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Impact of Biochar and Hydrogel Amendments on Hydrophysical Properties of Sandy Soil and Cowpea Yield (*Vigna unguiculata L.*) Under Different Water Regimes

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Abstract

South Mediterranean countries including Egypt and Tunisia are characterized by vast lands with uncultivated sandy soils. These soils have poor hydrophysical-bio-chemical properties that are being reclaimed due to population growth and the need to increase food supply. Furthermore, there is high production of crop and orchard residues from agricultural activities that lead to harmful effects to the environment. Therefore, converting these residues to biochar and their use as amendments with sandy soils could improve water retention. This research investigated the effect of three soil amendments: - biochar (50 g/plant and 100 g/plant), hydrogel (2.7 g/plant) and their mixtures (hydro-char) (50 g biochar and 2.7 g hydrogel) on some hydrophysical properties. The properties included soil water constants, pore size distribution and void ratios on yield parameters of the cowpea fodder crop under two irrigation levels (75 and 100% on base of ETc) evaluated under field experiment. The results showed that higher water content at field capacity (FC) and available water content (AW) was observed with the use of 50 and 100g/plant biochar followed by hydro-char combinations. Data revealed that higher values of drainable pores (DP) were recorded after 2.7 g hydrogel, and 100 g biochar; storage pores (SP) after 2.7 hydrogel and 100g biochar, and100g biochar; whereas none useful pores were recorded after2.7 hydrogel under 75 and 100% irrigation regimes. Positive correlations were recorded between FC drainable pores DP, storage pores SP, total porosity TP, and void ratio with *r*-values of 0.544*, 0.983**, 0.805**; 0.814**, respectively. Also, the biological yield exhibited positive correlations with water holding capacity (WHC), FC, AW, SP,TP, and void ratio with *r*-values of 0.797**, 0.835**, 0.864**, 0.879**, 0.628** and 0.631**, respectively. Yield variables increased in 75% than in 100% irrigation regimes. It was concluded that the ability of biochar to enhance the hydrophysical properties of sandy soils is highly dependent on the biochar characteristics and its application rates. Furthermore, biochar applications can increase water retention in sandy soils.

Keywords: Biochar, hydrogel, hydrochar, soil water constants, void ratio, cowpea, water stress, sandy soil.

Introduction

Under arid and semi-arid region environments, sustainable agriculture is hindered by several obstacles such as poor water retention and organic matter. In these areas, coarse-textured soils represent more than 50% of planned areas for cultivation [1]. These soils are characterized by poor soil structure leading to inadequate physical conditions, increased soil bulk density, and low water retention especially at field capacity, which directly affect plant growth and reduce yield [2]. Biochar is a black solid residue rich in carbon that is usually produced by pyrolysis of biomass of different agricultural residuals [3]. These residues can be used as soil conditioner to enhance not only the soil hydrophysical properties (e.g., reduce hydraulic conductivity and thus improves water retention in sandy soil) but also, the chemical ones. Increased total surface area relative to biochar application which has been pointed out as one of the main reasons for the improvement of the hydrophysical properties of coarse-textured soils [4]. Hydrogels absorb and store water hundreds of times more than their own weight, 400–1500 g water per dry gram of hydrogel [5]. Mikkelsen [6]classified hydrogels to three classes of

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commonly used can be generally categorized asnatural polymers, semi-synthetic and synthetic polymers.

Liu et al. [7] reported that the hydraulic properties of treated coarse-textured soils with biochar are mainly dependent on biochar source, pyrolysis temperature, application rates, and its fractionations. Furthermore, [8, 9] found that biochar activity depends mainly on the production temperatures, which increased water retention and consequently soil available water. The interactions of biochar particles with the soil matrix is highly dependent on the biochar particles size, where the fine fractions have a large surface area.

Materials and methods

Study area

This study was carried out at the National Research Centre Farm (Research and Production Farm), Al-Noubaria, El-Beheira Governorate, Egypt (30 4987^o N; 30 3188^o E), to evaluate the effect of adding biochar and hydrogel as well as their mixtures on the production of cowpea, as fodder crop, grown in sandy soils under different irrigation water regimes (75 and 100% from crop water requirement, ETc).

