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Research article

Applying biochar from date palm waste residues to improve the organic matter, nutrient status and water retention in sandy oasis soils

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Abstract

This study aimed to valorize the waste of date palm tree of oasis system in south Tunisia into biochar and used like amendment to improve physical and chemical characteristic of sandy soil in south Tunisia. Biochar obtained after pyrolysis of date palm tree waste in absence of oxygen in temperature of 500 °C, and incorporate in sandy soil of south Tunisia with different rates (5 t/ha, 10 t/ha,15 t/ha and 20 t/ha) compared with untreated soil.

The initial results indicate generally improvement in chemical characteristics with increase of biochar rates in soil like total carbon and nitrogen concentration and other essential elements in soil. Available water in soil increase with the increase of rate of biochar to attend a maximum in 20t/ha biochar, finally, production growth increase with biochar amendment to have a pic in the rate of 2t/ha. The promising results show a potential for biochar to become are important soil fertility amendment in Oasis farming, and at the same reducing residue waste.

Key words: Oasis farming system, date palm waste, biochar, water retention, organic carbon, sandy soils.

1. Introduction

Semi-arid and arid region are defined as region where evaporation exceeds precipitation, generally arid lands cover 41% of earth's land surface, At present, almost of 900 million peoples inhabit arid and semi-arid lands , the biodiversity in arid and semi-arid among plants and animals is generally lower than that in more humid ecosystems. Some arid and semi-arid system may be converted to farming land like oases system (Laghari et al., 2015). Oases only occupy less than 3% of the semi-arid regions of the world but feed from 7 to 10 million peoples (Clouet, 1995). The oasis farming systems in south Tunisia occupy an area of 450 km² (FAO, 2013), that feed a population of over 1.5 million inhabitants. With over 4.5 data palm million present in that area (Hajji, 2013), which each tree providing 33 $kg.yr^{-1}$ date palm tree residues. Means 150 Gg of material, which normally are burned to incorporate directly in the soils, compost it or make into biochar.

Among the problems, facing arid lands is the global climatic trend towards an increase in temperatures (Global Warming) which would lead to an increase in aridity and a decrease in the available moisture. This problem could probably be mitigated through carbon sequestration (CO_2 absorption and storage in plants). However, Soil organic matter (SOM) plays an important role in ecosystems by retaining and supplying plant nutrients, improving soil aggregation, reducing soil erosion, and enhancing water-holding capacity (Tisdall and Oades, 1982; Brady and Weil, 2002). Sandy soils in south Tunisia poor in organic matter because of climatic condition and agriculture management (Brahim and Ibrahim, 2018).

Oasis system are characterized by a very important mass of waste better 200g m-2 of date palm waste and 100 g m-2 of fruit tree waste (Ben Salah, 2014), as kind of valuation date palm waste is recovered in compost. Composting is a technology for recycling organic materials in order to achieve enhanced agricultural production. Biological and chemical processes accelerate the rate of decomposition and transform organic materials into a more stable humus for application to the soil. Composting proceeds under controlled conditions in compost heaps and pits (Bot and Benites, 2014). The farmers of the region used the organic manure to improve physical and chemical propriety of soil, the manure is still exposed to sunlight and is susceptible to rapid decomposition and drying (Mlih et al., 2016) and estimated the organic waste loss in Gabes oases of Tunisia to be more than 5.700 $t.yr^{-1}$ (Kouki, 2009). Because this reason farmer are obliged to add manure annually to improve their soil, or applicate inorganic fertilizers this can cause soil degradation and many environmental problems owing to more organic matter mineralization (Agegnehu et al., 2016). Compost heaps should have is suitable for more humid environments where there is potential for watering the compost, also composting is a long process to have mature compost we need to weight more than 3 months (Bastida et al., 2016) for this reason we tried to use the waste in biochar form. Biochar is produced in the partial or total absence of oxygen, the thermal decomposition of plant derived biomass (pyrolysis) can be manipulated to yield, and in addition to CO_2 and in variable ratio, combustible gases (chiefly H_2, CO_2, CH_4), volatile oils, tarry vapors, and a solid carbon-rich residue generally referred to as char. As distinct from char in general, biochar remains ill-defined (Sohi et al., 2010). Biochar quality and characteristics vary with production conditions and feedstock used (Song and Guo, 2012). Same research showed that higher temperature biochar has a higher carbon and plant nutrient content than lower temperature biochar (Al-Wabel et al., 2013), in other study they appear that the biochar created at low temperature may be suitable for controlling release of fertilizer nutrient (Day et al., 2005; Sohi et al., 2010), while high temperatures would lead to a material analogous to activated carbon (Ogawa et al., 2006; Sohi et al., 2010). For this reason biochar pyrolysis temperature condition was categorized into low <250 °C), medium (250-500 °C) and high (>500 °C) temperature biochar (Omondi et al., 2016).

