

**EFFECT OF BIOCHAR ON SOIL PHYSICAL PROPERTIES,  
CARBON POOLS AND PRODUCTIVITY OF MAIZE  
(*Zea mays* L.)**

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY  
COLLEGE OF AGRICULTURE, SHIVAMOGGA  
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CERTIFICATE

This is to certify that the thesis entitled "**EFFECT OF BIOCHAR ON SOIL PHYSICAL PROPERTIES, CARBON POOLS AND PRODUCTIVITY OF MAJZE (*Zea mays L.*)**" submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE) in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the College of Agriculture, Shivamogga, University of Agricultural and Horticultural Sciences, Shivamogga is bonafide record of research work carried out by **Ms. SHILPA, P. V., ID No. MAITAG0249** (shilpapv96@gmail.com) during the period of study in this university under my guidance and supervision and no part of this thesis has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

Shivamogga  
July, 2019




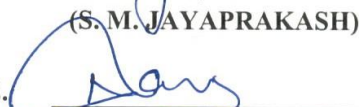

  
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*Shivamogga  
July, 2019*

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**“EFFECT OF BIOCHAR ON SOIL PHYSICAL PROPERTIES, CARBON  
POOLS AND PRODUCTIVITY OF MAIZE (*Zea mays* L.)”**

(SHILPA, P. V)

**ABSTRACT**

A field experiment was conducted at Agricultural and Horticultural Research Station, Bavikere, UAHS, Shivamogga during the year 2018, to know the “Effect of biochar on soil physical properties, carbon pools and productivity of maize (*Zea mays* L.)”. Two levels of cob rind biochar combination with and without three levels of FYM was applied to field. The experiment was laid out in a Randomized Complete Block Design with nine treatments and replicated thrice. The result revealed that application of higher level of biochar  $4 \text{ t ha}^{-1} + 100 \text{ per cent RD-FYM} + \text{RDF}$ , significantly increased the water holding capacity (37.41 %) and porosity (32.93 %) of soil compared to control treatment received  $\text{RDF} + \text{RD-FYM}$ .

Increase in soil pH and electrical conductivity was observed with the application of biochar at  $4 \text{ t ha}^{-1} + 50 \text{ per cent FYM} + \text{RDF}$ . But soil application of biochar at  $4 \text{ t ha}^{-1} + 100 \text{ per cent FYM} + \text{RDF}$  recorded significantly higher soil carbon pools like PDOC ( $10.89 \text{ g kg}^{-1}$ ), PPOC ( $494.01 \text{ mg kg}^{-1}$ ), MBC ( $365.77 \text{ mg kg}^{-1}$ ), CWEC ( $160.64 \text{ mg kg}^{-1}$ ), TOC ( $11.17 \text{ g kg}^{-1}$ ), TIC ( $0.82 \text{ g kg}^{-1}$ ) and TC ( $11.99 \text{ g kg}^{-1}$ ), soil available nutrients like nitrogen ( $316.10 \text{ kg ha}^{-1}$ ), phosphorus ( $55.18 \text{ kg ha}^{-1}$ ) and potassium ( $253.33 \text{ kg ha}^{-1}$ ), growth and yield parameters like plant height (182.20 cm), number of leaves (13.56), total dry matter production (295.00 g), grain yield ( $86.40 \text{ q ha}^{-1}$ ), stover yield ( $104.20 \text{ q ha}^{-1}$ ) and nutrient concentration like nitrogen (1.65 and 1.00 %), phosphorus (0.29 and 0.22 %) and potassium (0.49 and 1.07 %) in grain and stover of maize was observed.

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ಜೈವಿಕ ಇದ್ದಿಲಿನ ಬಳಕೆಯಿಂದ ಮಣ್ಣಿನ ಭೌತಿಕ ಗುಣಲಕ್ಷಣಗಳು, ಇಂಗಾಲದ ಭಿನ್ನರಾಶಿಗಳು ಮತ್ತು ಮೆಕ್ಯೂಜೋಳದ ಉತ್ಪಾದಕತೆಯ ಮೇಲಾಗುವ ಪರಿಣಾಮಗಳು

(ಶಿಲ್ಪ, ಪಿ. ವಿ.)