Design and experimentation

The experiment was laid down in a randomized complete block design (RCBD) in split-plot where irrigation regimes (75 and 100% from crop water requirements) formed the main-plot and soil conditioners (50, 100 g/hole biochar, hydrogel and the mixtures of 50 g biochar and hydrogel 2.7 g/plant) and the absolute control were regarded as sub-plot with the treatments in three replications. The field experimental was tilled and levelled then the fodder cowpea (*Vigna unguiculata L.*). Karim variety was planted on 27 May 2018 and last cut was taken on 10 October of 2018 (fodder beet was planted before cowpea). The seeds weighing 30 kg were used in sowing (soaked in water for 48 h).Three seeds were sown per hole in two lines/rows spaced between 30 cm making plant population of 40000 plants per feddan equivalent to 0.42 ha).

Fertilizers were applied based on the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation as follows:-90, 62 and 100 kg of N, $P_2O_5$and K_2O Fed^{-1}, respectively, distributed as basal dose during soil preparation including 20 kg of sulphur, 50 kg ammonium sulphate 20.5% N, 100 kg super phosphate (15.5% P_2O_5) and 50kg potassium sulphate (50% K_2O) per fed. After a month and two months from planting, 100 kg urea (46%N) and 50 $kgfed^{-1}$ potassium sulphate (K_2SO_4) were added 10 days after each cut in two equal doses.

Data collection

Cowpea plants were cutting at a plants height of 60 cm and about 10 cm was left above soil surface. Three cuts were taken after 50, 55, and 62 days with a total growth season of 141 days and their summation was considered as biological yield. The pods were separated from shoots and dried at 60^{o}C for 48 h.

Under irrigation regimes, the plants were drip irrigated. The irrigation interval was settled every two days regarding to the net water requirement of cowpea with the help of daily evapotranspiration in mm (ETo), which was obtained from Metrological Station in the Farm of NRC. The cowpea Kc values presented averages of 0.8 (initial state), 1.4 (crop development) and 0.8 in the last vegetative phase to get the seeds). Irrigation water of fodder cowpea crop was applied following Equation 1.

$$\mathbf{CWR} = \frac{ET_o \times K_c \times 1}{a \times \frac{1}{r} \times LR} \qquad (1)$$

Where, CWR is crop water requirements (mm/day), ETo is reference evapotranspiration (mm/day), Kc: fodder cowpea crop factor, *a* is irrigation system efficiency, r is reduction factor; LR is leaching requirement.

Chemical analysis soil and irrigation water

Irrigation water quality (well water) was measured for the following parameters: - pH (7.05) EC (1.57 dSm^{-1}) and sodium adsorption ratio (SAR= 3.21 $meql^{-1}$), which indicated that irrigation water was suitable for irrigation without any problem on soil and grown plants.

Soluble ions (cations and anions) were determined as described by [20], soil organic matter (SOM), calcium carbonate content, soil reaction (pH) were measured in soil: water ratio (1:2.5) and electrical conductivity (EC) in 1:1 soil: water extracted (Hanna Instruments, HI 2550 pH/ORP/EC/TDS/NaCl Benchtop Meter).

Soil samples (0-10 cm) were taken after harvest of cowpea to determine hydrophysical soil properties (i.e., soil texture and particle size distribution) using hydrometer method [21]. Experimental soil was characterized by sand in texture (total sand 88.5, silt 8.0 and clay 3.5%) pH (8.08), EC (0.85 dSm^{-1}), $CaCO_3$ (2.6 %), bulk density (1.64 g cm^{-3}), cation exchange capacity (4.02 C mole Kg^{-1}) and organic matter (0.15%). Soil moisture content at different soil water constant was 31.8 (water holding capacity), field capacity (18.43%) and wilting point (3.6%) on volume basis [22].

Applied biochar is characterized by 9.35 (pH, 1:20, after [18], 0.74 dSm^{-1}(EC) and its fractionation was >2mm(12.70 %), 2-1 mm (54.25%), 30.25 % (1-0.5 mm) and less than 0.5 mm (2.8 %) with total surface area (156.8 m^2 g^{-1}) [23] and 25.6 cation exchange capacities after [24].

The hydrogel was characterized by absorption capacity in deionized water, 0.9% NaCl, 0.4% $CaCl_2$ and saline water 1500 mg l^{-1}. The absorption time was up to 75% and complete absorption. Bio-parameter indicators: weight of the three cowpea cuts were taken after 50, 55, 62 days from planting and recorded in addition to the seed weight of the last cut as yield parameters.