Biochar has an aromatic structure that makes it stable and highly resistant to chemical and biological degradation in soil (Brahim and Ibrahim, 2018), but the key factor of physicochemical properties of biochar is feedstock used and pyrolysis temperature (Sohi et al., 2010). like the carbon content can be increase in biochar from 56% to 93% between 300 and 800 °C (Okimori et al., 2003), also surface area increasing in one study from 120 m^2g^{-1} at 400 °C to 460 m^2g^{-1} at 900°C (Day et al., 2005). There is widespread debate about the use of biochar and its agricultural benefits in soil from the history of terra preta soil (Young., 1804) to the use of biochar in current time in arid area(Sohi et al., 2010; Laghari et al., 2016; Liu et al., 2016; Omondi et al., 2016).

Biochar is increasingly being used as a soil amendment with the aim to improve soil physical, chemical and biological properties, reduce greenhouse gas emissions, and sequester carbon by withdrawing organic carbon from the cycle of photosynthesis and decomposition. Biochar sequestration directly removes carbon dioxide from the atmosphere (Lehmann, 2007; Sohi et al., 2010; Liu et al., 2016). However many study showed that the addition of biochar change total porosity by increase them over than 10% with plenty of nano-scale micropore (Omondi et al., 2016), this modification in soil structure improve available water capacity (AWC) (Uzoma et al., 2011; Laghari et al., 2015) in soil for the plant and increase growth of yield, also biochar enhance chemical proprieties of soil, the pH in soil amendment with biochar decrease or increase depended to soil and biochar proprieties (Saran et al., 2009; Xu et al., 2012). However the CEC increase after pouted biochar in soil which is consistent with many research (Laird et al., 2010; Uzoma et al., 2011), also the use of biochar increase plant nutients such as Ca, P and K (Sohi et al., 2010; Laghari et al., 2015). Many experiment tried to used biochar in arid area with sandy soil (Omondi et al., 2016; Liu et al., 2016; Borchard et al., 2014) but two experiment conducted (Al-Shankiti and Gill, 2014) in Dubai, and in United Arab Emirates (Khalifa and Yousef, 2015) suggested that biochar of date palm waste addition to sandy soil increases water holding capacity which might increase water availability for plant use and chemical propriety. A unique aspect of this work is that we are using feedstock considered to be a problematic waste in the country because approximately 90 thousand tons of waste in the form of tree clippings is generated and transported to landfills on an annual basis (Ben Salah, 2014). Conversion to biochar and subsequent use in soil maybe a good solution to deal with a problematic waste stream and at the same time to improve the quality of soil in South Tunisia.

The objective of this study was therefore to assess the initial impact of biochar amendment on the quality of a sand-textured soil representative of South Tunisia. The arid region of South Tunisia is characterized with an arid climate. This soil degradation process is largely due to carbon losses resulting from loss of vegetation cover and soil erosion. Leading to loss of food productivity and ultimate hunger (Dregne, 2002). However, the application of biochar (and thus C addition) soil in the oasis production system of Southern Tunisia maybe a mechanism to improve physical and chemical characteristic of sandy In this study, we evaluated the initial impact of using five different biochar application rates (0 to 20 t/ha) on physical (water retention) and chemical (fertility) parameters.

