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Integrated Plant Nutrient Management for Sandy Soil Using Chemical Fertilizers, Compost, Biochar and Biofertilizers
- Case Study in UAE -

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Abstract: Sandy soils are low in nutrient content and water holding capacity leading to frequent application of both nutrients and water to meet crop requirements. One of the best ways to improve soil properties and prevent nutrient losses is to improve soil quality through the use of organic amendments and minimizing the use of fertilizers. In order to achieve this we conducted a green house experiment using ten treatments with three replicates setting up a randomized block design to investigate integrated effects of chemical fertilizer, compost, bio-fertilizer and biochar on maize crop productivity and improvement in nutrient availability. The study revealed that application of compost and biochar did not impair plant growth and showed no signs of stress or nutrient deficiency. The results showed 19 % increase in plant height and 29% increase in the fresh biomass when biochar was used with the chemical fertilizer (T8) compared to where only chemical fertilizer was applied (T3). It was also found that when half of the chemical fertilizer than was applied in combination with bio-fertilizer and biochar (T10), a similar increase (19.6 %) in plant height and fresh biomass was found compared to when chemical fertilizer was added alone (T3). Cation exchange capacity and organic carbon content increased by 48-52 % and 9-15% in T8 and T10 compared to T3 in the postharvest soil respectively

Key Words: Biochar, Maize, Cation exchange capacity, Integrated nutrient management, Organic carbon.

1. Introduction

Soils in the United Arab Emirates are mostly sandy and lack sufficient organic matter to sustain microbial activity. Besides there is hardly any soil structure to make holding of water and nutrients possible in the potential root zone, an essential requirement for sustained vegetation development. These factors are thus responsible for the failure to introduce and sustain vegetation, whether natural or domesticated. Improvement of soil is not only important from the environmental point of view (lessening loose sand for dispersal around and into the atmosphere), but also because the region has to meet at least part of its food requirements through local sources. Issue of food security has become of paramount importance in the wake of rapidly increasing population especially in areas with limited food production capacity.

It is important therefore that the countries like United Arab Emirates that have financial means endeavor to manage their food security issues through improvement of local agriculture. Improvement of soil and availability of good quality irrigation water would seem to be the necessary pre-requisites.

Sandy soils lack a structure characteristic of productive soils mainly because there is hardly any aggregation essentially required for optimum air-water balance i.e. non-existence of micro-aggregates and thus the capillarity network. Soil aggregation and soil structuring is dependent on the organic matter reaching the soil through root activity i.e. rhizodeposition (Li *et al*., 2016) or through exogenous addition of organic matter (Oades, 1984). It is significant to note that >25% of the carbon assimilated by most crop plants is translocated below ground (Kuzyakov and Schnekenberger, 2004). This source of organic matter does not essentially exist in sandy/barren soils as there is hardly any vegetation. Thus addition of organic matter is the only way to initiate microbial activity and structuring sandy soil. Effective maintenance of organic matter in degraded soils can help preserve soil fertility and reduce erosion susceptibility by promoting soil aggregation stability, and improving hydraulic conductivity, and nutrients/water retention ability (Auerswald *et al*., 2003; Tejada and Gonzalez, 2007; Lehmann *et al*., 2003; Steiner *et al*., 2008; Major *et al*., 2010). Application of fresh organic matter to improve soils is a practical option in many respects but not in terms of transportation etc.. However, composting of organic matter acquired from municipalities and using composts would appear to be a more plausible option particularly because already an abundance of microbes has been generated during the composting process besides production of degradation products and microbial metabolites. As a result significant changes in physico-chemical and biological properties as well as fertility/productivity of soils have been reported following addition of composts (Stamatiadis *et al*., 1999). These benefits can be further improved through the use of microbial formulations that may consist of beneficial microorganisms as well as other additives including natural humates (Canellas and Olivares, 2014). Microbial inoculants have been used to improve process of composting and the

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product (Pan *et al*., 2011).

