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A short report on changes of quality indicators for a sandy textured soil after treatment with biochar produced from fronds of date palm

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Abstract

Soils in arid regions are not favourable for agricultural purposes because of intrinsic characteristics; mainly low water retention and poor fertility. We report initial results from on an on-going study into the effects biochar application on characteristics of a soil typically found in Abu Dhabi, UAE. Biochar was produced from fronds of date palm by carbonization at 400 ºC in an oven and applied at 0, 10, 50 or 100 g kg^{-1} soil. Treatment with biochar increased soil water retention up to 20%, increased Cation Exchange Capacity (CEC) slightly from 2.5 up to 6.7 meq $100g^{-1}$ and lowered the sodium adsorption ratio (SAR) of soil to below sodic levels (< 13). Biochar application at 50 g kg^{-1} soil appears to be the rate at which changes in soil quality become apparent. The data presented indicate that treatment of soil with biochar induces changes in soil that are favorable but long term studies are required to monitor the longevity of these effects.

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Keywords: biochar; CEC; sand; SAR; water retention

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1. Introduction

Soil quality defined broadly as the capacity of a soil to maintain plant, animal and human health is central for food production and functioning of global ecosystems [1]. The criteria used as indicators of soil quality relate to intended ecosystem services and often require multiple assessments of physical, chemical and biological parameters. Soil quality is inherently determined by the pedogenic factors of soil formation, with climate often being a dominant factor [2]. However, soil quality may change with time as a result of human impact such as land use decisions or natural events such as forest fires. Developing sustainable land management practices therefore require assessing and monitoring the direction of change in quality indicators [3].

A growing practice for managing soil quality is land amendment with biochar, a carbon rich product resulting from heating of biomass in low oxygen environments [4], [5]. Biochar is chemically and biologically stable and its application to soil is recommended as a form terrestrial carbon sequestration [6]. Furthermore, biochar land amendment is reported to increase crop yields, improve soil fertility and stimulate microbial activity (e.g. [4], [5], [7]) . The objective of this study was therefore to make an assessment of the initial impact of biochar amendment on the quality of a sand-textured soil representative of the United Arab Emirates (UAE). The UAE is characterized with a hyper-arid climate and is vulnerable to desertification - a soil degradation process that is largely due to carbon losses resulting from loss of vegetation cover and soil erosion [8], [9]. That being said, biochar land amendment in the UAE maybe a mechanism to combat desertification through the addition of carbon to soil. A unique aspect of this work is that we are using feedstock considered to be a problematic waste in the country because approximately 50 thousand tons of waste in the form of tree clippings is generated and transported to landfills on an annual basis (personal communication with Abu Dhabi centre for waste management). Conversion to biochar and subsequent use in soil maybe a good solution to deal with a problematic waste stream and to improve the quality of soil in the UAE. In this study, we evaluated the initial impact of using three biochar application rates (10, 50 and 100 g kg^{-1} soil) on physical (bulk density and water retention) and chemical (fertility indicators such as pH and Cation Exchange Capacity and Sodium Adsorption Ratio) properties commonly used as quality indicators.

2. Materials and Methods

2.1 Soil and Biochar

Feedstock (date palm fronds *Phoenix dactylifera*) were collected from a farm in Abu Dhabi, UAE, air-dried over 72 hours, milled into 2 mm pieces and carbonized at 400 ^oC for 30 minutes in a muffle furnace prior to characterization via proximate analysis as described earlier [10]. Soil was collected from the same farm which happened to fall within the extensive soil survey (1:100,000) of Abu Dhabi (**www.uaesis.ae**) and is classified as Typic Torripsamments. The soil is texturally graded as medium sized sand (contain 3.6% (w/w) Clay, 2% (w/w) silt, and 94.4% (w/w) sand) as determined using the hydrometer method [11]. Biochar was added at a rate of 0, 10, 50 and 100 g per kg of oven dry soil in glass beakers and homogenized by mixing with a spatula prior to analysis.

2.2 *Water content and chemical analysis of soil*

Dry bulk density was determined by measuring the mass of oven dry soil (105^oC) per unit volume in a 50 mL falcon tube. Using this information soil treatments were packed in 50 mL glass filtration columns and saturated with de-ionized water equivalent to two pore volumes and allowed to drain over 48 hours at room temperature (22^oC) for determination of gravimetric water content at field capacity. Available water was determined using the membrane pressure plate extraction method [12] 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 [13] and of biochar as described in [10]. Cation Exchange Capacity (CEC) was determined following USEPA method 9080. Sodium Adsorption Ratio (SAR) was determined following the USDA handbook no 6 protocol of creating a saturated paste extract, and analyzing the concentrations of ions in the leachate through ion chromatography[14].

3. Results and Discussion

Characteristics of the biochar used in the study are presented in Table 1. The fixed carbon, ash content and pH are lower than what we reported for date palm biochar that was produced in a pyrolysis reactor [10]. This is most likely attributed to different conversion conditions [15] – those being the duration of heating and atmospheric conditions in which feedstock conversion to biochar took place. In this study, we used a shorter heating duration and it was also not possible to establish a complete nitrogen atmosphere because of background oxygen levels present in the conversion oven.

The quality of soil in the UAE is considered poor and not suitable for agricultural production because of its (1) physical structure (poor water retention due to sandy texture and low organic matter content), (2) low fertility due to warm climate and parental materials (soils are alkali and often sodic due to the accumulation of sodium, carbonates and gypsum in top layers), and (3) low support for biological productivity (low vegetation and microbial activity due to moisture availability). We evaluated the effect of biochar amendment on soil quality by evaluating several key indicators. Specifically, we evaluated physical properties (bulk density and water retention) and chemical properties (pH, CEC and SAR) of soil directly after treatment with biochar using non-treated soils as reference. These properties were assessed at different rates of biochar application (10, 50 and 100 g kg^{-1}) to determine the effective rate required to induce changes.

