15 cm depth) soil of Iwo and Egbeda soil series were collected from the Teaching and Research Farm, OAU. The experiment was carried out over a period of 12 weeks in the screenhouse. The antecedent soil properties were determined in the University's Soil Science Laboratory and k was determined using disk infiltrometer. The data generated were subjected to analysis of variance and the significant means were separated using Duncan's Multiple Range Test at 95% levels of probability. Results showed that biochar addition significantly improved soil hydraulic conductivity ($K_{0.5}$ and K_{-2} cm at 450 kg/ha and 900 kg/ha) of the two soil series. The peak values for $K_{0.5}$ (0.013 cm/s) of Iwo series were observed at both 450 kg/ha and 900 kg/ha while it was 0.024 cm/s for coarser Egbeda series. The highest K_{-2} cm were 0.009 cm/s and 0.026 cm/s for Iwo and Egbeda series at 450 kg/ha, respectively. Further, saturated hydraulic conductivity of soil treated with biochar at 450 kg/ha was one of the highest. Overall, biochar addition at rate of 450 and 900 kg/ha appeared to be more beneficial to adequately improving movement of water in the soil.

Keywords: *Biochar, Egbeda series, Iwo series, Ultisol, Unsaturated hydraulic conductivity.*

INTRODUCTION

Ultisols are low base status soils, strongly leached, acidic with relatively low native fertility. Ultisols are mainly sandy in nature. Sandy soils usually have high hydraulic conductivity and low ability to retain water and nutrients which make it difficult for some plants to survive in soil (Chen *et al.*, 2018). Soil Hydraulic Conductivity is the intrinsic permeability of the soil to water. It is also the movement (vertical and lateral) of water within the soil profile. It can be measured

at saturation (saturated hydraulic conductivity, K_s) and under unsaturated conditions (unsaturated hydraulic conductivity, $K(h)$) (Topp *et al.* 1997). The soil hydraulic conductivity influences infiltration, runoff and the transport of nutrients in soil. It varies with time and soil types. Soil serves as a medium for plant growth by acting as a reservoir of nutrients and water, providing a skeletal framework for anchorage among other functions.



In a world of increasing population and growing economy, global issues including climate change, food insecurity and energy demand necessitate identification of innovative techniques of sustainable management of soils. Since the inception of agriculture, farmers had resorted to fertilizer application as a major practice approved to sustain food production for the growing population. However, since organic application is naturally mineralized, the accomplished benefits are limited (Schneider *et al.*, 2009). This limitation can be overcome by biochar addition to soil (Zimmerman, 2010). Biochar is produced by pyrolysis of biomass (Lehmann *et al.*, 2006; Verheijen *et al.*, 2009 and Inyang *et al.*, 2010). Biochar is a stable solid, rich in organic carbon and can remain in soil for thousands of years which enable it to improve soil structure. It has been found to alleviate soil compaction by decreasing bulk density, which increases porosity and accentuates favorable soil processes (Laird *et al.*, 2010). Therefore, biochar application is important to maintain soil properties and improve the nutrient availability of soil for long term usage.

Impact of biochar on soil hydraulic properties is complex. Several studies have reported that biochar addition to soil increased saturated and unsaturated hydraulic conductivity (Herath *et al.*, 2013; Oguntunde *et al.*, 2008) while there was a decrease in other studies following biochar additions (Githinji, 2014; Uzoma *et al.*, 2011). Gaskin *et al.*, (2007) reported in their findings that hydraulic properties of a sandy soil are affected by the rate of biochar addition.

Charcoals, produced by pyrolysis of biomass, are locally produced primarily for use as fuel for cooking. However, there is little knowledge on their potential for improvement of soil properties. It is therefore necessary to determine the effects of this biochar type, sourced from Nigerian local market on soil hydraulic conductivity.