2. Materials and methods

2.1. Sample collection, preparation and experimental design

Surface samples were collected at two different times: 28th January 2018 and 28th May 2018. Soil was collected from the sandy soil at the latitude of 33° 21"16' East and longitude of 10° 30"19' South East of Tunisia. The soil is texturally graded as total sand (contain 1.7% Clay, 8.8% silt, and 89 % sand) as determined using the Pipette Robinson method.

Samples were collected from five treatments and each sample divided into three replicates in the first sampling time and three replicates in the second time. All samples were placed in plastic pages, labelled and taken to the laboratory. Soil from each replicate was air dried, sieved and stored for chemical analysis.

2.2. Biochar

The experimental design was a randomized in pots with five treatments and three replicates; Biochar was sourced of Kebili oasis of South Tunisia (33.30° and 34.15°N; 8.30° and 9.10°E); feedstock consisted of date palm waste pyrolysis in a continuous flow kiln at temperatures up to 500 °C (Hans et al., 2016; Laghari et al., 2016) for 30-40 min. The biochar had a pH of 7.63, contained 81.2% organic matter (OM), 0.608 % $NH4^{+}$, extractable P and 2976 mg kg^{-1} K and 54.6 meq/100g CEC. Physical characteristics of the biochar are also detailed by the determination of water reserve which is 5.19%. Biochar was added at a rate of 0t/ha, 5t/ha, 10t/ha, 15t/ha and 20t/ha with sandy soil sieved in 2 mm.

2.3. Water content and chemical analysis of soil

Available water was determined using the membrane pressure plate extraction method (Klute, 1986) by taking the difference in water content between at 0.1 and 15 bars. A pH probe was used to determine buffered soil pH (1:1 soil: water) as described in (Mclean, 1965) and of biochar as described in (Jouiad et al., 2015) and by analyzing Colwell phosphorous, Colwell potassium, sulphur (KCl), organic carbon (Walkley-Black) and nitrogen (Kjeldhal).

2.4. The Bean "Vicia faba" Growth experiment

The bean growth experiment was from December to June in 2018. 10 seeds were sowed to every experimental pot. After maturation, ground and underground biomass was harvest and dried (60 °C), also total mass production per plant are weight. The effect of the various biochar treatments on chemical, physical and biological parameters were statistically analyzed by ANOVA using SAS to assess the level of significance of the various biochar additions on soil properties compared to an unamended control and compost addition treatments with probability of 5%.

3. Results

3.1. Chemical properties

The effect of biochar to the soil has a direct significant ($p <0.05$) positive impact on soil organic C (SOC) content in total carbon, i.e. from 0.17 (±0.10%) in untreated soil to increase with the increase of biochar rate in soil and attend their maximum through 1.40 (±0.10%) in soil amended with 20 t/ha biochar.

However, this difference was retained after 3 months with SOC in soil amended with 20 t/ha biochar being 1.47% (±0.99) and not significantly ($p >0.05$) different than what was initial added, SOC in untreated soil decrease to attend a minimum with 0.13(±0.094%) (Figure 1).

There was not significant ($p>0.05$) difference s in the pH value of the soils with and without the biochar amendment, 7.62 (±0.024) and 7.80 (±0.046), respectively and this was irrespectively of the amount of biochar added to the soil.

The EC did significant increase ($p<0.05$) with the addition of biochar, it increase from 1.9mS/cm (±0.65) in control soil to 9.47mS/cm±0.64 in soil amended with 20t/ha biochar, the EC decrease with the increase of experimental duration and have a significant effect in soil ($p <0.05$) to attend 7.58 mS/cm (±0.64) in soil amended with 20 t/ha biochar (see tables 1).