Pore size distribution was estimated as percentage from total porosity as in Equations 2-5.

$$\mathbf{TP} = \frac{\mathbf{1} - \boldsymbol{BD}}{\boldsymbol{RD}} \times \mathbf{100} \qquad (\mathbf{2})$$

Where, BD is the bulk density and RD is a real density.

$$\textbf{Drainable pores} = \frac{\textbf{\textit{Water conent at SP}} - \textbf{\textit{Water content at FC}}}{\boldsymbol{TP}} \times \mathbf{100} \qquad (\mathbf{3})$$

$$\textbf{Storage pores} = \frac{\textbf{\textit{Water conent at FC}} - \textbf{\textit{Water content at WP}}}{\boldsymbol{TP}} \times \mathbf{100} \qquad (\mathbf{4})$$

$$\textbf{Non} - \textbf{useful pores} = \frac{\textbf{\textit{Water conent at WP}}}{\boldsymbol{TP}} \times \mathbf{100} \qquad (\mathbf{5})$$

Where, SP is water content at saturation present, FC is water content at field capacity and WP is water content at wilting point.

The calculation of the void ratio was run from as described by **[25]** using Equation 6.

$$\mathbf{e} = \frac{\boldsymbol{TP}}{\mathbf{1} - \boldsymbol{TP}} (\mathbf{6})$$

Where e is void ratio and TP is total porosity.

The degree of saturation (Sr) was calculated using Equation 7.

$$\mathbf{Sr} = \frac{\boldsymbol{\Theta} \times \mathbf{RD}}{\mathbf{1} + \boldsymbol{e}} (\mathbf{7})$$

Where,Θ is soil moisture content and RD is soil real density.

The air void ratio was calculated using Equation 8.

$$\textbf{Air void ratio} = \frac{(\mathbf{e} - \boldsymbol{\Theta}) \times \mathbf{RD}}{\mathbf{1} + \boldsymbol{e}} (\mathbf{8})$$

Statistical analyses

In a randomized complete block with split-plot design was performed with irrigation regimes (75 and 100%) forming main-plot and soil conditioners (50, 100 g/hole biochar, hydrogel and mixtures 50 g biochar and hydrogel 2.7 g/plant) and the control forming the sub-plot [1]. The factor effect model is as shown in Equation 9.

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij} \qquad (9)$$

Where, *Yij* is the observation in the *ijth* factors; *μ* is the overall (grand) mean; α_i, β_j are the main effects of the factors irrigation regimes (*α*) and soil conditioners (*β*); $(\alpha\beta)_{ij}$ are the two-way (first factor) interaction effects between the factors*α* and *β*; *εij* is the random error associated with the observation in the ij^{th} factors.

However, in evaluating the hydrophysical characteristics of soils using soil conditioners only, ONE-WAY ANOVA was deployed for the measured variables with the assessed factor being soil conditioners (biochar, hydrogel and their mixture (hydro-char)) and the factor effect model is as shown in Equation 10.

$$\mathbf{Y}_{\boldsymbol{i}} = \mu + \boldsymbol{\alpha}_{\boldsymbol{i}} + \boldsymbol{\varepsilon}_{\boldsymbol{i}} \qquad (\mathbf{10})$$

Where, *Yi* is the observation in the i^{th} factor; *μ* is the overall (grand) mean; α_i is the main effect soil conditioners; *εi* is the random error associated with the observation in the i^{th} factor. The significant treatment means were compared by the Least Significant Differences (LSD) test at 5% probability.

Results and Discussion

Effect of soil conditioners and irrigation regimes on soil properties and cowpea

The results of the effect of biochar, hydrogel and their mixture (hydro-char)on soil water constants and pore size distribution (PSD), total porosity (TP), void ratio and cowpea (as fodder crop) yield under 75 and 100% irrigation regimes are presented in Table 1. Considering the percentage of ETc after harvesting of cowpea, the data revealed that application of amendments to the experimental sandy soil improved most of the soil hydor-physical parameters especially available water (AW). In addition, the increase in moisture content for the different soil water constants was higher under 75 irrigation regime, except at WP where the opposite was realized.

