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Effect of biochar on the growth and yield of cotton and maize: A review

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Abstract
Improper management of soil along with exhaustive monocropping practices have led to loss of soil structure, salinity and erosion and thereby decreasing the soil productivity. Furthermore, misappropriate application of synthetic fertilizers have driven contamination of food and water, pollution of environment creating an endangerment to human health. Therefore, an urgent need to find an alternative solution in improving the soil health without reduction in the productivity from a unit area in a sustainable manner is of prime focus. This review is related to biochar, its role in improving soil fertility in combination with fertilizers and manures on growth and yield of cotton and maize crop. The retention and mobilization of nutrients in biochar applied soil tremendously aid in increasing the fertilizer use efficiency. Moreover, studies have shown improved germination and biomass accumulation over time along with better yield attributes and yield of most crops which majorly include cotton and maize. This lays a foundation to utilize abundantly available problematic plant *Prospis* sp. and crop residues like cotton and maize from agricultural fields for biochar preparation rather than burning thus supporting in the reduction of global warming issues.

Keywords: Biochar, cotton, maize, prosopis biochar, cotton biochar, maize biochar

Introduction

Cotton is one of the most important natural fibre crops cultivated worldwide and termed as “King of fibres” and “White gold” due its higher economic value. Cotton occupies a major sector in India’s economy and plays a vital role in the livelihood of Indian farming community. It provides 85 per cent raw material to the textile industry besides earning foreign exchange by exporting raw materials and finished goods. Cotton as a cash crop is being cultivated in many parts of the world occupying an area of 31.2 million hectares with a production of 20.6 million tonnes and productivity of 792 kg ha^{-1} (USDA, 2017) [62]. Further, India occupies highest acreage in the world with an area of 12.4 million hectares. The cotton production during 2017-18 was 6.29 million tonnes with productivity of 505 kg ha^{-1}. The tremendous production of cotton was achieved mainly through use of synthetic fertilizers and pesticides, along with high yielding fertilizer responsive cultivars under irrigated condition (Peshin *et al.*, 2014) [43].

Among the cereal crops, maize is one of the most important crop in the world and used as food for human beings and feed for animals and poultry. The yielding ability of maize is on higher side than other cereals and therefore named as “Queen of Cereals”. Maize is cultivated in different countries with total area of 197.2 million hectares, production of 1134.7 million tonnes and productivity of 5755 kg ha^{-1} (FAOSTAT, 2017) [17]. In India, it occupies third place as an important crop after rice and wheat. Maize grain serves as important feed material for poultry and cattle industries and its demand is increasing all over India. In India, maize is grown in an area of 9.2million hectares, with a production of 28.7milliontonnes and the average productivity is 3115 kg ha^{-1} during 2017-18. Maize is highly suitable crop to cultivate throughout the year and well suited in the cropping system in Tamil Nadu, which gives not only higher productivity but also a remunerative crop to the farmers.

At present, crop diversification through cropping system has gained much importance from research perspective to improve soil health. Adoption of cropping system has many advantages like improvement in yield, increased nutrient, water and land use efficiency. It also improves sustainability of the system along with economic benefits to the farmers through different cropping sequences. In Tamil Nadu, cotton – maize cropping system is gaining importance among the farmers as it provides higher profitability along with productivity.

It is a fact that in India around 91 – 141 million tonnes of crop residues are produced annually which have surplus biomass and are subjected to on-farm burning. Cereal crops produce 82 million tonnes of surplus residues, in which 44 million tonnes is from paddy. Fibre crops contribute around 33 million tonnes of surplus residues, in this 80 per cent are from cotton (IARI, 2017) [25]. Farmers usually burn excess residues in the field for easy preparation for planting next crop. This unidentified loss of nutrients from biomass moreover also release toxic as well as greenhouse gases into the atmosphere.

The use of biochar, a porous, carbon rich material prepared from crop biomass through pyrolysis process could help in saving nutrient losses sustainably. The crop biomasses are subjected to thermo-chemical conversion under absence of oxygen with a temperature range 350 °C to 500 °C. Al-Wabel *et al.* (2013) [4] stated that biochar has been extensively used for increasing the fertility of agricultural soils. It has drawn special attention due to its potential of climate change mitigation (Atkinson *et al.*, 2010) [7]. Biochar absorbs moisture and retains nutrients in the soil, thereby reduces the amount of mineral fertilizer required and protects crops from drought impacts (Laghari *et al.*, 2016) [31].