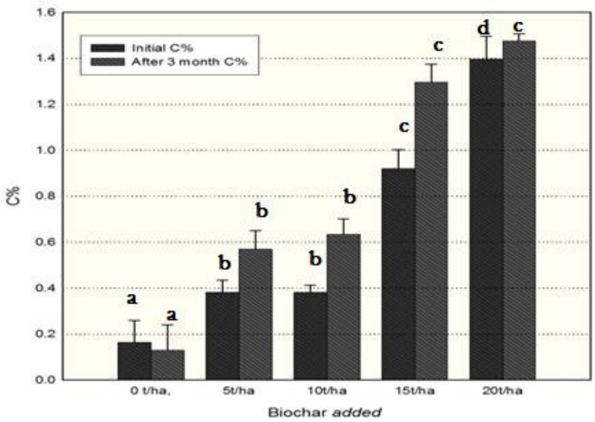

Fig. 1. Influence of different levels of biochar soil amendment on soil organic carbon. Letters above the bars indicate differences according to Tukey's test (p‹0.05)

The biochar fertilizers have a significant effect to improve soil fertility with moderate to high levels on N, P, and K in soil.

The total nitrogen ($p <0.05$) increase with the quantity of biochar added in soil and be maximum in 20 t/ha biochar with 0.53% (±0.63) larger than minimum value 0.36% (±0.48) in untreated soil, but the concentration of total nitrogen decrease with the increase of experimental duration ($p < 0.05$) to attend 0.38 % (±0.64) in soil amended with 20t/ha but this concentration rest more important than the untreated soil (0.26% ±0.51).

The exchange potassium (K ex) also has a significant effect ($p <0.05$) and increase from 153.03 mg kg-1 (±0.67) in the control soil to 1697.76 mg kg-1 (±0.52) in the amended soil with 20 t/ha biochar, the phosphorus (P) concentration in soil don't have a significant effect ($p >0.05$) but they concentration in soil increase from 1356.08 mg kg-1 (±0.22) to 1749.57 mg kg-1 (±0.29) but after the increase of experimental period the phosphorus have a significant effect in soil ($p <0.05$) and they concentration decrease to attend a minimum in 20 t/ha biochar with 846 mg kg-1 (±0.23).

Table 1. Soil chemical characteristics of unamended control and biochar amended soil, including the Least Significant Difference (L.S.D) and the p-value.

Parameters		Control	5t/ha biochar	10t/ha biochar	15t/ha biochar	20t/ha biochar	LSD	P value
pH	**A**	7.80±0.02a	7.71±0.03a	7.74±0.008a	7.68±0.10a	7.62±0.046a	ns	0.1589
	B	7.66±0.07a	7.55±0.04a	7.7±0.02a	7.7±0.01a	7.78±0.02a	ns	0.1444
Electric conductivity (mS/cm)	**A**	1.90±0.6a	4.63±0.2a	5.95±0.16b	7.77±0.28c	9.47±0.64d	S	<.05
	B	2.59±0.6a	4.58±0.3a	5.30±0.16b	6.43±0.28c	7.58±0.6d	S	<.05
Exc. Potassium (mg.kg^{-1})	**A**	152 ±0.6a	08±0.64a	1105±0.19b	1453±0.29c	1697±0.52d	S	<.05
	B	305±0.6a	665 ±0.2a	1387±0.1b	1846±0.3d	2592±0.6e	S	<.05
Phosphorus Colwell (mg.kg^{-1})	**A**	1356±0.2a	1708±0.3a	1719±0.07a	1746±0.3a	1749±0.2a	ns	0.4599
	B	859±0.1a	871±0.1b	868±0.06ab	860±0.9ab	846±0.2d	S	<.05
Total nitrogen (%)	**A**	0.37±0.4a	0.44±0.3b	0.47±0.2ab	0.48±0.3c	0.53±0.6d	S	<.05
	B	0.27±0.1a	0.29±0.3b	0.33±0.1ab	0.34±0.2c	0.38±0.7d	S	<.05

L.S.D = least significant difference. ns = non-significant. S=significant, letter indicate diffences according to Tukey's test (p‹0.05), A: soil directly after amendment with biochar; B:soil after 3 months with biochar amendement

3.2. Physical properties

The field capacity or soil moisture, after soak, after receiving a volume of water, the soil is saturated then this water progressively migrates by gravity into the drainage pores, it remains in the part of the Shipping dry soil only the capillary water on which the forces of gravity are no longer acting. The indicator sand is characterized by a very low ability to retain water; this is explained by the presence of macroporosity.