Recently, however, another approach has been gaining importance i.e. conversion of agricultural and city wastes into biochar and the use of latter as a soil amendment/conditioner. Biochar is a solid material obtained from slow pyrolysis of biomass, is high in carbon content and is largely decomposition resistant (Al-Wabel *et al*., 2013). Significant benefits of biochar for soil improvement have recently been reported (Steiner *et al*., 2007; Major *et al*., 2010; Chan *et al*., 2007). However, biochar approach is mainly being proposed as a means to sequester carbon over extended periods of time (Windeatt *et al*., 2014).

Optimum plant growth requires nutrients in sufficient and balanced quantities (Chen, 2006). Currently integrated nutrient management (INM) is gaining importance for sustainable crop production and environmental protection. The INM includes offsetting nutrient requirement of crops using a combination of nutrient sources including organic, inorganic fertilizers and microbial enhancers. Biofertilizers, unlike chemical and organic fertilizers, do not directly supply nutrients but help decompose organic matter to mineralize and release nutrients, organic acids, and many types of metabolites. An integrated nutrient management experiment conducted at ICBA over a period of two years (2013/2014) has increased fresh biomass of legume crops (cow pea, pigeon pea, sesbania, and labalab) significantly. The best results were observed when chemical fertilizer (NPK) was applied with compost and biofertilizer, and that microbial soil enhancer performed positively well when added in top of compost in soil as well as foliar application. Similar results have been reported in a long term study of INM in mustard crop (Chand *et al*., 2006). Dutta *et al*. (2003) reported improved soil health and microbial biomass by the combined use of organic and chemical fertilizers, compared to the addition of inorganic or organic fertilizers alone. The use of biofertilizer in general leads to an increase in crop yield, and reduce disease incidence and environment pollution (Mia and Shamsuddin, 2010; El-Yazeid *et al*., 2007). In view of above a comprehensive research programme is underway at International Centre for Biosaline Agriculture with the aim to transform waste into compost and biochar from date palm waste for use as soil conditioner/amendment. Objective of the present experiment was to test the effect of biochar, compost with or without the addition of a microbial soil enhancer (Bontera^{TM}) in an integrated manner on growth of maize and some selected soil properties.

2.Material and methods

2.1. Characteristics of soils

The soil used is collected from the surface (0-20 cm) of a Typic Torripsamment soil class as per US Soil Taxonomy (Soil Survey Staff, 2014; Shahid *et al*., 2014). Air-dried and sieved (<2 mm) soil showed the following characteristics: texture, fine sand; pHs, 7.51; ECe, 1.65 mS cm^{-1}; total organic matter, 0.2%; total N, 27.6 mg kg^{-1}; available P, 24.95 mg kg^{-1} ;cation exchange capacity, 3.25 cmol^{+} kg^{-1} (meq 100g^{-1}); $CaCO_3$ equivalent, 54%; sand, 98%; silt, 1%; and clay 1%. Standard procedures were followed for soil analysis.

The pH was measured on a saturated soil paste (pHs) and EC in the saturation extract (ECe) collected from the saturated soil paste under vacuum. The calcium carbonate equivalents were determined by Calcimeteric procedure, where a known amount of soil was reacted with 1N HCl, and the CO_2 produced is measured and converted to $CaCO_3$ equivalents (53%). Modified Walkley-Black method (1947) was used to determine organic matter content of soil. Available *P* was determined using the method (sodium carbonate, pH 8.2) described by Olsen and Dean (1965). Total *N* was determined by micro-Kjeldahl method of Bremner and Mulvaney (1982). Cation exchange capacity (CEC) was determined by saturating the soil exchange complex with 1N sodium acetate (pH 9.2), washing with 95% ethanol and replacing the Na with 1N (pH 7) ammonium acetate solution, and through measuring displaced Na by flame photometer and the values are reported on meq 100g^{-1} soil basis.

2.1.1. Biochar characteristics

Biochar was prepared from date palm waste at 350°C using a simple on-site facility developed at ICBA. The biochar was powdered and sieved (0.10-0.50 mm). The pH and Electrical Conductivity (EC) were measured in 1:10 (biochar: water w/v) suspension after shaking for 30 minutes (ASTM Standard, 2009). It had the following characteristics: moisture content, 6.52%; EC, 2.5 dS m^{-1}, pH, 8.9; C, 43.5% (Walkley-Black 1947); N, 0.007% (Chintala *et al*., 2014); total *P*, 15.8 mg kg^{-1} (Shaheen *et al*., 2009); total *K*, 7.95 mg kg^{-1}; ash content, 24.9% (Combustion at 550 °C).

