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# Influence of different sources of biochar on soil physical and chemical properties in cotton (*Gossypium hirsutum* L.)

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**Abstract**
Agricultural lands are facing major issues like reduction in soil fertility and soil health as due to mono cropping, improper use of synthetic fertilizers, use of poor quality water for irrigation, soil erosion and loss of nutrients. These created a necessity to improve and maintain soil health in sustainable manner for better crop production. In this context, a study was framed to evaluate the different biochars on soil physical, chemical and biological properties and its effect on cotton. The field trial was conducted at TNAU in collaboration with ICAR-CICR, Regional station, Coimbatore during the years 2017-18 and 2018-19. The experiments were conducted with three sources of biochars *viz.*, maize biochar, cotton biochar and Prosopis biochar under different doses of 2.0 t $ha^{-1}$, 3.0 t $ha^{-1}$ and 4.0 t $ha^{-1}$ respectively. The study revealed that application of biochar prepared from different biomass significantly influenced the soil physico-chemical properties. Application of prosopis biochar and cotton biochar @ 4.0 t $ha^{-1}$ significantly increased organic carbon, cation exchange capacity, porosity and reduction in bulk density of soils during both the years of study over control plots. This inferred that Biochar when applied as soil amendment not only improves soil fertility, which in turn keeps the soil in a sustainable manner for a long term to crop production.

**Keywords:** Biochar, cotton, soil properties, soil fertility, soil health

## Introduction
The challenging task in present day agriculture is to produce food, fodder, fibre and fuel to meet out the demand of growing population in a sustainable manner by restoring soil health, improving water quality, mitigating climate change and preserving soil and natural resources for future use. The soil health is deteriorated due to continuous use of synthetic fertilizers with imbalanced application, soil erosion, monocropping and use of high yielding cultivars. Management options to maintain and improve soil health includes amelioration of soil physical environment, enhancing soil chemical and biological qualities through Integrated Nutrient Management (INM), soil test based fertilizer recommendation, balanced application of micronutrients and use of different cropping sequence and recycling of crop residues (Elangovan and Chandrasekaran, 2014) [3].

Returning biochar to field is a potentially viable agricultural practice that improves physical and chemical properties of the soil, reduces greenhouse gas emissions (Spokas *et al.*, 2009) [16] and improves the microbial health of soil. Biochar consists of particles with low density and returning it to soils can reduce soil bulk density, increase soil softness and improve the soil structure (Masulili *et al.*, 2010) [10]. By adding biochar, the soil is better able to retain moisture and the soil quality improves in terms of various carbon and energy sources as well as mineral nutrition for the development and reproduction of microbes (Meng *et al.*, 2011) [11]. As compared with other organic matter, the carbon present in biochar is more stable in soil environment and remains in soil for hundreds to thousand years. The mineral nutrients in biochar increase the nutritional value of the soil particularly for poor and degraded sandy soils (He *et al.*, 2011) [6].

Biochar is produced through the thermo-chemical processes of biomass in the absence of oxygen or no oxygen (Huang *et al.*, 2017) [7]. Biochar when applied to soil enhances the soil fertility and crop productivity, increases soil nutrients and water holding capacity and reduces emissions of other greenhouse gases from soils. The enhanced nutrient retention capacity of the soil not only reduces the total fertilizer requirements, it also protect the environmental damage associated with fertilizers, including nitrous oxide emissions, phosphorus runoff in to surface waters and nitrogen leaching in to ground water (Laghari *et al.*, 2016) [8].

Biochar with a large specific surface area has a narrow micropore distribution with good pore structure and adsorption ability (Tan *et al.* 2017) [9, 18].

Even though it is clear that application of biochar has positive impact on soil still it lacks clear evidence on the effect different raw materials used in preparation and its optimum quantification on soil application. In view of this, the present experiment was aimed to study the influence of different biochars on improvement of soil health in cotton crop.