Regarding the effect of irrigation regimes on the soil water constants after harvesting of cowpea crop, results indicated that there was an increase in the water content at WHC, FC,WP and consequently soil AW (Table 2).The used soil amendments possessed positive effects on the soil water content at WHC, FC, WP and AW. Biochar and/or hydrogel increased WHC, FC, WP and AW after application. Soil amendments (biochar, hydrogel and hydro-char) effect can be arranged in a descending order of 100 g biochar >hydro-char>hydrogel > 50 g biochar >control. Meanwhile, the application of 50 g biochar recorded the lowest increase in WHC, FC, WP and AW. Highly significant variations were observed in the physical and surface properties of the soil and biochar mixtures. The results in the present study are supported by [11] who found that coarse-textured soils are characterized by large amounts of macro-pores. Therefore, these soils have limited ability to retain water against gravity forces [4]**.** Moreover, they indicated that an application of fine particles of biochar could improve intra-particle porosity and enhance the ability to retain more water.

With respect to the pore size distribution (PSD), results showed that the highest and lowest values of drainable pores (DP), storage pores (SP) and non-useful pores were recorded to differ depending on the factors and treatments evaluated. Glab et al. [27] found an increase in water content at field capacity when sandy soils were amended with fine-textured biochar. El-Hady et al. [28] stated that relative effectiveness of the hydrogels depends mainly upon the chemical properties of the hydrogel. According to [29]**,** available water content increased two-fold of the control in clay and two to three-folds in loamy and sandy loam soils, respectively, with an application of hydrogel at 8 g kg^{-1}.

The results also indicated that the reduction in irrigation water by 25% caused a reduction in drainable pores and non-useful pores by 0.75 and 4.63%, respectively, but increased the storage pores by 1% (Table 2). An application of soil conditioners (biochar, hydrogel, hydrochar) to the experimental sandy soil was associated with increased PSD and/or redistribution of the total porosity. The highest increase was recorded after 100 g biochar (60%) for drainable pores (DP), hydrogel (31%) for storage pores and for non-useful pores compared with the control. The results revealed that there was a negative relationship between BD and the application of biochar, hydrogel and hydro-char where BD decreased compared with control under two irrigation regimes (Table 2).Use of 50 and 100 g of biochar resulted in reduction of SP and non-useful pores by 1.4 and 2.4%, respectively.

Effect of soil conditioners on soil properties and cowpea

Results indicated that soil conditioners caused a reduction in BD (Table 2). The hydrogel alone caused a significant reduction in BD compared with the control. This finding agreed with those obtained by [28], which is mainly due to the compaction and rearrangement of soil particles as a result of wetting and drying cycles. In addition, biochar application reduced the BD of the soil. Glab et al. [27] found an increase in water content at FC when a sandy soil was amended with biochar characterized by fine particles.

The current study findings suggest that despite the observed enhancement in TP and PSD of the soils treated with biochar, soil pores with sizes greater than 30 mm will retain water from saturation to FC [1].Therefore, water retained in this capillary range does not usually contribute to the AW, whereas the opposite is true with fine particles less than2 mm that increase storage pores. The findings of our study are supported by those of Hillel [30] who found that biochar particles greater than0.5 mm usually contribute to the increase of macro-porosity in soils, which could enhance soil water content at FC and AW. However, Abdulaziz et al. [31] added that the change in soil porosity pathway and particle redistribution could increase AW if the micro-porosity occurred.

Also, Glab et al. [27] recorded an increase in water content at FC when a sandy soil was amended with biochar characterized by fine particles. The application of biochar and hydrogel and hydrochar had a positive effect on void ratios (Table 2). However, the use of 5 and 100 g biochar improved SP by 10% (Fig. 1).

Data in Table (1) showed the effect of investigated amendments (biochar, hydrogel and their mixture on the soil BD and the soil porosity under two irrigation regimes, results revealed that there was a negative relationship between BD and the application of biochar, hydrogel and hydrochar where BD values decreased compared with control under both irrigation regimes. The highest BD values were found with control; meanwhile the highest values were attained after application 100 g biochar under 75% and 100% irrigation regime. Also, data pointed out that increase irrigation quantity by 25% led to an increase in BD by 2% and the opposite was true with for total porosity, of course is reversely proportional (Fig. 2).

With respect to the effect of the studied soil conditioners, data on hand indicated that these soil conditioners caused a reduction in BD by about 1.8, 5.8, 0.3 and 4.2% for 50, 100 g biochar, hydrogel and hydrochar, respectively (Table 2). Also, it is clear that the hydrogel alone caused a significant reduction in BD compared with control. This finding agreed with those obtained by [28], which is mainly due to the compaction and rearrangement of soil particles as a result of wetting and drying cycles, in addition, biochar application reduced the BD of the soil and biochar mixtures. Glab et al. [27] found an increase in water content at FC when a sandy soil was amended with biochar characterized by small particle size of 0.5 mm.