Table 2 show that biochar amendement have a significant effect (p <0.05) in field capacity which increase with the increase of biochar rate in soil from 4.38% (±0.65) in control soil to 13% (±0.64) in soil amended with 20 t/ha biochar. (Table 2) correspond to the permanent wilting point this corresponds to the moisture in which all plants show signs of wilting, the evolution of pf is significant (p <0.05) and proportional to the evolution in the rate of biochar in soil, pf increase from 3.9% (±0.65) in unamended soil to 9.68% (±0.64) in soil amended with 20t/ha biochar . The calculation of water retention characteristics measured on control and amended soil, showed that useful (UW) water in soil have a significant effect (p <0.0001), and UW increase from 0.48% (±0.06) in control soil to 3.32% (±0.04) in soil amended with 20 t/ha biochar.

3.3. Effect of biochar amendement in fresh matter (FM) and dry matter (DM) and production of bean plant

Biochar amendement have no significant effect (p >0.05) in the FM of bean plants, it increase from 1.22 % (±0.16) in untreated soil to 1.35% (±0.11) in soil amended with 20 t/ha biochar, also DM is no significant with biochar amendment (p >0.05), it decrease from 0.165 % (±0.04) in control soil to 0.19 % (±0.17) in soil amended with 20t/ha biochar, but they have significant effect (p <0.05) in bean production, the number of pods/plants increase from 1pods/plants in unamended soil to attend a maximum in soil amended with 2 t/ha biochar with 5 pods/plants, but the soil amended with 20 t/h biochar don't have a maximum production despite they have excellent physical and chemical characteristic (Table 3).

4. Discussion

The result support that soil biochar amendment improving physical and chemical properties in sandy poor soil in south Tunisia, the lack of significant changes in any of the key soil fertility indicators such as soil organic carbon, phosphorus, potassium, total nitrogen, pH, EC and useful water. However the significant increase in the soil organic carbon concentration after biochar treatment indicate that the soil's health and release nutrients has been improved, other studies have reported an increase in soil organic carbon after application of biochar in soil (Ibrahim et al., 2016).

Table 2. Soil physical characteristics of unamended control and biochar amended soil, including the Least Significant Difference (L.S.D) and the p-value.

Parameters	Control	5t/ha biochar	10t/ha biochar	15t/ha biochar	20t/ha biochar	LSD	P value
WS (FC%)	4.38±0.6a	5.55±0.1a	8.53±0.1a	10.25±0.2a	13±0.6a	ns	0.774
WS (wp %)	3.99±0.6a	4.24±0.2a	6.46±0.1a	7.46±0.3a	9.68±0.6a	ns	0.626
AW	0.478±0.05a	1.305±0.12b	2.076±0.007c	2.79±0.02c	3.32±0.03d	S	<.05

L.S.D = least significant difference. ns = non-significant. S=significant, letter indicates diffences according to Tukey's test (p‹0.05); WS (FC%) = field capacity; WS(wp%)= wilting point; AW=available water.

Table 3. Bean plant characteristics of unamended control and biochar amended soil, including the Least Significant Difference (L.S.D) and the p-value

Parameters	Control	5t/ha biochar	10t/ha biochar	15t/ha biochar	20t/ha biochar	LSD	P value
FM(%)	1.22±0.16a	1.28±0.16a	1.31±0.14a	1.34±0.08a	1.35±0.11a	Ns	0.7745
DM	0.165±0.04a	0.166±0.08a	0.167±0.08a	0.178±0.16a	0.187±0.17a	Ns	0.6267
TP	1±0.28a	5±0.96b	2±0.60c	1±0.28a	0.66±0.29d	S	<.0001

L.S.D = least significant difference. ns = non-significant. S=significant, letter indicates diffences according to Tukey's test (p‹0.05); FM: Fresh matter; DM=Dry matter ;TP=Total production.