**Materials and methods**

The trial was conducted at TNAU in collaboration with ICAR – Central Institute for Cotton Research farm in Coimbatore during the year 2017-18 and 2018-19. Soil of the experimental field was sandy clay loam (27.7% course sand, 17.8% fine sand, 20.8% silt and 33.7% clay). The physical, chemical and biological properties of the experimental locations are presented in Table 1. In order to avoid cumulative effect of biochars during succeeding year, different field sites were used for the conduct of this experiment in these two years of study. The soils of two experimental sites were alkaline in nature with pH of 7.90 and 8.10 (Table 1). The other parameters like bulk density (1.38 g $cm^{-3}$ and 1.34 g $cm^{-3}$), porosity (47.2 per cent and 49.8 per cent), organic carbon (5.31g $kg^{-1}$ and 5.24g /$kg^{-1}$), EC (0.24 $dSm^{-1}$ and 0.34 $dSm^{-1}$) and CEC (13.2cmol/ $g^{-1}$ and 13.7 cmol $kg^{-1}$) shown slight variation between the two experimental sites. The nutrient status of the soil was low in available nitrogen (172$kgha^{-1}$ and 165$kgha^{-1}$), almost medium in phosphorus (12.1$kgha^{-1}$ and 10.9$kgha^{-1}$) and high in potassium (730 kg $ha^{-1}$ and 765kg $ha^{-1}$) content.

The treatment consists of three levels of maize biochar @ 2.0t $ha^{-1}$, 3.0t $ha^{-1}$ and 4.0t $ha^{-1}$, three levels of cotton biochar @ 2.0 t $ha^{-1}$, 3.0 t $ha^{-1}$ and 4.0 t $ha^{-1}$, three levels of prosopis biochar @ 2.0t $ha^{-1}$, 3.0 t $ha^{-1}$ and 4.0 t $ha^{-1}$ besides Farm Yard Manure (FYM) @ 12.5 t $ha^{-1}$ and control. Randomized Block Design (RBD) was followed for conduct of the experiment with these eleven treatments and three replications. The recommended dose of fertilizers of 60:30:30 kg $ha^{-1}$ N, $P_2O_5$ and $K_2O$ were applied to all the plots irrespective of treatment. Cotton variety Suraj released from ICAR-CICR was used in this experiment.

After completion of primary field preparations, ridges and furrows were formed with help of ridger. The plots were demarked with bunds and treatments were imposed in each plot as per randomization method. After incorporation of biochars, cotton variety Suraj was sown with spacing of 75 cm x 45 cm during winter irrigated season. All the cultural practices were adopted as per the package of practices. After harvest of cotton crop, post-harvest soil samples from each plots were collected and analysed under the laboratory as per the standard procedures to find the physico-chemical properties of the soil.

**Table 1:** Soil properties of the experimental field

| Parameters | First year (2017-18) | Second year (2018-19) |
|---|---|---|
| Texture | Sandy clay loam | Sandy clay loam |
| Bulk density (g $cm^{-3}$) | 1.38 | 1.34 |
| Particle density (g $cm^{-3}$) | 2.64 | 2.67 |
| Porosity (%) | 47.2 | 49.8 |
| Organic carbon (g $kg^{-1}$) | 5.31 | 5.24 |
| pH | 7.90 | 8.10 |
| EC (dS $m^{-1}$) | 0.24 | 0.34 |
| CEC (cmol $kg^{-1}$) | 13.2 | 13.7 |
| Available Nitrogen (kg $ha^{-1}$) | 172 | 165 |
| Available Phosphorus (kg $ha^{-1}$) | 12.1 | 10.9 |
| Available Potassium (kg $ha^{-1}$) | 730 | 765 |
| Total Bacteria (CFU x $10^6$ g of soil) | 25.3 | 26.8 |
| Total Fungi (CFU x $10^3$ g of soil) | 12.2 | 13.9 |
| Total Actinomycetes (CFU x $10^4$ g of soil) | 13.5 | 10.5 |