MATERIALS AND METHODS

Soil samples were collected from the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife. It is a region within the humid zone of southwestern part of Nigeria between Latitude 7° 32' N and 7° 33' N and between Longitude 4° 33' E and 4° 35' E. The vegetation over the soil was cleared with cutlass before the soil samples were collected. Bulk top soil (0-15 cm) samples were obtained randomly in the field with a spade before being sub-sampled for analysis. Two soil types were sampled which are; Iwo and Egbeda series. Both Iwo and Egbeda soil series were classified as Ultisol according to the Soil Survey Staff (2014). Ultisols are low base status soil with finer textured sub-soil horizons. It is acidic, contain low organic matter content and have reddish-colored argillic or kandic horizons (Soil Survey Staff, 2014)

Soil samples of both Iwo and Egbeda soil series were air-dried and sieved through a 6.7 mm sieve in order to preserve the aggregates. Another fraction of the soil was also sieved through a mesh of 2 mm diameter to determine selected laboratory analyses for physical and chemical properties of the soil prior to the commencement of the experiment. These

include soil pH, particle size distribution, bulk density, field moisture capacity and saturated hydraulic conductivity. The charcoal used for the experiment was crushed into fine particles to increase its surface area for better reaction within the soil and then allowed to pass through 0.5 mm sieve.

The experiment was laid in a randomized complete block design with four replicates in screenhouse. The treatments consisted of control (soil without biochar addition) (C₁), Soil + 450 kg biochar /ha (C₂), Soil + 900 kg biochar /ha (C₃), Soil + 1344 kg biochar /ha (C₄). Each cup was maintained at 70% field moisture capacity throughout the course of the 12 - week experiment. Perforated plastic cups (868 ml), plugged with cotton wool at the bottom to allow free water drainage were filled with 1 kg air-dried soil and thoroughly mixed with the milled biochar. This was done for the two soil types (Iwo and Egbeda series).

The soils particle size analyses were determined according to Bouyoucos (1962) hydrometer method described by Gee and Or (2002), while the soil textural triangle (Soil Survey Staff, 1994) was used to classify the soils into textural classes.

Soil pH was determined potentiometrically in a soil-water suspension ratio of 1:2 in 0.01 M CaCl₂ using a glass electrode pH meter (Thomas, 1996). Soil organic carbon content was determined using wet digestion method of Walkley-Black (1934), which involve the oxidation of the soil organic matter with potassium dichromate (K₂Cr₂O₇) using concentrated sulphuric acid (H₂SO₄) and the percent organic carbon determined by titrating

with 1 N ferrous ammonium sulphate solution.

Unsaturated hydraulic conductivity was measured every fortnight for 12 weeks using a mini disk infiltrometer at 2 cm and 0.5 cm suctions. Saturated hydraulic conductivity of each experimental unit was determined at the termination of the study. Undisturbed soil samples were collected from each pot with a cylindrical core sampler of volume 91.1 cm³. The samples were covered with cheese cloth held in place with a rubber band. The saturated hydraulic conductivity was determined with a constant head permeameter with a water head of 5 cm while the unsaturated hydraulic conductivity was determined using mini disc infiltrometer (infiltration). Hydraulic conductivity was calculated from the Darcy's law derived from the case flow in vertical column (Hilel, 1980).

$$\text{Darcy's Law: } Q = KA \left(\frac{H}{L} \right)$$

where; A = cross sectional area, Q = flow rate (cm/s) H = total hydraulic head, L = length of the porous media saturated hydraulic conductivity in the laboratory was calculated by using: $K = \frac{Q}{A} \left(\frac{H}{L} \right)$

The data generated were subjected to analysis of variance (ANOVA) and the significant means were separated using Duncan's New Multiple Range Test at 95% levels of probability.

RESULTS AND DISCUSSION

The physical and chemical properties of the soil used for the experiment are shown in Table 1. The particle size distribution for Iwo series indicated sand, silt and clay contents of 781.6, 66.8 and 151.6 g kg⁻¹ respectively while the Egbeda series

contained 841.6, 46.8 and 111.6 g kg⁻¹ of sand, silt and clay, respectively. This indicates that Iwo series textural class was sandy loam while that of Egbeda series was loamy sand. The organic carbon (OC) contents of both Iwo and Egbeda series were 2.7 and 4.3 g kg⁻¹, respectively. The soil pH was moderately acidic (6.0) in Iwo series and slightly acidic (6.4) in Egbeda series. These values are in the same pH range given by Adepetu (1990) and Ogunjinmi *et al.* (2017). The value observed in OC could have influenced the soil pH by enhancing buffering capacity of the soil (Havlin *et al.*, 2005).