The current study findings suggested that despite the observed enhancement in TP and PSD of the soils treated by biochar, [30], who found that soil pores with sizes >30 mm will retain water from saturation to FC, therefore, water retained in this capillary range does not usually contribute to the AW, whereas the opposite was true with fine particles < 2 mm that increase storage pores,, which is fulfilled the increase net AW. Also, Herath et al. [32] supported our data and found that biochar particles > 0.5 mm usually contribute to the increase of macro porosity in soil, which could enhance soil water content at FC and AW. However, Abdulaziz et al. [31] added that the change in soil porosity pathway and particle redistribution could increase AW if the micro-porosity occurred. Also, Glab et al. [27] obtained an increase in water content at FC when a sandy soil was amended with biochar characterized by small particle size of 0.5 mm. Regarding to degree of saturation (DOS), data in Tables (1 and 2) indicated that there was an improvement in DOS after treating experimental sandy soil by soil conditioners under both irrigation regimes, where their values under 100% irrigation regimes were higher than 75%.

Moreover it was noticed that the lowest values of DOS were attained at (control – 75% irrigation regime), while the highest one was recorded at hydrogel under 100% irrigation regime. With respect to the effect of irrigation regime on the DOS, one can notice that increasing the irrigation quantity by 25% had led to an increasing DOS by 4% , whereas, application of biochar, hydrogel and hydrochar was associated with an increase of DOS by 9.5, 7.0, 27.7 and 17.9% for 50 ,100 g hydrogel and hydrochar compared with control, respectively.

According to the void ratio as affected by application of biochar and hydrogel and hydrochar , data in Tables (1 and 2) revealed that these materials have a positive effect on void ratio values under 75% irrigation regime, which were higher than under 100% irrigation regime. In addition, it has been evident that the lowest values of the void ratio were observed at control and hydrogel under 100% irrigation regime. The increase in the quantity of irrigation water from 75 to 100% led to a reduction in void ratio values by about 3% (Fig. 3). However, application of 50 and 100 g biochar, hydrogel and hydro-char enhanced void ratio by 3.0, 9.5, 0.5; 7.0 %, respectively. The same trend was attained in case of air void ratio but in the opposite was true where they have got the lowest values under 100 g biochar, which scored the highest values under both studied irrigation regimes. These results are in harmony with those obtained by [33]**,** who stated that minimum void ratio is an important parameter for evaluating soil hydrophysical properties, that is strongly related to the compressive properties, permeability and are greatly increased PSD. They also mentioned that minimum void ratio first decreased and then increased with the increase of the fines soil content.

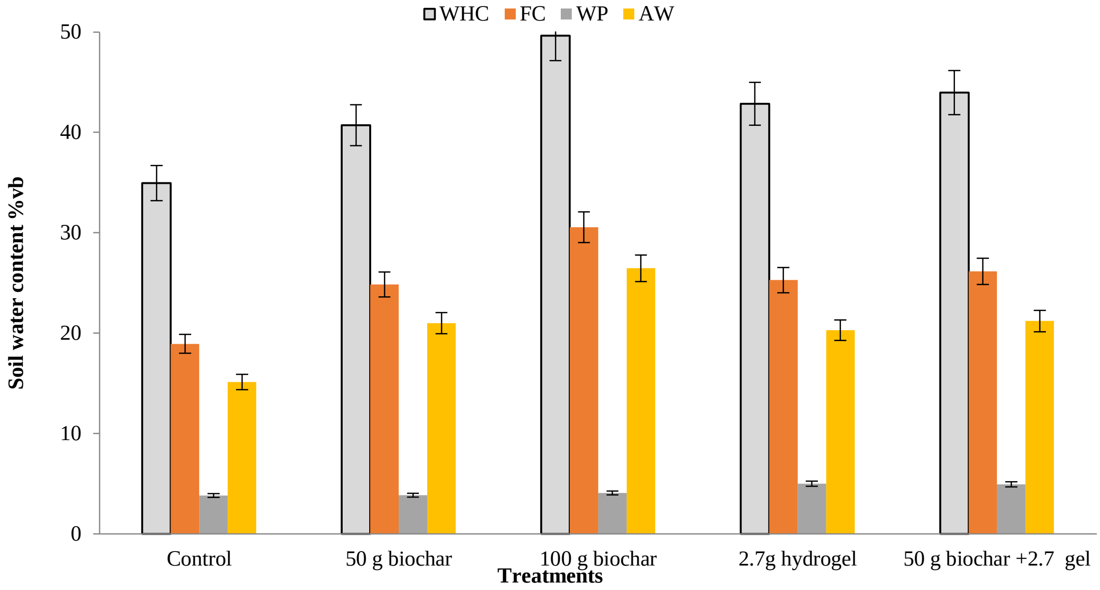

Fig.1.Effect of the biochar, hydrogel and their mixture (hydro-char) on the soil water constants after harvest of cowpea.