**Results and discussion**

**Properties of biochars**

The required biomass materials of maize stover, cotton stalk and prosopis wood materials were collected locally and chopped in to small pieces for easy loading in to the biochar preparation chamber. Biochar required for conduct of experiment was produced through the pyrolysis machine and made in to powder form for easy incorporation in to the field. Properties of biochars were analysed in the laboratory and presented in Table 2. The biochar properties like bulk density pore space, pH, EC and CEC were the highest in prosopis biochar and this was followed by cotton biochar and maize biochar. The conversion efficiency of prosopis biochar was the highest with value of 42.3 per cent followed by cotton biochar (39.7percent), while maize biochar recorded the lowest conversion efficiency (32.2percent). Higher total nitrogen content was recorded in cotton biochar (2.74 g $kg^{-1}$) while lower nitrogen content was observed in prosopis biochar (2.15 g $kg^{-1}$). The biochar produced from cotton stalk registered the highest total P (3.26 g $kg^{-1}$) and total K (6.64 g $kg^{-1}$) in maize biochar. The variation in quality of biochar and nutrient composition was highly influenced by the source of feedstock.

**Table 2:** Properties of maize, cotton and prosopis biochar

| Parameters | Maize Biochar | Cotton Biochar | Prosopis Biochar |
|---|---|---|---|
| Bulk density (g $cm^{-3}$) | 0.36 | 0.44 | 0.50 |
| Particle density (g $cm^{-3}$) | 0.75 | 0.84 | 0.91 |
| Pore space (%) | 47.9 | 52.4 | 55.3 |
| pH | 7.80 | 8.30 | 8.70 |
| EC (dS $m^{-1}$) | 1.15 | 1.42 | 1.87 |
| CEC (cmol $kg^{-1}$) | 12.8 | 15.1 | 17.9 |
| Organic carbon (g $kg^{-1}$) | 71.6 | 77.7 | 81.5 |
| Total Nitrogen (g $kg^{-1}$) | 2.29 | 2.74 | 2.15 |
| Total phosphorus (g $kg^{-1}$) | 2.77 | 3.26 | 1.31 |
| Total potassium (g $kg^{-1}$) | 6.64 | 3.45 | 3.10 |
| Total Calcium (g $kg^{-1}$) | 0.67 | 0.71 | 0.86 |
| Total Magnesium (g $kg^{-1}$) | 0.44 | 0.48 | 0.53 |
| Ash content (%) | 22.7 | 28.5 | 32.6 |
| Conversion (%) | 32.2 | 39.7 | 42.3 |

**Bulk density (BD)**

The results from the study indicated that the soil amended with different sources of biochar reduced the bulk density of the soil though there was not significant reduction (Table 3). Prosopis biochar @ 4.0 t $ha^{-1}$ with RDF treatment recorded lower bulk density of 1.31 g $cm^{-3}$ and this was followed by cotton biochar @ 4.0 t $ha^{-1}$ + RDF (1.32 g $cm^{-3}$) and higher bulk density was observed in control (1.38 g $cm^{-3}$). The same trend was observed during 2018-19 also. The result showed that application of biochar has influenced the soil bulk density. This was in confirmation with the findings of Liu *et al.* (2017) [7, 9] and Shalini *et al.* (2017) [14]. Bulk density of soil has a significant effect on soil properties as well as on plant growth. The soil with lower bulk density has less compaction with lots of pore space providing easy movement of air and water. It also facilitates for easy penetration of roots into the soil resulting in more root volume and root mass leading to higher uptake of nutrients in turn vigorous crop growth.