2.1.2. Biofertilizer

Bontera^{TM} (a commercial product by Flozyme Corporation Inc., USA) was used as a test biofertilizer. Bontera^{TM} is a blend of effective microorganisms and humic compounds presented as liquid concentrate. The microorganisms combine functionalities like growth hormone production, biocontrol, humates sysnthesis, exopolysaccharides production, and organic matter decomposition. Humates consist of both humic acid and fulvic acid and are derived from leonardite. Humates contained in Bontera^{TM} are selected from a wide range of products available on the basis of functionality like enhanced seed germination, root growth promotion and overall improvement in plant growth. This product is used in highly diluted (1:500) form at rates equivalent to 0.5 L-3 L depending upon the crop type.

2.2. Test crop

Maize (*Zea mays* L.) variety Sahiwal-2002 used in the study was obtained from Ayub Agricultural Research Institute, Faisalabad, Pakistan.

2.3. Experimental setup

Ten kg portions of soil were used per pot (total 30 pots; 30 cm × 28 cm) and treated as follows:

T1. Control (No fertilizer)
T2. Compost @ 5 tons ha^{-1}
T3. Compost @ 5 tons ha^{-1} + NPK 100%
T4. Compost @ 5 tons ha^{-1} + Bontera^{TM} 5L ha^{-1}
T5. Compost @ 5 tons ha^{-1} + NPK 50% + Bontera^{TM} 5L ha^{-1}
T6. Compost @ 5 tons ha^{-1} + NPK 25% + Bontera^{TM} 5L ha^{-1}
T7. Compost @ 5 tons ha^{-1} + Biochar 5 tons ha^{-1}
T8. Compost @ 5 tons ha^{-1} + NPK 100% + Biochar 5 tons ha^{-1}
T9. Compost @ 5 tons ha^{-1} + Bontera^{TM} 5L ha^{-1} + Biochar 5 tons ha^{-1}
T10. Compost at 5 tons ha^{-1} + NPK 50% + Bontera^{TM} 5L ha^{-1} + Biochar 5 tons ha^{-1}

Control treatment without fertilizer was included to see the potential of soil to provide nutrients for plant growth. In the greenhouse experiments this is the normal practice.

Triplicate pots were used for each treatment. The rate of biochar incorporation (equivalent to 5 tons ha^{-1}) was similar to that previously reported by Van Zwieten *et al.* (2010). Compost and biochar were thoroughly mixed with the soil before pot filling. Commercial NPK fertilizer (100N: $50P_2O_5$: $50K_2O$) was applied at a rate equivalent to 200, 100 or 50 kg (100, 50 and 25% of recommended rate, respectively). While compost and biochar were mixed with the soil before seed sowing, NPK was split into 3 equal doses applied after 1, 4 and 6 weeks of seed sowing. Both NPK and Bontera^{TM} were applied after dissolving in appropriate quantities of water. Fifteen maize (*Zea mays* L.) seeds were sown pot^{-1} at a depth of 3-4 cm. After seed germination, ten best seedlings were kept pot^{-1}. During the growth period, soil water contents was kept at field capacity by regularly weighing the pots and making up the weight loss with fresh water.

During 60-days pot experiment, plant height was measured periodically. At 60 days post-germination, plant materials above and below ground were harvested, fresh weight was recorded, plants dried at 65°C for dry weight measurements.

2.4. Statistical analysis

The data were subjected to mean separation analysis using the 1-way ANOVA to test mainly the effect of biochar on soil properties (*e.g.*, EC, pH, CEC, and organic carbon) and plant growth parameters (*e.g.*, biomass, plant height). The least significant difference (LSD) test was applied to assess the differences among the means of three replications at P <0.05 (n = 3).