Effects of biochar amendment on soil unsaturated hydraulic conductivity

At week 2, 4 and 6, Iwo soil series that had biochar applied at rate of 450 kg/ha and 900 kg/ha had the significantly ($P < 0.05$) highest unsaturated hydraulic conductivity at 0.5 cm suction ($K_{0.5}$), both having peak

values of 0.013 cm/s, compared with other rates (Fig.1). However, $K_{0.5}$ was higher in control plots at week 8, 10 and 12 compared to the soil amended with biochar at different rates. On the other hand, in the coarser surface soil of Egbeda soil series (Fig. 2), particularly in the first four weeks and week 12, $K_{0.5}$ for the soil amended with biochar at 1344 kg/ha along with 450 kg/ha can be ranked highest. The highest $K_{0.5}$ (0.035 cm/s) for Egbeda series, was observed on the soil amended with biochar at the rate of 1344 kg/ha in the 12th week of greenhouse study. The highest $K_{0.5}$ value at 450 kg/ha was 0.024 cm/s. This implies a differential response by two soil types to biochar addition. Githinji (2013) reported that biochar amendment had a positive impact on the hydraulic properties of the soil which led to an increase in soil aeration and volumetric moisture content of the soil.

Table 1: Some physical and chemical properties of the soil used for the experiment

| Parameters | Iwo series | Egbeda series |
|---|------------|---------------|
| Sand (g kg ⁻¹) | 781.6 | 841.6 |
| Silt (g kg ⁻¹) | 66.8 | 46.8 |
| Clay (g kg ⁻¹) | 151.6 | 111.6 |
| Texture | Sandy loam | Loamy sand |
| Soil bulk density (g/cm ³) | 1.14 | 1.12 |
| Field moisture capacity (%) | 21 | 16 |
| pH in 0.01 M CaCl ₂ | 6.0 | 6.4 |
| Organic carbon (g kg ⁻¹) | 2.7 | 4.3 |
| Saturated hydraulic conductivity (cm/s) | 0.024 | 0.022 |

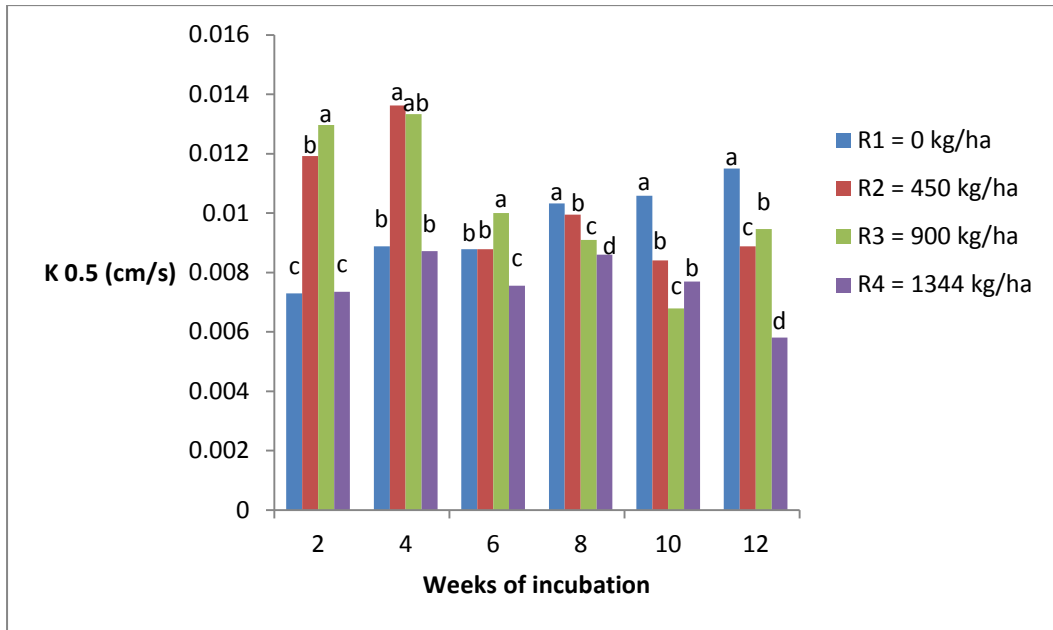


Fig 1: Effects of biochar addition on the unsaturated hydraulic conductivity at 0.5 cm suction ($K_{0.5}$) for Iwo soil series.