Also, the increase of soil organic carbon after 3 month of application of amendment indicate that the

lt process in arid area with the climatic condition who activate mineralization in sandy soil (Mlih et al., 2016), in the same context (Borchard et al., 2014) showed that the addition of biochar in sandy soil improve carbone sequestration. While other studies have reported an increase in soil pH following biochar application (Kimetu et al., 2008), our results showed a decrease in soil pH after the addition of biochar. The effect of biochar on soil pH is dependent on the pH of biochar itself and the liming value, which is dependent on the feedstock and pyrolysis conditions used for biochar production (Bookana et al., 2011; Lehman et al., 2011; Laghari et al., 2015). As the biochar in this study had a pH of 6.4, it was not surprising that it did not have a liming effect as has been observed in biochar with high pH values. An increase in organic matter following the addition of biochar decrease soil pH due to the microbial activity and organic acids released during organic matter decomposition The enhancement of microbial community structure is more likely to be due to the physiochemical characteristics of biochar added to the soil (Saison et al., 2006; Prendergast et al., 2013) showing that biochar is a direct source of nutrients. Many Studies have reported that the effect of biochar on the adsorption of P is highly influenced by the pH of the soil[42][43]. Indeed,

carbon is sequestrated in sandy soil, this is a very difficu

at pH around 7 and 7.5, however, the ability of biochar to increase P retention in soils is quite variable. It varies with P concentration in the soil solution [44]. Some studies have found an increase in the concentration of nitrogen in soil amended with biochar (Gaskin et al., 2008; Laird et al., 2010; Borchard et al., 2014; Prendergast et al., 2013; Borchard et al., 2014). According to Borchard et al., (2014) the addition of biochar enhanced N mineralization moreover, Noguera et al., (2010) attributed the increase in the concentration of nitrogen in the soil amended with biochar. Indeed, the availability of NO3 decline in the presence of biochar can be explained by greater consumption of nitrogen by the plant (Johannes et al., 2004; Martinsen et al., 2014). The concentrations of K +and PO43- were slightly higher in the substrates amended with biochar (Alling et al., 2014), Given its special physical properties, biochar therefore influences the texture, structure, porosity, size and pore distribution and the density of the soil in which it is incorporated (Laghari et al., 2016; Omondi et al., 2016). The author reported the following relationships between biochar amendement and total porosity this confirmed with study of (Omondi et al., 2016) after laboratory experience with different rate of biochar in sandy soil, they showed that total porosity increase with biochar rate in soil. After modification in total porosity the available water capacity tend to increase with biochar application rate (Omondi et al., 2016; Liu et al., 2016). Also, Laghari et al., (2015) after experience in Kubuqi desert confirm that the water holding capacity in sandy soil increase with the increase of biochar rate added in soil these results are confirmed by our study which provides improved RU in the sandy soil of arid regions.

Biochar have a significant effect in the increase of production in the rate of 2 t/ha in sandy soil of south Tunisia, but the high rate don't give the mashers production, this study is confirmed with same study of (Viger et al., 2015), that suggest the biochar with important quantity in soil lowers the activity of plant genes that help to defend against insect and pathogen attacks, also Luhman, (2015) say that the application of biochar in high rate can cause a decrease in yields, Also After study of the effect of biochar in Ryegrass (Lolium perenne) in sandy soil (Liu et al., 2016) suggest that higher application rate have no significant increase in production but based to the study of Major et al., (2010) that this rate can be significant after 2 or 3 years , finally Zimmerman et al., (2011) suggests that using wrong rate of biochar can negatively impact the soil's microbiota. But, the application of biochar can increase the yield production, same study of Jefferya et al., (2011) found an overall average yield increase of 10% rising to 14% in acidic soils, also, Crane-Droesch et al., (2013) study the effect of biochar in degraded sandy soil of Kenya and showed that the production increase with 32% in soil amended with biochar.

5. Conclusion

The results of this study support our hypothesis and suggest that the application of biochar to subtly influence soil characteristics leading to changes in physical and chemical proprieties of sandy soil and increase production. With the climatic condition of south Tunisia the biochar can be a good solution to improve the situation of agriculture with low cost and help to save oasis environment in poor country like south Tunisia, in this context world bank conclude that biochar may be a key element of climate-smart agriculture practices in developing country and help to mitigate climate change and reduce vulnerability to its effects. The question now is if the farmers of southern Tunisia accepted biochar as a new type of amendment with manure or compost and solve the problem of no usable waste in oases system.

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