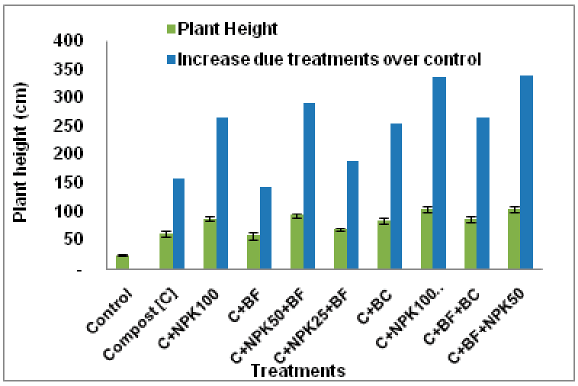

Fig. 1. Average plant height (cm) affected by biochar (BC), compost, soil enhancer (BF) and NPK.

3. Results

All the soil treatments had a positive effect on plant height that varied from 23.9 to 104.5 cm (**Fig. 1**). Biochar (BC) addition had a supplemental effect to that of NPK application; plant height being 104.5 cm and 87.6 cm, with Biochar+NPK and NPK respectively. Biochar applied or together with biofertilzer (BF) also had a positive effect, with BF having a slight additional benefit. However, BF gave an effect at 50% NPK (*i.e.* NPK applied at 50% of the recommended rate) that was similar to that found for BC and 100% NPK (*i.e.* NPK applied at 100% of the recommended rate).

These results are clearer from figure 1 that shows percent increase in plant height due to different treatments. A maximum increase of 338% compared to control was observed for BC applied together with 100%NPK and BF with 50% NPK; the two treatments have a similar effect. When applied alone, BF did not show a significant effect on plant height. However, BC applied alone showed 254% increase in plant height, an effect that was only slightly less than 100% NPK *i.e.* 267%. When both BC and 100%NPK were applied 338% increase in plant height was observed. Interestingly, BF applied with 50% NPK had an effect better than 100% NPK *i.e.* 292% increase compared to 267%. Impact of different treatments on biomass yield followed a trend similar to that observed for plant height and there was a significant correlation between the two parameters (R = 0.94, n = 10). Root biomass increased from 5.2 g pot^{-1} in control to a maximum of 93 g pot^{-1} where BF was applied with 50% NPK (**Fig. 2**). Shoot biomass was maximum (737 g pot^{-1}) where BC was applied with 10% NPK compared to 21.7 g pot^{-1} in control and 671 g pot^{-1} in case of BF + 50% NPK. Root and shoot biomass in soil receiving BC alone was 66 and 323 g pot^{-1}, respectively. Compost application alone resulted in root

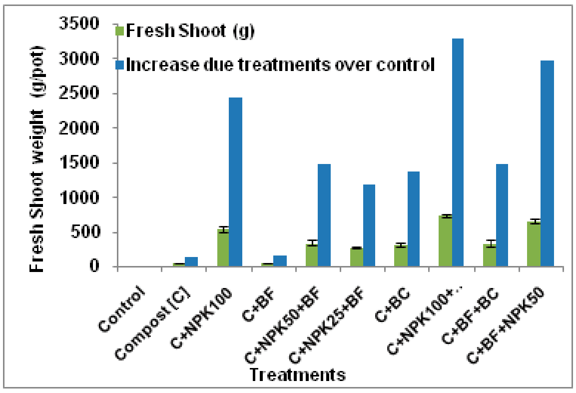

Fig. 2. Average fresh shoot weight (g/ pot) affected by biochar (BC), compost, soil enhancer (BF) and NPK.

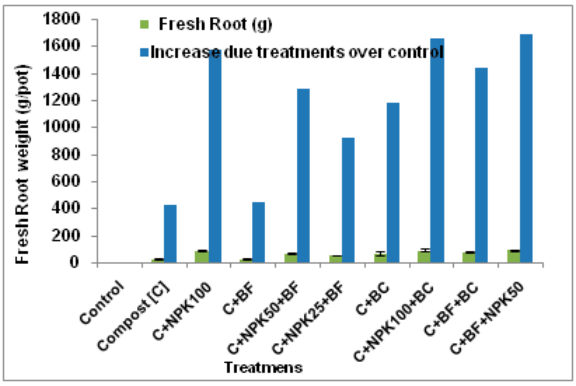

Fig. 3. Average fresh root weight (g/ pot) affected by biochar (BC), compost, soil enhancer (BF) and NPK.