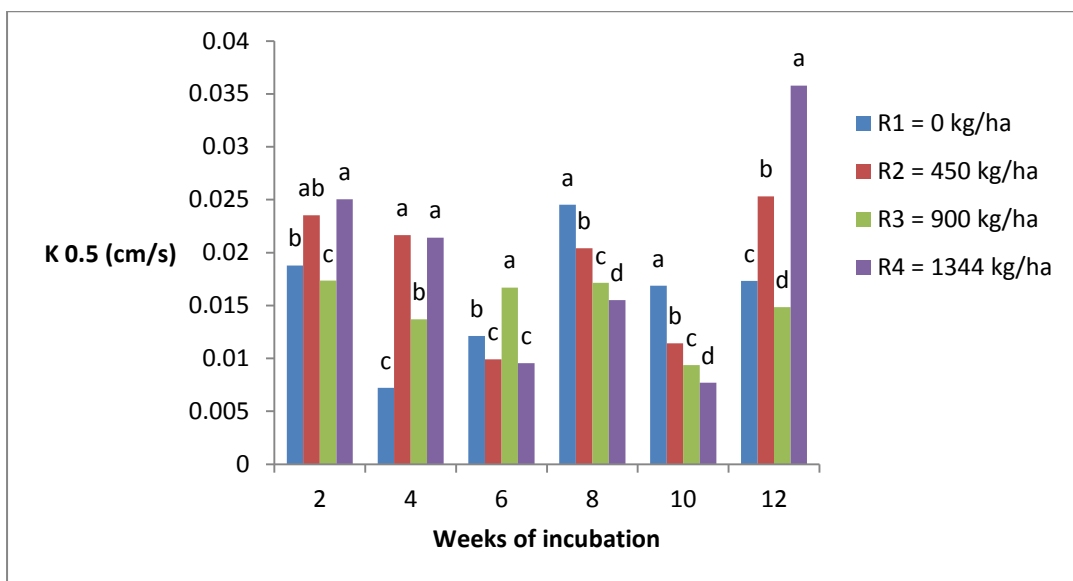


Fig 2: Effects of Biochar addition on the unsaturated hydraulic conductivity at 0.5cm suction ($K_{0.5}$) for Egbeda Soil Series.

Figures 3 and 4 show the effects of the treatments on soil hydraulic conductivity at a suction of 2 cm (K_2) over 12 weeks after amendment. In Iwo Series (Fig. 3), biochar applied at rate of 900 kg/ha had a significantly highest hydraulic conductivity ($P < 0.05$) (0.009 cm/s) than

other treatments. However, at week 6, the values K_2 were highest in soils treated with biochar applied at rate 450 kg/ha (0.006 cm/s) when compared with other treatments. This increase may be due to enhanced soil structure after the application of biochar with concomitant

increased infiltration of water into the soil (Uzoma *et al.*, 2011). Hydraulic conductivity at 2 cm suction in Egbeda series was somewhat different (Fig. 4). Except for week 8, K_2 (with peak value of 0.034 cm/s) of pots amended with 1344 kg/ha biochar exceeded that of soils amended with other rates, particularly at

week 4 and 12. This underscore the importance of time and texture. Since soil texture is an important physical property related to soil hydraulic properties (Nimmo, 1997), variation in the effect of biochar on soil hydraulics conductivity may be as a result of soil textural differences.