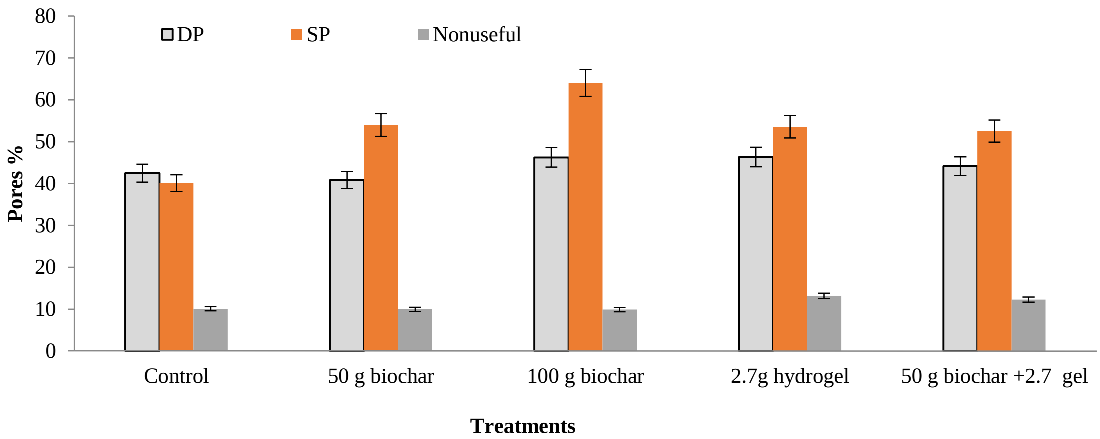

Fig. 2. Effect of biochar, hydrogel and their mixture (hydro-char) on the pore size distribution after harvest of cowpea.

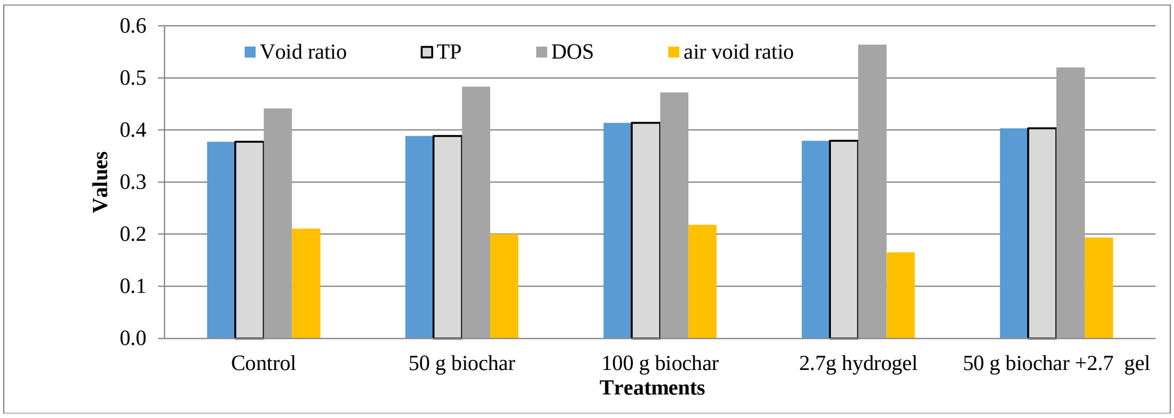

Fig. (3) Effect of the biochar, hydrogel and their mixture (hydrochar) on the soil total porosity and void ratio after harvest of cowpea.

Accordingly, the cowpea biological yield (three cuts) and seed yield that was obtained in the third cut as affected by application of 50, 100 biochar, hydrogel and hydrochar, the results indicated that there were increases in the studied yield variables with application of these soil conditioners but the increase under 75% irrigation regime was higher than 100%. Meanwhile, the lowest values of the biological and seed yield were attained at control under both irrigation regimes.