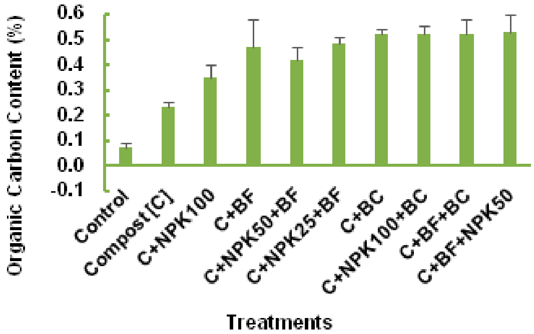

Fig. 4. Organic carbon content in response to biochar (BC), compost, soil enhancer (BF) and NPK.

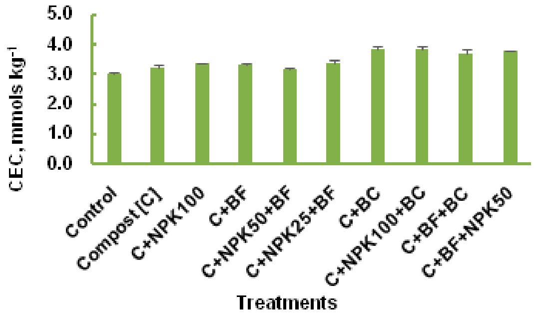

Fig. 5. Cation exchange capacity in response to biochar (BC), compost, soil enhancer (BF) and NPK.

and shoot biomass of 27 and 57 g pot^{-1}, respectively, compared to 5.2 and 21.7 g pot^{-1}, in un-amended soil. Different treatments impacted root and shoot biomass in a similar way and a significant correlation was observed between the two parameters (r = 0.97, n = 10). As a whole, there was several times increase in root and shoot biomass due to different treatments. Root biomass (**Fig. 3**) showed an increase over control that ranged from 424 (no additional treatment except for compost addition) to a maximum of 1686% (16 times) in case of BF + 50% NPK.

Application of BC alone caused an increase of 1178% and the impact increased to 1652% when 100% NPK was also applied with BC. Application of BF together with BC further enhanced the impact 1438% compared to 1178% when BC was applied alone.

Percent increase in shoot biomass was generally more as compared to that of shoot biomass (Fig. 2), although the two parameters were affected in a similar fashion as shown by a significant correlation (r = 0.97). Trends in percent increase of total biomass were similar as observed for root or shoot portion separately. Interestingly, BC treatments (3 treatments where BC was added) showed an average increase in root, shoot and total biomass of 1422%, 2058% and 2428%, respectively, as compared to 1055%, 1410% and 1692% in treatments without BC (6 treatments) suggesting a highly positive role of BC in improving plant growth.

The soil used in this study (essentially sand) has very low organic matter content. At plant harvest, organic matter content increased from 0.07-+0.02% (in control; untreated/un-amended soil) to an average of 0.45+0.05% (**Fig. 4**). This increase was expected as in all cases; compost was added while BC was also added in three treatments. Part of the increase may also be due to root exudates and debris. Supplemental treatment with BF appeared to have an added effect on build of soil organic matter.

Cation exchange capacity (CEC) of the soil showed a positive impact of soil treatments (**Fig. 5**) and increased from 2.99 mmol kg^{-1} in control to an average of 3.51 mmol kg^{-1} when all treatments were taken together. Impact of BC was relatively more compared to other treatments, average of 3 BC treatments being 3.78 mmol kg^{-1} compared to 3.37 mmol kg^{-1} for the remaining 6 treatments. A positive correlation (r = 0.89, n = 10) between organic matter content and CEC demonstrated the role of the former in nutrient binding in soil plant system.

Electrical conductivity of the soil increased from 2 dS m^{-1} to an average of 3.0 dS m^{-1} for different treatments taken together. Addition of BC had a positive impact on EC of soil that averaged 3.63 dS m^{-1} for 3 BC treatments compared to an average of 2.74 dS m^{-1} for the remaining 6 treatments and 2.54 dS m^{-1} for the compost-only treatment.