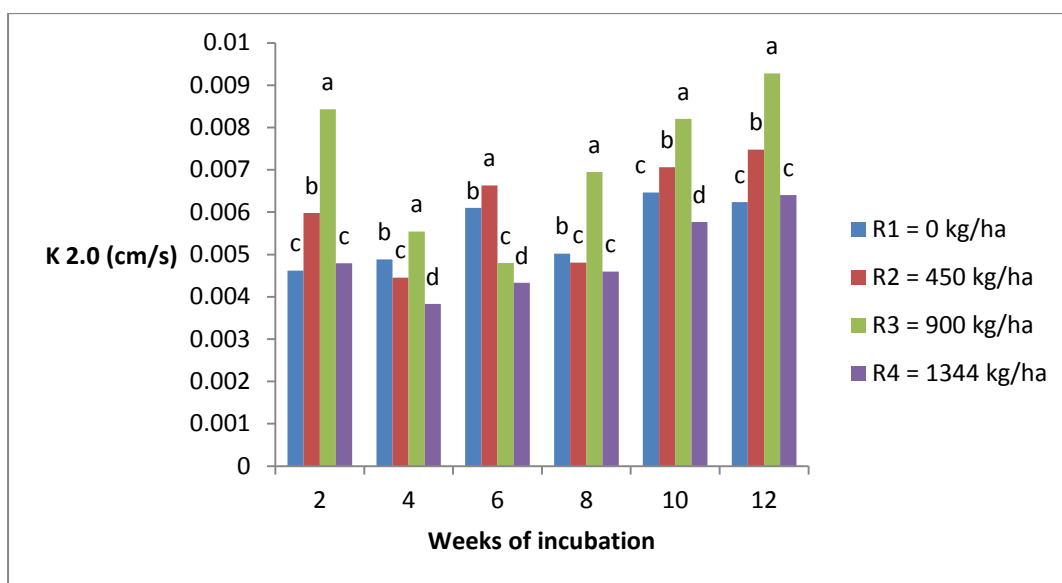


Fig 3: Effects of biochar addition on the unsaturated hydraulic conductivity at 2 cm suction (K_2) for Iwo soil series.

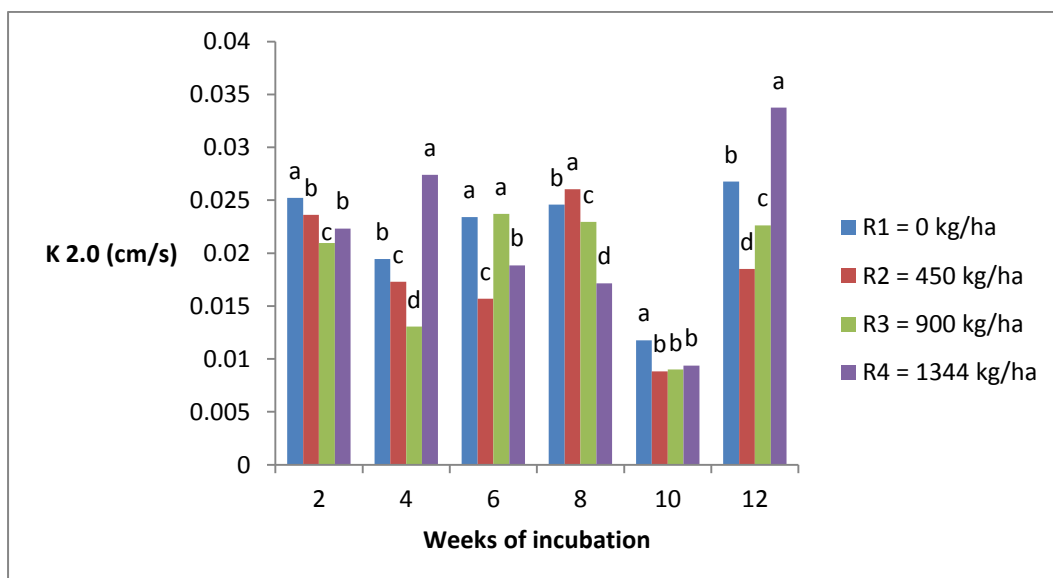


Fig 4: Effects of biochar addition on the unsaturated hydraulic conductivity at 2 cm suction (K_2) for Egbeda soil series.

Effects of Biochar Application on soil Saturated Hydraulic Conductivity (K_{sat})

The effect of treatment on soil saturated hydraulic conductivity (K_{sat}) over a period of 6 and 12 weeks after incorporation (WAI) are presented in Tables 2. In the Iwo series, biochar applied at rate of 450 kg/ha at 6 WAI significantly ($P < 0.05$) improved soil K_{sat} compared with other treatments. On the other hand, biochar at rate of 1344 kg/ha had higher significant ($P < 0.05$) effect on K_{sat} at the end of 12th week. At week 12, the higher the biochar rate, the higher the K_{sat} . These biochar rates significantly improved soil hydraulic conductivity and the increase observed in saturated hydraulic conductivity could be due to the tendency of biochar to decrease soil bulk density thus enabling it to transmit more water. The enhanced transmission of water in soil may have benefitted from increase in pore spaces due to the improved bulk density (Laird *et al.*, 2010; Jones *et al.*, 2010; Chen *et al.*, 2011). The treatments at rate 450 kg/ha and 1344 kg/ha improved the saturated hydraulic conductivity of Iwo series than Egbeda series. Surprisingly, water movement in control pot was significantly higher than other treatments up to the 6th week. After the 6th week, soils treated with highest rates (900 and 1344 kg/ha) were joint highest while control became significantly the least water-conducting soils thereafter. This could be as result of soil pore condition which contributes to the adsorptive properties of biochars. In addition to textural differences between the two coarse-textured soils used in this study, higher organic matter content in loamy sand Egbeda series may have acted as 'hydraulic buffer' limiting the