The properties of biochar material produced through pyrolysis process depend upon the biomass used and also the temperature involved in preparation. Biochar application into the soil as an amendment improves soil physical, chemical and biological properties and thereby solves many of the soil related issues (Singh *et al.*, 2012) [54]. Biochar is persistent in soils and its beneficial effects are longer lasting compared to other forms of organic matter. The unique nature of the biochar is that it retains most of the applied nutrients and makes them available to growing plants than other organic matter like on farm common leaf litter, compost or manures (Schulz *et al.*, 2013) [51].

The excess crop residues accumulated in the field after harvest can be effectively utilized for biochar preparation. The different types of biochar in combination with organic and inorganic fertilizers significantly improve soil tilth (Glaser *et al.*, 2002) [22], crop productivity (Graber *et al.*, 2010) [24] and nutrient availability (Lehmann *et al.*, 2006; Silber *et al.*, 2010) [53, 32]. The increase in crop yield in biochar incorporated soil was due to higher nutrient availability and concentrations of basic cations (Uzoma *et al.*, 2011a) [53]. In acid soils, liming effect of biochar enhances soil microbial diversity and its function, together with increasing cation exchange capacity and crop water availability (Anderson *et al.*, 2011) [6]. Sandy soils which have smaller surface area compared to other soil types, when applied with biochar improve the water holding capacity. Porous nature and higher surface area of biochar leads to retention of higher amount of soil moisture available for crop uptake (Fang *et al.*, 2014) [16].

The biochar has major benefits like improving soil fertility, structure, water holding capacity, organic carbon content, increased biological activity, thereby, improved crop yield in a sustainable manner (Masto *et al.*, 2013) [38]. It also serves as better alternate for other organic manures as it does similar work as that of FYM and other composts.

Effect of biochar on nutrients retention and availability

According to DeLuca *et al.* (2009) [13] biochar produced at temperatures higher than 300 °C resulted in significant increase in available P content and no change in total P content of soil. The increased availability of phosphorus resulted from the oxidation and combination of Al and Fe in soils with biochar, which released the fixed P in the soil. Jha *et al.* (2010) [26] reported that significant reduction in leaching of N, Ca and Mg was observed through biochar addition. The soil organic C and total N content was increased when biochar was applied on chromium polluted and unpolluted soils. Soils applied with 10 t ha^{-1} maize stalk biochar recorded higher organic carbon and total nitrogen. This was due to higher carbon and nitrogen content present in the maize stalk (Nigussie *et al.*, 2012) [39].

Manikandan and Subramanian (2013) [37] observed that the biochar produced at low temperature contained more than 98 per cent carbon and oxygen and there act as suitable adsorbent for controlled/slow release of fertilizer nutrients. Kamara *et al.* (2015) [28] claimed that the rice straw biochar applied soil had higher available phosphorus of 11.5 mg kg^{-1} soil and higher cation exchange capacity of 10.2 cmol kg^{-1} than control. This showed that application of rice straw biochar improved soil physical and chemical properties.

Srinivasarao *et al.* (2014) [59] studied the residual effect of biochar on soil quality and crop performance with one time application of different biochar prepared from maize, castor, cotton and pigeon pea stalk at different rates to maize (DHM 117) in rainfed alfisols and found that residual maize stalk biochar @ 4 t ha^{-1} in soil along with RDF and FYM resulted in higher soil available nitrogen (175.6 kg ha^{-1}), phosphorus (22.5 kg ha^{-1}), potassium (328.0 kg ha^{-1}) and organic carbon content (15.1 g kg^{-1}). Ok *et al.* (2015) pointed out biochar amended soils recorded higher nutrients especially N, P, organic C and other mineral elements compared with unamended soil.