**Table 3:** Effect of different biochars on post-harvest soil physical and chemical properties in cotton

| Treatment | First year (2017-18) | | | | | | Second year (2018-19) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bulk density (g $cm^{-3}$) | Porosity (%) | pH | EC (dS $m^{-1}$) | OC (g $kg^{-1}$) | CEC (cmol $kg^{-1}$) | Bulk density (g $cm^{-3}$) | Porosity (%) | pH | EC (dS $m^{-1}$) | OC (g $kg^{-1}$) | CEC (cmol $kg^{-1}$) |
| $T_1$: Control (No Manure) | 1.38 | 44.1 | 8.15 | 0.24 | 5.07 | 13.3 | 1.34 | 49.8 | 8.10 | 0.34 | 5.02 | 13.7 |
| $T_2$: FYM @ 12.5 t $ha^{-1}$ | 1.32 | 47.4 | 7.73 | 0.25 | 5.73 | 14.1 | 1.28 | 50.0 | 7.68 | 0.35 | 5.60 | 14.5 |
| $T_3$: Maize Biochar @ 2.0 t $ha^{-1}$ | 1.36 | 45.4 | 7.91 | 0.29 | 5.49 | 14.9 | 1.32 | 50.2 | 7.86 | 0.37 | 5.37 | 15.3 |
| $T_4$: Maize Biochar @ 3.0 t $ha^{-1}$ | 1.35 | 46.2 | 7.95 | 0.32 | 5.75 | 15.6 | 1.31 | 50.6 | 7.90 | 0.40 | 5.63 | 16.0 |
| $T_5$: Maize Biochar @ 4.0 t $ha^{-1}$ | 1.35 | 47.1 | 7.98 | 0.36 | 5.87 | 16.1 | 1.31 | 51.2 | 7.93 | 0.45 | 5.74 | 16.6 |
| $T_6$: Cotton Biochar @ 2.0 t $ha^{-1}$ | 1.36 | 45.4 | 8.19 | 0.34 | 5.54 | 16.8 | 1.32 | 50.7 | 8.14 | 0.44 | 5.43 | 17.3 |
| $T_7$: Cotton Biochar @ 3.0 t $ha^{-1}$ | 1.33 | 47.6 | 8.20 | 0.39 | 5.78 | 17.5 | 1.29 | 50.9 | 8.15 | 0.49 | 5.67 | 18.0 |
| $T_8$: Cotton Biochar @ 4.0 t $ha^{-1}$ | 1.32 | 48.8 | 8.26 | 0.41 | 5.89 | 18.0 | 1.28 | 51.4 | 8.21 | 0.52 | 5.77 | 18.5 |
| $T_9$: Prosopis Biochar @ 2.0 t $ha^{-1}$ | 1.34 | 47.7 | 8.28 | 0.35 | 5.61 | 18.6 | 1.30 | 51.3 | 8.23 | 0.48 | 5.50 | 19.1 |
| $T_{10}$: Prosopis Biochar @ 3.0 t $ha^{-1}$ | 1.33 | 47.4 | 8.32 | 0.43 | 5.81 | 19.1 | 1.29 | 51.6 | 8.27 | 0.55 | 5.74 | 19.6 |
| $T_{11}$: Prosopis Biochar @ 4.0 t $ha^{-1}$ | 1.31 | 49.6 | 8.40 | 0.48 | 5.92 | 19.3 | 1.27 | 52.1 | 8.35 | 0.61 | 5.85 | 19.9 |
| Sem± | 0.05 | 2.10 | 0.34 | 0.014 | 0.144 | 0.63 | 0.043 | 2.13 | 0.32 | 0.018 | 0.138 | 0.70 |
| CD (P=0.05) | NS | NS | NS | 0.041 | 0.431 | 1.85 | NS | NS | NS | 0.056 | 0.408 | 2.06 |

**Porosity**

Soil pore space (porosity) plays major role in aeration, movement and retention of nutrients and water. It also provides space to microbes for the activity in soil. In the study, application of different biochar did not markedly influence the porosity. However, prosopis biochar @ 4.0 t $ha^{-1}$ and cotton biochar @ 4.0 t $ha^{-1}$ along with recommended dose of fertilizers recorded higher porosity of 49.6 % and 48.8% respectively for the first year, similarly 52.1% and 51.6% in the second year. Lower porosity of 44.1 % and 49.8% was observed in the plot which received only recommended dose of fertilizers (control). The increase in porosity of the soil is due to the porous nature of biochar and also particle size, pore size distribution, connectivity, mechanical strength and interaction of biochar particles in the soil. Other factor which influences the porosity of the biochar is nature of the feed material used for the preparation and soil type in which biochar applied. Also observed same results in his experiment.