4. Discussion

Soil health and fertility/productivity of soils is dependent mainly on its organic matter content and microbial population. The former is serving not only as a source of carbon and energy for the microbes to function but has an important role to plant in maintaining soil structure conducive for nutrient and water retention (Carter, 2002; Wortmann and Shapiro, 2008; Hargreaves *et al*., 2008). Microorganisms that dwell on the expense of organic matter originating from the exogenous sources or derived from root activity of plants are the agents of nutrient release and mobilization besides performing many other functions in the soil (Marcel *et al*., 2008). Soil used in the present study can be termed as a dead matrix consisting mainly of sand and therefore growth (height and biomass) was very poor (Figs 1-3).

Application of compost significantly increased height and biomass of maize (Figs. 1-3). This increase in plant growth following compost application has been a common observation (Tejada and Gonzalez, 2007; Lehmann *et al*., 2003; Steineret *et al*., 2008; Major *et al*., 2010). Therefore, use of compost in improving plant growth is considered an appropriate approach (Parr *et al*., 1986).

In the present study, application of biochar further enhanced plant growth by several-folds (up to 16 times in one case) as suggested by vigor and biomass (Figs. 1-3). A combined effect of BC and compost has been reported to be more positive (Schulz *et al* 2014). The BC can improve soil fertility at least on the short run as observed 64% increase in maize growth in the absence of NPK and 146% increase in the presence of NPK. This improvement in plant growth is attributed to many factors and use of biochar is now being recommended as a plausible approach to sequester carbon and thus reduce CO_2 concentration in the atmosphere, but also as a means to improve soils and increase nutrient use efficiency of plants (Downie *et al*., 2009) Lehmann et al (2006) reviewed 24 studies with BC additions to soil and found 20 to 220% improvement in productivity at application rates of 0.4 to 8 tons carbon $ha^{-1.}$ Steiner *et al*. (2007) reported a doubling of maize grain yield using a combination of NPK fertilizer with BC compared to use of NPK fertilizer alone. These observations could be attributed to many factors including improvement in soil structure, soil health, microbial activity and nutrient availability through a variety of mechanisms (DeLuca *et al*., 2009; Kolb *et al*., 2009; Thies and Rillig, 2009; Warnock *et al*., 2007; Major *et al*., 2010; Novak *et al*., 2009, Laird *et al*., 2010; Kammann *et al*., 2012).

In view of the low microbial activity and diversity in sandy soils, a microbial-based biofertilizer (Bontera^{TM} produced by Flozyme Inc, USA) was also used in conjunction with compost and BC. There was slight improvement in plant biomass due to BF. However, application of BF together with BC led to an additional advantage and biomass showed an increase of 1438% compared to 1178% when BC was applied alone (Figs. 2-3). The significance of using biofertilizers in different plant production systems is frequently reported (Ghumare *et al*., 2014) and a diversity of such products are available in the market. Therefore, it may be helpful to introduce an appropriate biofertilizer together with compost and BC.

In the present study, soil amendment with compost and biochar led to a significant increase in the organic matter content and cation exchange capacity of the soil (Figs. 4 and 5). Such an improvement has often been reported an increase of 4-17% in CEC by the addition of 1% BC. Compost together with BC provides more exchange sites for different cations and in this way improve nutrient availability to plants. A significant correlation was observed between CEC and organic matter content of the soil. An increase in electrical conductivity of the soil observed in the present study is also suggestive of higher ion retention on the soil particles.

5. Conclusions

The conclusion of the research suggests a positive interaction between compost, BC and biofertilizers. The combined effect of the three was a multi-fold increase in biomass of maize. Biochar application affected significantly to soil chemical properties (OC and CEC). This approach could be of particular significance for sandy soils that not only lack organic matter but microbial population and biodiversity. The integrated use of compost, biochar and biofertilzers has proved as eco-friendly approach, affordable by farmers and has the potential to play key role in crop productivity improving soil health. This preliminary study under greenhouse condition has shown great promise in nutrient management thus suggesting to explore further under field condition, therefore, further studies are needed to optimize the composition of additives to sandy soils for maximum benefit in terms of soil structure build-up and crop production.

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