Agegnehu *et al.* (2016) [1] inferred that application of biochar with fertilizer increases soil K and Mg content by 1.2 and 1.1 times, respectively over the control. The leaf P content was higher on biochar amended soil due to availability of P to the plants than in control, implying that biochar supplied P through improved availability by reducing sorption and leaching. Biochar along with compost application resulted increased soil organic carbon, total N, available P and exchangeable Ca by 43–73 per cent, 14–29 per cent, 59–117 per cent and 31–54 per cent, respectively. Amendment of cotton stalk biochar in sandy soil increased nutrient content of phosphorus by 4.2 times and potassium by 13.9 times compared to control. Further, application of cotton biochar in fine textured soil resulted in minor increase in pH (Zhang *et al.*, 2016) [75].

Pandian *et al.* (2016) [41] concluded that the soil available nitrogen content was in the range from 158 to 178 kg ha^{-1} in biochar incorporated soil. Redgram stalk biochar and maize stalk biochar @ 5 t ha^{-1}applied soil recorded 25 per cent higher soil available nitrogen and phosphorus than the control. The highest available K was observed in soil treated with redgram stalk biochar and cotton stalk biochar @ 5 t ha^{-1}.

Berihun *et al.* (2017) [8] opined that biochar application results in significant increase in carbon, nitrogen, potassium and available phosphorus in biochar treated soil. Wisnubroto *et al.* (2017) [70] stated that after harvesting of rice crop, the soil applied with ammonium enriched biochar had higher nitrogen content of 0.14 per cent than nitrate enriched biochar of 0.11 per cent and control of 0.09 per cent.

Effect of biochar on nutrient use efficiency

Gaskin *et al.* (2008) [19] indicated that biochar, when applied in combination with fertilizers reduced fertilizer requirement as it prevent leaching of applied nutrients. Application of biochar @ 5 t ha^{-1} decreased fertilizer need by 7 per cent. The impact of biochar application was seen in highly degraded acidic or nutrient depleted soils. According to Sohi *et al.* (2010) [56] biochar created impact on crop production through the direct modification of soil chemistry with its elemental composition, by providing chemically active sites. This alters the dynamics of soil nutrients by soil reactions or by modifying the physical character of the soil resulted in better root growth, nutrient and water retention and acquisition. Peng *et al.* (2012) [42] suggested that biochar addition along with fertilizers leads to better establishment and growth of crops compared to chemical fertilizer application alone. Widowati *et al.* (2014) [69] recorded that biochar addition decreased N fertilizer requirement and increased soil organic carbon. Uzoma *et al.* (2011b) [64] reported that application of biochar along with manure increased maize yield by 98–150 per cent and water use efficiency by 91–139 per cent. Alburquerque *et al.* (2014) [5] observed increased fertilizer use efficiency when biochar was combined with fertilizer.

Deb *et al.* (2016) [12] pointed out biochar enhanced nutrient supply by retaining higher amount of nutrients in soil. Through sorption of nitrates and phosphates, leaching losses were minimal. Ghezzehei *et al.* (2014) [21] found that biochar can adsorb up to 20–43 per cent of 5 mg per gram of biochar ammonium and 19–65 per cent of the phosphate.

Effect of biochar on plant growth characteristics

Germination

Van Zwieten *et al.* (2010) [67] claimed improvement in germination of wheat with application of paper mill waste biochar @ 10 t ha^{-1}. Solaiman *et al.* (2012) [57] recorded that the germination percentage was increased from 93 to 98 per cent in wheat crop with the addition of biochar @ 10 t ha$^{–1}$ produced from different source materials.

Kamara *et al.* (2015) [28] pointed out application of maize stover biochar recorded significantly higher germination per cent and seedling emergence in rice and maize crops. Manikandan (2014) [36] found that the application of biochar @ 2.5 t ha^{-1} to 10 t ha^{-1} increased the germination from 93.9 per cent to 96.4 per cent. Rajalakshmi *et al.* (2015) [46] tested the effect of prosopis biochar on germination in the soil less petridish bioassay with green gram, rice and cotton with dose ranging from 10-30 t ha^{-1}. The results showed increased germination and root length of the seedlings in the petridish.

Agegnehu *et al.* (2016) [1] inferred that the positive effect of biochar on germination of maize was due to alteration in the physical condition of soil, modification in thermal dynamics as a result of dark colour of biochar, possible water availability and hormonal effects. Ramzani *et al.* (2017) [47] concluded that application of biochar @ 5 to 10 t ha^{-1} in low fertility soils improved the germination per cent, shoot length, shoot dry weight and shoot fresh weight of wheat. The maximum germination percentage of 96.02 per cent and germination index of 24.03 per cent were recorded in lantana biochar applied treatment in garden pea (Berihun *et al.* (2017) [8].