**Soil pH**

The experimental location of the soil belongs to alkaline condition, application of biochar had less influence in increasing pH of the soil and no significant difference was observed between the treatments. On comparison, higher soil pH was noted in prosopis biochar applied treatments than cotton biochar irrespective of the quantity applied to the soil. This might be due to higher pH of the prosopis biochar (8.70) which eventually increased in pH of the soil. Further, the increase in soil pH due to application of biochar could be because of higher surface area and porous nature of biochar that increased the cation exchange capacity of the soil. It was also found to improve nutrient availability which in turn increased crop yield. Similar results were recorded by Pandian *et al.* (2016) [13] and Utomo *et al.* (2017) [19].

**Electrical conductivity (EC)**

Among the different treatments, biochar application insignificantly influenced EC of the incorporated soil.

Prosopis biochar @ 4.0 t $ha^{-1}$ applied plots registered conspicuously higher EC (0.48 $dSm^{-1}$) than all other treatments. It was followed by prosopis biochar @ 3.0 t $ha^{-1}$ and cotton biochar @ 4.0 t $ha^{-1}$ which were on par. The plots where only recommended dose of fertilizers applied (control plot) recorded the lowest EC. The trend was almost similar during second year of the study even though the experiment was conducted at different sites. The biochar is dominated by carbonates of alkali and alkaline earth metals, variable amounts of silica, heavy metals, sesquioxides, phosphates and small amounts of organic and inorganic N. This could be the reason for increase in EC of biochar applied soils. Another reason for increase of EC might be due to increased concentration of Cations and anions in soil solution and thus increased the EC of soil as reported by Elangovan and Chandrasekaran, 2014 [3].

**Cation exchange capacity (CEC)**
CEC is an important indicator of soil quality and higher CEC of biochar indicated capacity for nutrient fixation, which is beneficial for plant growth (Shenbagavalli and Mahimairaja, 2012) [15]. The experiment indicated that the application of different sources of biochar significantly increased the CEC of soil. Higher CEC was observed in prosopis biochar applied plots and the increase in CEC was in the order of increased application doses (2.0 t $ha^{-1}$, 3.0 t $ha^{-1}$ and 4.0 t $ha^{-1}$ respectively). The CEC of 4.0 t $ha^{-1}$ of prosopis biochar applied treatments was similar to that of 2.0 and 3.0 t $ha^{-1}$ besides cotton biochar application of 3.0 and 4.0 t $ha^{-1}$. The lowest CEC was noted in control plot. The increase in CEC with similar trend was also observed during second year of the experiment. The oxygen active groups present on the biochar surface, such as $COOH^-$ or $OH^-$ react with metal cations in the soil and form metal ion complexes and due to negative charge of these ions, biochar has a high CEC (Gan *et al.*, 2012) [4]. Sudeshna Bhattacharjya *et al.* (2015) [17] also confirmed that the CEC of biochar influenced the soil CEC, which improved the physical and chemical properties.

**Organic carbon (OC)**
Significantly higher and comparable organic carbon content was observed in all biochar applied plots over control plot. The highest organic carbon content was observed in prosopis biochar @ 4.0 t $ha^{-1}$ applied treatments (5.92 g $kg^{-1}$) and this was followed by cotton biochar @ 4.0 t $ha^{-1}$ amended plots (5.89 g $kg^{-1}$). The lowest organic carbon was recorded in control plots (5.07 g $kg^{-1}$). The second year of study was also confirmed the increased organic carbon content in biochar added soil and the increase was almost in the same trend like that of first year. The study revealed that the addition of fertilizers along with biochar might have role in decomposition process and in turn increased organic carbon content of the applied soil (Elangovan and Chandrasekaran, 2014) [3]. The another parameter for increased organic carbon content might be the higher amount of carbon present in biochar, resulted in increased the carbon content of the soil. The results were in accordance with the findings of Oladele *et al.* (2019) [12] also.

**Conclusion**
From the study it could be concluded that the application of prosopis or cotton biochar @ 4.0 t $ha^{-1}$ improved the soil health, fertility and productivity by influencing the soilphysical and chemical properties. The biochar applied plots significantly increased the porosity, organic carbon and CEC of soil which could be accounted for higher nutrient uptake. Ultimately this may increase the yield of the crop. Hence, preparation of biochar at farm level by the farmers from the crop residue of cotton or prosopis and returning the same to the field is highly beneficial to the soil and pushing towards sustainability.

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