The bulk density of a soil depends on its mineral and organic composition as well as its compaction. It is not an intrinsic property, but is rather dependent on management practices [16]. Addition of organic materials to mineral soils tends to reduce bulk density [16], [17] because organic matter have lower particle density, and are more porous in nature. That said, because the bulk density of biochar (0.36 g cm^{-3}) (Table 1) is less than that of untreated soil (Table 2), its addition to soil is expected to lower soil bulk density. Indeed, the addition of biochar reduced bulk density from 1.5g cm^{-3} in non-treated soil down to 1.1 g cm-3 in biochar treatment with 100 g kg^{-1} soil (Table 2). However, the lowest biochar application rate (10 g kg^{-1}) soil treatment had similar bulk density to untreated soils (Table 2). A reduction in soil bulk density using similar rates of biochar application has been reported in another study utilizing hardwood biochar [18]. Water retention, another quality indicator, is dependent on bulk density and organic matter content [17]. Other studies have reported an increase in water retention as a result of biochar treatment [19][18]. Therefore, we predicted that soil treatment with biochar will also accompany an increase in water retention in comparison to untreated soil. Two soil water retention measurements were made in this study - (1) field capacity, which is the maximum amount of water that can be held in soil against gravity and (2) available water, which is water easily accessible to plants and is determined by taking the difference in water content of soil at 0.1 bar and 15 bar [20]. As expected water retention increased with higher rates of biochar application - up to 20% and 2.4% more for field capacity and available water for the 100 g kg^{-1} biochar treatment in comparison to non- treated soil (Table 2).

pH, Cation Exchange Capacity (CEC) and Sodium Adsorption Ratio (SAR) were used as chemical or fertility indicators of soil quality in this study. Soil pH is an important property because it impacts mineral dissolution, nutrient availability and microbial activity. In alkaline soils the availability of important nutrients such as phosphorus become limited and the addition of biochar was shown to increase its bioavailability [21]. In this study, addition of biochar to soil reduced pH slightly from 8.4 to 7.9 (Table 2), with all biochar application rates being equally effective. That is to say, treatment of soil with biochar using application rates > 10 g kg^{-1} does not warrant additional benefits in terms of pH conditioning. Soil CEC, expressed in meq 100 g^{-1} is equivalent to charge per kg of cation exchanger (cmol kg^{-1}) and is in an indicator of the capacity of a soil to retain plant nutrients. The CEC of soils varies according to texture, minerology and organic matter content. Sand made of pure silica typically has very low CEC (< 2meq 100g^{-1}), whereas smectite clay has CEC values ranging from 67-161 meq 100g^{-1} [22]. Soil used in this study have a CEC value of 2.5 meq 100g^{-1} (Table 2) and treatment with biochar increased CEC slightly, the highest being 6.7 meg 100g^{-1} for the 100 g Kg^{-1} soil treatment (Table 2). Lastly, soils in the UAE are known to be saline and sometimes sodic which impairs plant productivity [8]. Sodic soils are very prone to erosion because sodium ions interact with soil particles and cause them to disperse therefore resulting in poor structure and stability [23]. Therefore, we conducted soil SAR analysis (a measurement exchangeable sodium in relation to total salts) to determine whether the study soil is sodic and if biochar treatment will impact the measurement. Typically, soils with SAR greater than 13 are classified as Sodic but the severity of SAR on soil depends on many factors such as soil texture and water irrigation quality [23].

Table 1. Characteristics of biochar.

Bulk density (g cm^{-3})	0.4
pH	7.0
Proximate analysis (% wet weight)	
moisture	4.2
volatile	49.6
ash	6.5
fixed carbon	39.6

Table 2. Characteristics of soil treated with biochar.

Measurement	**biochar treatment (g kg^{-1} soil)**			
	0	**10**	**50**	**100**
pH	8.4	7.9	7.9	7.9
CEC (meq 100g^{-1})	2.5	4.0	4.6	6.7
SAR	20.1	10.9	11.6	11.0
dry bulk density (g cm^{-3})	1.5	1.5	1.3	1.01
Water – field capacity (%)	21.2	24.4	31.3	41.2
Water – plant available (%)	2.2	2.9	3.9	4.6

In this study, the SAR of untreated soil is 20, classifying it as sodic (Table 2) and the addition of biochar reduced SAR to below sodic levels (< 13) (Table 2). The decrease in SAR was constant across the biochar application rates used in this study, with the lowest application rate of 10 g kg^{-1} to be equally effective as the highest application rate of 100 g kg^{-1} (Table 2). The reduction in SAR (also expressed as Exchangeable Sodium Percentage) as a result of biochar amendment has been reported in another study [21], and is most likely due to an increase in CEC which reduce the fraction of sodium ions in comparison to other base cations (Ca^{+2}, mg^{+2}).

4. Conclusions

While there are many factors influencing the effect of biochar on the surrounding environment [24], there are potential benefits that are related to the application of biochar. In this study, water retention characteristics are clearly improved, particularly starting with the 50 g Kg^{-1} biochar amendment. This is of relevance to the United Arab Emirates, as the soil is dry, and rainfall is sparse. However, little improvement is observed for CEC and pH which suggest that biochar application maybe suitable for textural conditioning of sandy soil but would provide little benefit to improvement in fertility. It is also evident that large amounts of biochar application are required for improvement in properties of sandy soils because the lowest application rate (10g kg^{-1}), which is commonly used in other studies [25] did not warrant substantial benefits. The results reported in this study are measurements made directly after treatment with biochar, such that additional and periodic analysis are required to effectively evaluate the benefits of biochar application on sandy soil.

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