Plant growth parameters

Kamara *et al.* (2015) [28] stated that growth of the rice plants was significantly influenced by rice straw biochar and higher plant height was noted in biochar treated plots than control. Pandian *et al.* (2016) [41] recorded higher plant height in groundnut crop with application of redgram stalk biochar @ 5 t ha$^{–1}$ and control plot registered shorter plants. Height of beans, fenugreek and mint was recorded as 36 cm, 12 cm and 20 cm, respectively in biochar treated soil and these are 55 per cent, 62 per cent and 35 per cent greater than control plot, respectively (Kalyani, 2016) [27]. According to Berihun *et al.* (2017) [8] the application of 12 t ha$^{–1}$of *Lantana camara* biochar considerably improved plant height. Wisnubroto *et al.* (2017) [70] reported that 45 days after planting of rice, plant height in non-biochar plot was only 29.3 cm and higher plant height of 40.3 cm was noted in biochar applied plots.

Leaf chlorophyll

Significant increase in leaf chlorophyll content was observed by Agegnehu *et al.* (2015) [2] when biochar was applied along with compost and fertilizer in maize. The increase in leaf chlorophyll content with plant age was in correlation with availability of nutrients and water over period of time with application of organic amendments.

Dry matter production

Yeboah *et al.* (2009) [73] claimed that application of 3 t ha$^{–1}$ biochar along with 120 kg N ha$^{–1}$ recorded higher shoot dry weight in maize due to improved nutrient retention of biochar. The shoot dry weight ranged from 41 to 45 g pot$^{–1}$ for the sandy loam soil and 28 to 35 g pot$^{–1}$ for the silt loam soil. Revell *et al.* (2012) [48] stated that incorporation of cow manure biochar @ 15 and 20 t ha^{-1} increased dry matter yield of maize by 150 per cent and 98 per cent respectively compared non treated plots.

Agegnehu *et al.* (2017) [3] found that addition of organic amendments along with biochar increased leaf chlorophyll content. Thereby facilitated production of healthier plants which ultimately resulted in higher biomass and grain yield of crops. Pandian *et al.* (2016) [41] inferred that application of redgram stalk biochar and maize stalk biochar @ 5 t ha$^{–1}$ in groundnut resulted in longest root of 12.5 cm and higher root biomass of 351 g, which was 36 per cent and 45 per cent higher than the control. Further, dry matter accumulation (2202 kg ha$^{–1}$) and pod yield (1661 kg ha$^{–1}$) was highest in redgram stalk biochar @ 5 t ha$^{–1}$ applied plots and the increase was 24 and 29 per cent over control, respectively.

Berihun *et al.* (2017) [8] concluded that amendment of *Lantana* biochar @ 18 t ha$^{–1}$ significantly increased fresh shoot and root biomass resulting in higher dry matter production. Wisnubroto *et al.* (2017) [70] opined that application of nitrogen enriched biochar significantly increased rice dry biomass to 69.4 g pot^{-1} compared to control of 43.2 g pot^{-1}.

Effect of biochar on crop yield parameters and yield

Kimetu and Lehmann (2010) [30] stated that maize yield doubled after addition of biochar @ 8 t ha^{-1}. Application of biochar along with inorganic fertilizer increased crop productivity and also generate additional income by reducing the cost and quantity of inorganic fertilizer used (De Gryze *et al.*, 2010) [11]. Purakayastha *et al.* (2015) [44] indicated that application of wheat straw biochar @ 1.9 t ha^{-1} along with recommended dose of fertilizers of 180:80:80 NPK ha^{-1} significantly increased the yield of maize and this was superior over control. According to Vaccari *et al.* (2011) [65] amendment of biochar at 10 t ha^{-1} recorded higher grain yield in maize, wheat and also in ryegrass in pot culture trials. Galinato *et al.* (2011) [18] reported that biochar application to acid soil resulted in 58 per cent yield increase in wheat.

