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Conversion of Organic Municipal Wastes into Biochars and their Effect on Fertility Parameters of Normal and Sabkha Soils of Qatar

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Qatar is undergoing rapid economic growth fueled by its ambitious national vision 2030 which specifically aims to achieve sustainable development. To achieve the latter, durable and sustainable alternatives for municipal solid waste management are needed, especially since Qatar tops most nations in terms of per capita solid waste generation with nearly 2.5 million tons/year of which 60% consists of organic waste. Current disposal methods include incineration, composting, and land filling which generate greenhouse gases that contribute to global warming. At the same time, the soils in most of the country are poor with weak aggregation, low in organic matter, and low water holding capacity. Hence, it makes economic and environmental sense to convert solid organic wastes generated by municipalities into biochars that improve soil quality and act as carbon sink. The suitability of biochar as an effective soil amendment has been related to but not limited to boosting soil fertility by raising soil pH, increasing water holding capacity (WHC) and retention of nutrients in soil, providing a habitat for beneficial fungi and microbes, improving Cation Exchange Capacity (CEC), and reducing nutrients leaching. In addition, biochar has the ability to reduce the emission of the most potent greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). The objectives of this study were to: (1) produce and characterize biochars from solid organic wastes commonly found in Qatar municipal waste streams, (2) determine the effects of solid waste-based biochars on major soil fertility characteristics of normal and sabkha soils of Qatar, (3) select the best performing biochars for use in plant growth experiments.

Four feedstocks [paper, landscape waste, wood, and a mixture of all three) were pelletized, dried, and used as precursors for the production of biochars following a 4×3×3 factor factorial design consisting of the type of precursor (four different municipal solid organic precursors), pyrolysis temperatures (300, 500, and 750°C) and residence time

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(2, 4, and 6 hours). Feedstocks were pyrolyzed under N2 gas at a flow rate of 0.1 mL min^{-1} using a Lindberg box furnace equipped with an air tight retort. Yields, surface area, and chemical properties [ash content, pH, surface charge, Electrical Conductivity (EC), Total Carbon (TC), and elemental analysis] of biochars with relevance to soil applications were determined. Qatari sandy soils (Normal and Sabkha) from the Ap horizon (0–15 cm deep) were collected, air dried, and 2-mm sieved. The incubation experiment was conducted in greenhouse pots. To each pot, sufficient amount of 0.25-mm sieved biochar was mixed with soil to yield carbon to soil ratios of 0, 1, and 2% (wt/wt). Box-Behnken experimental design was used instead of the full factorial to decrease the number of treatments to a manageable level (126 treatments) with three replications at the center. The biochar-amended soils (Normal sandy and Sabkha soils) were incubated for 120 days in a greenhouse at a 10% (wt/wt) moisture level. Samples of incubated soils were collected at time 0 (T0: after 8hrs) and at time120 (T120: after 120 days of incubation) for evaluation of soil fertility characteristics (pH, EC, WHC, aggregate stability, TCN content, macro, and micronutrients composition). In addition, pots were leached at days 60 and 120 and their leachates weighed, filtered, and analyzed for total organic carbon (TOC), pH, EC, micro, and macronutrients.

The application of biochars from different precursors to normal soil at different application rates showed a slight increase in pH of treated soil compared to the soil control at T0 and T120, particularly for biochars produced at high temperature and application rate. The increased soil pH is attributable to buffering effect of biochars pH which typically increases as the pyrolysis temperature increases. The same trend was observed for EC where the pyrolysis temperature of biochars seems to be the most influential on the normal soil EC, especially as it ages. The aggregate stability for the normal soil did not increase as the biochar application rate increases, except for hard wood-based biochar produced at high temperature which had a positive effect on the aggregate stability. However for sabkha soil, the pyrolysis temperature and biochar rate significantly increased the aggregate stability of this soil regardless of the precursor. This can be explained by the accumulation of organic matter that was favored by the binding of organic biochar compounds to abundant soil minerals through cation bridging and the formation of microaggregates that would then form large soil aggregates. The addition of biochars has significantly increased the total carbon (TC) of both soil types compared to the control soils. The total carbon increased with both application rate and pyrolysis temperature. Biochar pyrolysis temperature and application rates favored increased TC with variation depending on the type of precursor, soil type, and duration of incubation. This may be attributed to the oxidation and microbial activity processes that speeded up the process of mineralization in the soil. Overall, the TC in normal soil was higher compared to the sabkha soil which may be due to the fact that the starting carbon concentration in the normal soil was higher than that of sabkha soil. In terms of water holding capacity, it significantly increased in both soil types following biochar amendment, especially those produced at high pyrolysis temperature. The positive effect of soil amendment with biochars on WHC was most pronounced in the sabkha soil which exhibited markedly increased ability to absorb and retain water after biochar addition. This is likely due to the high surface area and porosity of the biochars combined with the effect of the polarity of compounds on the surface of biochars which physically retain water and/or improve soil aggregation thereby retaining more water in the soil. The addition of biochars to soil had a positive effect on the pH of normal soil leachates but less so on leachates from sabkha soil. Some pH variations were also observed within the pH of the same soil leachates as a function of the type of precursors used to produce biochars, most likely due to difference in initial composition of the precursors. This implies that biochars with greater liming capacity can provide greater benefit to arable soils that require liming. The results of cluster analysis were used to determine the group of biochar-amended soils which are the most significantly different from the control treatment in terms of soil fertility parameters (pH, EC, TC, WHC, aggregate stability, leachate pH, micro and macronutrients). From the four precursors, only two (soft and mixed materials) were found to be most effective for normal soil and all improved sabkha soil. To further narrow the selection, a secondary selection was carried out based on the biochars precursor type, yield, and energy required for biochar production. Two biochars emerged as the best performing biochars for normal and sabkha soils. Biochars produced from mixed materials pyrolyzed at 500–750°C for 4–6 hours of pyrolysis time and used 2% application rate are best for amendment of normal soil while soft and mixed materials pyrolyzed at 300–500°C for 4 hours and used at 0.5–1% application rates as most suitable for the amendment of sabkha soil. These biochars were found to improve all soil fertility parameters, especially in terms of pH and WHC.

From the above discussion, it is clear that Biochar characterization and short-term soil incubations can provide insights into the potential effectiveness of biochar as soil fertility enhancer and aid in the selection of potential biochars that can improve crop productivity. Overall, normal soil seems to require mixed material produced at high temperature and longer time and applied at high rate while sabkha soil required softer materials produced at lower temperature and shorter time and applied a low application rate. This is encouraging results for carbon depleted soil in Qatar where the application of biochar to agricultural soils has the potential to greatly improve soil physical and chemical conditions while serving as a long term carbon sink. These best performing biochars are being tested in plant growth experiments designed to assess their impact on plant biomass and productivity as indicator or their potential in field agriculture in Qatar.