With regard to the effect of irrigation regime on the biological and seed yield of cowpea crop, data in Tables (1 and 2)exhibited that the reduced irrigation quantity by 25% led to an increase in biological yield by 2.3% where the opposite was true in case of cowpea seed yield. Regardless of irrigation regime, application of the examined soil conditioners improved both biological and seed yield of cowpea (Fig. 4). Obviously noticed that there were increases in the biological and seed yield expressed in percentage as follows 18.4, 27.5, 14.2; 8.5% and 52.3, 117.9, 69.3, .

70.7%, respectively. Bakry et al. [34] supported our results where the fluxes of plant growth characters improved by biochar application are enriched with humic acid. Meanwhile, similar trend was attained after corn treated by biochar [18]**.**

Simple correlation was carried out among the studied hydrophysical properties and resulted data indicated that highly positive correlation between FC and each of DP, SP, TP and void ratio with r values 0.544*, .983**, 0.805**; 0.814**, respectively. Same trend was attained between AW values with r values 0.477*, 0.987**, 0.827**, 0.832**, in the same sequence. Conspicuously, one can notice that biological yield was highly and positively correlated with WHC, FC, AW, SP ,TP, and void ratio; with r values 0.797**, 0.835**, 0.864**, 0.879**, 0.628** and 0.631**, respectively. These findings supported the objectives of the present study improvement in the soil ability to retain more water was associated with an increase in biological and seed yield

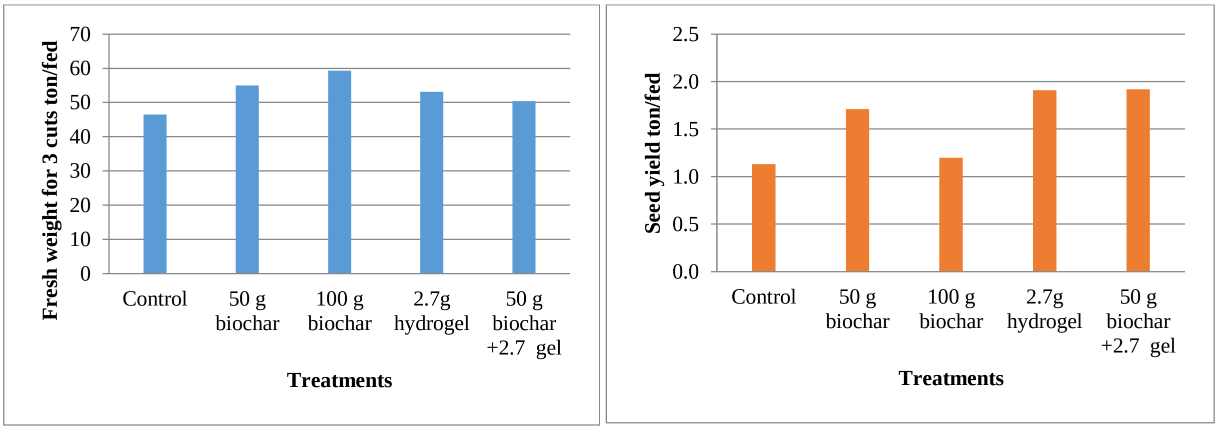

Fig. (4) Effect of the biochar, hydrogel and their mixture (hydrochar) on the biological and seed yield of cowpea.

Table 1. Effect of the biochar, hydrogel and their mixture (hydro-char) on some hydrophysical characteristics after harvest of cowpea under two irrigation regimes