The highest pigeonpea grain yield of 1685 kg ha^{-1} was recorded with alternate year application of cotton stalk biochar @ 3 t ha^{-1} along with fertilizers. Castor stalk biochar application @ 6.0 t ha^{-1} either every year or alternate year with recommended dose of fertilizers gave marginally higher yield than other treatments (CRIDA, 2012) [10]. Suppadit *et al.* (2012) [60] studied the effect of biochar on soybean yield attributes and yield in pot experiment using sandy soil and observed significant yield increase with 98.4 g biochar application per pot.

Zhang *et al.* (2013) [77] claimed that biochar amendment produced significant effect on rice yield by 10 per cent in the first cycle and by 9.5–29 per cent in subsequent cycle. Liu *et al.* (2013) [33] reviewed biochar effect on productivity of different crops (from 59 pot experiments and 57 field experiments from 21 countries) and stated that the increase in crop productivity was on an average of 11 per cent. Under field conditions, application of biochar at less than 30 t ha $^{-1}$ was advantageous and increase in crop productivity varied with crops i.e. 30 per cent in legumes, 29 per cent in vegetables, 14 per cent in grasses, 8 per cent in corn, 11 per cent in wheat and 7 per cent in rice.

Srinivasarao *et al.* (2013) [58] found that the maize grain yield in biochar treated plots was significantly higher than control plots. Further, higher nitrogen use efficiency of 91.0 kg grain^{-1} kg N was recorded with application of biochar @ 6.0 t ha^{-1} + RDF followed by biochar @ 3.0 t ha^{-1} + RDF with N use efficiency of 52 kg grain kg^{-1} N. Van Vinh *et al.* (2015) [66] inferred that in comparison with NPK applied plots, rice yields were increased by 5.9-22.3 per cent in biochar treated plots and by 26.3- 34.2 per cent in compost mixed with 5 per cent biochar. In case of vegetables, biochar application increased the yield by 4.7-25.5 per cent compared to normal cultivation practices.

Coumaravel *et al.* (2015) [9] concluded that under Integrated Plant Nutrition System (IPNS), application of biochar @ 10 t ha^{-1} along with RDF of 250:75:75 kg ha^{-1} + FYM @ 12.5 t ha^{-1} and Azospirillum @ 2 kg ha^{-1} had recorded significantly higher yield and NPK uptake with sustained soil fertility. Gebremedhin *et al.* (2015) [20] opined that grain and straw yields of wheat were significantly increased by 15.7 per cent and 16.5 per cent, respectively in plots applied with biochar and fertilizers of 100 kg urea +100 kg DAP + 4 ton biochar ha^{-1} over the control plot which received only inorganic fertilizers.

Gokila and Baskar (2015) [23] stated that application of biochar @ 5 t ha^{-1} with RDF and bio-fertilizer recorded the highest 100 grain weight (38.9 g), cob length (23.5 cm) and cob weight (310 g) over other treatments and control in maize crop. The higher grain and stover yield of 8100 and 12150 kg ha^{-1}, respectively were also recorded in the same treatment. Application of biochar @ 5.0 t ha^{-1} significantly improved the yield attributes and yield of maize and French bean (Srinivasarao *et al.*, 2014) [59]. Yang *et al.* (2016) recorded the maize yield of 12.2 and 12.6 t ha^{-1} with application of 2 t ha^{-1} and 4 t ha^{-1} in maize stalk biochar and control plot yield was 4.2 t ha^{-1}.

Deb *et al.* (2016) [12] indicated that biochar applied along with Phosphorus Solublizing Mycorrhizae (PSM) recorded significant mean crop yield for jute, rice, radish, and tomato in India and for radish in Thailand. Further, biochar alone applied plot shown less beneficial effect on crop productivity. According to Kang *et al.* (2016) [29] the rice yield was higher in order of biochar applied plot of 421.8 g m^{-2} and lower yield of 198.5 g m^{-2} was control in plot.

Berihun *et al.* (2017) [8] found that the highest pod numbers were recorded in garden peas under the application of *Lantana* biochar @ 12 t ha^{-1}. Wisnubroto *et al.* (2017) [70] claimed that rice planted in nitrogen enriched biochar soil yielded a higher grain yield of 49.3 g pot^{-1} compared to that of planted on non-biochar treated soil of 27.2 g pot^{-1}.