effect of the biochar amendment when recently added.

The effects of soil texture and resident time of biochar on soil hydraulic conductivity

The results of the near saturated soil hydraulic conductivity relative to soils of different texture as presented in Figs. 1 – 4, are further revealing in some ways. On average, biochar applied at 900 kg/ha was the best for $K_{0.5}$ under Iwo series having sandy loam (sand<80%) texture. This was not the case with the coarser Egbeda series that is loamy sand (sand>80%) texture. It appears that at higher biochar rate (e.g. 1344 kg/ha), Iwo soil series with sand less than 80% may have been clogged by biochar's nanoparticles (Cosentino *et al.*, 2018) compared to Egbeda series with sand content greater than 80%, making the best biochar application rate debatable. Seeing that K_2 for the soil of Iwo series responded better at 900 kg/ha biochar application rate but dropped when biochar was added at 1344 kg/ha implies that a moderate increase in biochar may stabilize soil structure but excessive addition still pose problem to water transport in less coarse soils. Reduction in K_{sat} with increase in biochar application rate in coarse textured soils has been reported by other authors. Lim *et al.* (2016) observed that, there was a decrease in K_{sat} as biochar rate increase in fine sand and coarse textured soil but reversed was the case in clayey soil. This is in line with Githinji (2013) work on loamy sand amended with biochar. The improvement in K_2 at higher rate beyond four weeks of biochar application, in coarser (loamy sand) surface soil of the Egbeda soil series (Fig. 4), combines masking effect of

coarser soil (>80% sand) with time-variable transformation of easily degradable component of the biochar on near saturation hydraulic conductivity. This corroborate the works of Novak *et al.*, (2015) who reported that time is the major factor affecting infiltration rate of biochar amended soil. Naisse *et al.*, (2015) and Spokas *et al.*, (2014) also noted that biochar can physically disintegrate with time. The time-dependent favourable response of hydraulic conductivity to

biochar amendment and transformation concept were more reinforced when all the pores are engaged at K_{sat} (Table 2). This suggests that recently introduced biochar may have stayed in coarser soils that may contain more macropore and are less entangled in transformation or reaction with soil aggregation in a way similar to organic carbon as reported by Thomsen *et al.* (1999) and thus temporarily hinders water movement in soil.

Table 2: Effects of biochar addition on saturated hydraulic conductivity of Iwo and Egbeda Series over a period of 6 and 12 weeks

| Parameter | Rate (kg/ha) | 6 | | 12 | |
|-------------------------|-----------------|--------|--|--------|--|
| | | Weeks | | | |
| Iwo K_{sat} (cm/s) | Control | 0.026c | | 0.024d | |
| | 450 | 0.036a | | 0.031c | |
| | 900 | 0.017d | | 0.033b | |
| | 1344 | 0.033b | | 0.038a | |
| Egbeda K_{sat} (cm/s) | Control | 0.041a | | 0.022c | |
| | 450 | 0.020c | | 0.025b | |
| | 900 | 0.026b | | 0.029a | |
| | 1344 | 0.024b | | 0.029a | |

Means with the same letter on a column are not significantly different ($P < 0.05$) according to Duncan's New Multiple Range Test.

CONCLUSION

Movement of water (soil hydraulic conductivity) was positively enhanced in sandy loam soil (Iwo series) with biochar addition, at lower amendment rates whereas, the reverse was observed in loamy sand soil (Egbeda series) at higher rate due to coarse-texture and time effects. Overall, biochar addition at rate 450 and 900 kg/ha appeared to be more beneficial to adequately improving water movement in the soil. However, further investigation under field condition will be necessary.

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