Irrigation regime Etc (%)	Soil conditioners	Moisture content (%)				Pore size distribution (%)			Soil porosity					Yield ton/fed	
		WHC	**FC**	**WP**	**AW**	**DP**	**SP**	**Non useful Pores**	**BD g cm^{-3}**	**TP%**	**Void ratio**	**DOS**	**air void ratio**	**Sum of three cuts**	**Seed**
	Control	34.89	19.23	3.80	15.43	41.09	40.48	9.97	1.64	38.11	0.381	0.439	0.214	48.00	1.10
75%	50 g biochar	41.69	25.40	3.85	21.55	41.51	54.91	9.81	1.61	39.25	0.392	0.472	0.207	54.00	1.58
	100 g biochar	50.32	31.24	3.94	27.30	45.55	65.18	9.41	1.54	41.89	0.419	0.460	0.226	57.34	2.40
	2.7g hydrogel	43.56	25.46	4.96	20.50	47.02	53.26	12.89	1.63	38.49	0.385	0.555	0.171	53.00	1.91
	Hydro-char	44.25	26.17	4.92	21.25	43.96	51.66	11.96	1.56	41.13	0.411	0.508	0.202	55.00	1.88
	Mean	**42.94**	**25.50**	**4.29**	**21.21**	**43.83**	**53.10**	**10.81**	**1.60**	**39.77**	**0.398**	**0.49**	**0.20**	**53.47**	**1.77**
	Control	35.01	18.64	3.81	14.83	43.82	39.70	10.20	1.66	37.36	0.374	0.444	0.208	44.98	1.15
	50 g biochar	39.75	24.31	3.88	20.43	40.11	53.08	10.08	1.63	38.49	0.385	0.495	0.194	56.09	1.85
	100 g biochar	48.97	29.84	4.21	25.63	46.94	62.89	10.33	1.57	40.75	0.408	0.485	0.210	61.23	2.50
	2.7g hydrogel	42.15	25.11	5.02	20.09	45.61	53.78	13.44	1.66	37.36	0.374	0.573	0.159	53.21	1.90
100%	Hydro-char	43.68	26.12	4.96	21.16	44.32	53.40	12.52	1.60	39.62	0.396	0.533	0.185	45.87	1.96
	Mean	**41.91**	**24.80**	**4.38**	**20.43**	**44.16**	**52.57**	**11.31**	**1.62**	**38.72**	**0.387**	**0.51**	**0.19**	**52.28**	**1.87**
	LSD 5%irrigation	0.21	0.36	0.14	0.62	0.17	0.13	0.26	ns	0.36	0.009	0.01	0.01	0.11	0.06
	LSD5%interaction	1.67	2.01	1.11	1.75	1.68	0.98	0.16	0.04	0.24	0.54	0.03	0.02	1.03	0.13

Hydro-char: 50 g biochar +2.7 hydrogel, WHC: water holding capacity, FC: field capacity, WP: wilting point, AW: available water, DP: drainable pores, SP: storage pores, BD: bulk density, TP: total porosity, DOS: degree of saturation

Table (2) Effect of the biochar, hydrogel and their mixture (hydro-char) on some hydrophysical characteristics after harvest of cowpea

Soil conditioners	Moisture content (%)				Pore size distribution (%)			Soil porosity					Yield (ton/fed)	
	WHC	**FC**	**WP**	**AW**	**DP**	**SP**	**Non-useful pores**	**BD g cm^{-3}**	**TP**	**Void ratio**	**DOS**	**air void ratio**	**Biological**	**Seed**
Control	34.95	18.94	3.81	15.13	40.09	10.08	10.08	1.65	37.74	0.377	0.44	0.21	46.49	1.13
50 g biochar	40.72	24.86	3.87	20.99	53.99	9.95	9.95	1.62	38.87	0.389	0.48	0.20	55.05	1.71
100 g biochar	49.65	30.54	4.08	26.47	64.03	9.87	9.87	1.56	41.32	0.413	0.47	0.22	59.28	2.45
2.7g hydrogel	42.86	25.29	4.99	20.30	53.52	13.16	13.16	1.65	37.92	0.379	0.56	0.17	53.11	1.91
Hydrochar	43.97	26.15	4.94	21.21	52.53	12.24	12.24	1.58	40.38	0.404	0.52	0.19	50.44	1.92
LSD 5% soil conditioners	3.14	2.56	1.36	2.33	2.71	1.25	0.24	0.02	0.18	0.076	0.02	0.02	1.23	0.21

Hydro-char: 50 g biochar +2.7 hydrogel, WHC: water holding capacity, FC: field capacity, WP: wilting point, AW: available water, DP: drainable pores, SP: storage pores, BD: bulk density, TP: total porosity, DOS: degree of saturation

Conclusion

The particle size of biochar mixed with a sandy soil greatly enhanced soil hydrophysical properties that were clearly observed at FC and AW with 100 g biochar followed by hydrochar and 50 g biochar. An application of biochar and hydrochar increased micro-porosity in the soil and increased the ability to retain more water particularly at water potentials near to FC, but did not significantly affect the water content at WP. However, BD was reduced, which developed pore size distribution and consequently water flow through soil profile and this reduction was larger the size of the biochar 100 g/plant, which was mainly attributed to the increased micro-pores. Also enriched biochar by mixing with hydrogel could contribute to improving of the water retention, PSD and yield of treated sandy soil.

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