Impact of biochar on growth, yield and quality of cotton

Elangovan (2014) [15] found that the plant height was higher throughout the growing stages of cotton crop in biochar @ 10 t ha^{-1} along with RDF and FYM applied plots over control. Xu *et al.* (2016) [71] inferred that at China in cotton crop, two years after biochar application improved the boll number (118 bolls m^{-2}) and cotton yield (0.69 kg m^{-2}) in the second year. Shen *et al.* (2018) [52] in China concluded that biochar applications to silt loam soil to cotton crop increased seed cotton yields and the increases in cotton yield could be attributed to the addition of required nutrients along with biochar resulted in improvement in soil structure.

Fibre length and fibre strength was significantly greater in the biochar applied @ 20 t ha^{-1} treatment than in the control. Fiber elongation greatly increased in biochar applied @ 10 and 20 t ha^{-1} treatments compared with the control (Tian *et al.*, 2018) [61].

Qian *et al.* (2017) [45] opined that soil amendment of biochar has significant influence on the soil bacterial community, which increased the microbial diversity in cotton under continuous cropping systems. Zhang *et al.* (2017) [76] also reported similar findings. Biochar effects on soil microbial population are complex in nature and are mainly depends on type and quantity of biochar added in the soil (Lu *et al.*, 2018; Singh Mavi *et al.*, 2018) [55].

Zeng *et al.* (2019) [74] stated that in China, biochar application in continuously cropped cotton soil up to 20 years, significantly increased bacterial diversity. At the same time, up to 40 years significantly decreased microbial diversity and richness under all the biochar application rates.

Impact of biochar on growth, yield and quality of maize

Major *et al.* (2010) [35] indicated that biochar application had no significant effect on maize yield in the first year, but increased maize yields during the next 3 years by 28–140 per cent. According to Varela Milla *et al.* (2013) applied biochar improved the biomass production by increased plant weight, increased the root size and leaf width. Zhu *et al.* (2017) reported that biochar + NPK amendment of a red soil increased maize total biomass upto 2.7–3.5 and 1.5–1.6 times compared to that of NPK only and biochar only amendments, respectively.

Zhang *et al.* (2017) [76] observed that, maize yield was increased to the tune of 11.9 per cent and 35.4 per cent in balanced fertilization system with wheat straw biochar @ 20 t ha^{-1} over control during two years of study period (2011 and 2012) in calcareous inceptisol soils of China. Agegnehu *et al.* (2016) [1] claimed that in Australia application of biochar along with RDF produced higher total biomass of 21.0 t ha^{-1} and grain yield of 9.2 t ha^{-1} in maize crop than control with 17.7 t ha^{-1} and 7.0 t ha^{-1} respectively.

Sarkhot *et al.* (2013) [50] found that as Nutrient Enriched Biochar (NEB) having high surface area, it adsorbed the nutrients of NH_4^+, NO_3^-, K^+, Ca^{2+}, Zn^{2+} and reduced losses and this offered great mechanisms for developing slow release fertilizer by using biochar which in turns improved nutrient use efficiency and increased the crop yield. Eazhilkrishna *et al.* (2017) [14] pointed out that application of 125 per cent RDF through NEB recorded higher grain yield of 5677 kg ha^{-1} and stover yield of 9504 kg ha^{-1} maize over the control. The nutrient uptake was also higher in same treatment compared to control.

Sampathkumar *et al.* (2012) [49] studied on the impact of water deficit in cotton-maize cropping sequence revealed that, mild deficit i.e. alternate deficit irrigation at 100 per cent ETc once in three days registered higher seed cotton yield of 3670–3760 kg ha^{-1} and grain yield of maize 7420–7590 kg ha^{-1} with water use efficiency of 9.0 and 18.0–20.4 kg $ha^{-1}mm^{-1}$ for cotton and maize, respectively.

Conclusion

From the foregone review, it is evident that there is possibility of favourable influence by biochar application on the productivity of most crops majorly focused on cotton and maize. The soil health can also be sustained by converting crop residues into biochar and by applying along with inorganic fertilizers instead of burning on field which is a major practiced in most parts of our country. However, there exist some lacunae in the current level of knowledge regarding the source and quantity of biochar application which needs to be addressed in mere future.

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