ಸಾರಾಂಶ

ಕೃಷಿ ಮತ್ತು ತೋಟಗಾರಿಕಾ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಶಿವಮೊಗ್ಗದ ಕೃಷಿ ಮತ್ತು ತೋಟಗಾರಿಕಾ ಸಂಶೋಧನಾ ಕೇಂದ್ರ, ಬಾವಿಕೆರೆಯಲ್ಲಿ ಕ್ಷೇತ್ರ ಪ್ರಯೋಗವನ್ನು ೨೦೧೮ನೇ ಸಾಲಿನಲ್ಲಿ ಕೈಗೊಳ್ಳಲಾಗಿದ್ದು, ಎರಡು ಪ್ರಮಾಣದ ಜೋಳದ ದಿಂಡಿನ ಜೈವಿಕ ಇದ್ದಿಲನ್ನು ಒಂದೊಂದಾಗಿ ಹಾಗೂ ಅವುಗಳನ್ನು ಮೂರು ಪ್ರಮಾಣದ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರಗಳ ಸಂಯೋಜನೆಯೊಂದಿಗೆ ಭೂಮಿಗೆ ಹಾಕಲಾಯಿತು. ಒಂಬತ್ತು ಉಪಚಾರಗಳನ್ನು ಮೂರು ಬಾರಿ ಪುನರಾವರ್ತನೆಗೊಳಿಸಿ, ಪ್ರಯೋಗವನ್ನು ಯಾದ್ಯಚ್ಛಿಕ ಸಂಪೂರ್ಣ ಬ್ಲಾಕ್ ವಿನ್ಯಾಸದಲ್ಲಿ ಸ್ಥಾಪಿಸಲಾಯಿತು. ಬರೀ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಗೊಬ್ಬರ ಮತ್ತು ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ ಉಪಚರಿಸಿದ ತಾಕುಗಳಿಗೆ ಹೋಲಿಸಿದರೆ, ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ೪ ಟನ್ ಜೈವಿಕ ಇದ್ದಿಲು + ಶೇ. ೧೦೦ ರಷ್ಟು ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ ಹಾಗೂ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಗೊಬ್ಬರ, ಉಪಚರಿಸಿದ ತಾಕುಗಳಲ್ಲಿ ಅತಿ ಹೆಚ್ಚಿನ ನೀರು ಹಿಡಿದಿಡುವ ಸಾಮರ್ಥ್ಯ (೩೭.೪೧ %) ಹಾಗೂ ರಂಧ್ರತೆಯು (೩೨.೯೩ %) ಕಂಡುಬಂದಿರುತ್ತದೆ.

ಮಣ್ಣಿನ ರಸಸಾರ ಮತ್ತು ವಿದ್ಯುತ್ ವಾಹಕತೆಯು ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ೪ ಟನ್ ಜೈವಿಕ ಇದ್ದಿಲು + ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ (೫೦ %) ಹಾಗೂ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಗೊಬ್ಬರ ಉಪಚರಿಸಿದ ತಾಕುಗಳಲ್ಲಿ ಹೆಚ್ಚಾಗಿರುವುದು ಕಂಡುಬಂದಿರುತ್ತದೆ. ಆದರೆ ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ೪ ಟನ್ ಜೈವಿಕ ಇದ್ದಿಲು + ಶೇ. ೧೦೦ ರಷ್ಟು ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ ಹಾಗೂ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಗೊಬ್ಬರ ಉಪಚರಿಸಿದ ತಾಕುಗಳಲ್ಲಿ ಇಂಗಾಲದ ಭಿನ್ನರಾಶಿಗಳಾದ ಸಾವಯವ ಇಂಗಾಲ ಉತ್ಪರ್ಷಣೆಯ ಪೊಟ್ಯಾಷಿಯಂ ಡೈಕ್ರೋಮೇಟ್ (೧೦.೮೯ ಗ್ರಾಂ/ಕೆ.ಜಿ.), ಸಾವಯವ ಇಂಗಾಲ ಉತ್ಪರ್ಷಣೆಯ ಪೊಟ್ಯಾಷಿಯಂ ಪರ್ಯಾಂಗನೇಟ್ (೪೯೪.೦೧ ಮಿ.ಗ್ರಾಂ/ಕೆ.ಜಿ.), ಸೂಕ್ಷ್ಮ ಜೀವರಾಶಿಯ ಇಂಗಾಲ (೩೬೫.೭೭ ಮಿ.ಗ್ರಾಂ/ಕೆ.ಜಿ.), ತಣ್ಣೀರಿನ ಇಂಗಾಲದ ಸಾರ (೧೬೦.೬೪ ಮಿ.ಗ್ರಾಂ/ಕೆ.ಜಿ.), ಒಟ್ಟು ಸಾವಯವ ಇಂಗಾಲ (೧೧.೧೭ ಗ್ರಾಂ/ಕೆ.ಜಿ.), ಒಟ್ಟು ನಿರವಯವ ಇಂಗಾಲ (೦.೮೨ ಗ್ರಾಂ/ಕೆ.ಜಿ.) ಮತ್ತು ಒಟ್ಟು ಇಂಗಾಲದ ಪ್ರಮಾಣವು (೧೧.೯೯ ಗ್ರಾಂ/ಕೆ.ಜಿ.) ಗಮನಾರ್ಹವಾಗಿ ಹೆಚ್ಚಾಗಿರುವುದು ಕಂಡುಬಂದಿರುತ್ತದೆ. ಇದೇ ರೀತಿಯಾಗಿ ಮೇಲೆ ನಮೂದಿಸಿದ ತಾಕಿನ ಮಣ್ಣಿನಲ್ಲಿ ಲಭ್ಯವಿರುವ ಪೋಷಕಾಂಶಗಳಾದ ಸಾರಜನಕ (೩೧೬.೧೦ ಕೆ.ಜಿ. ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ), ರಂಜಕ (೫೫.೧೮ ಕೆ.ಜಿ. ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ) ಮತ್ತು ಪೊಟ್ಯಾಷಿಯಂ (೨೫೩.೩೩ ಕೆ.ಜಿ. ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ) ಹೆಚ್ಚಾಗಿರುವುದು ಕಂಡುಬಂದಿರುತ್ತದೆ. ಸಸ್ಯದ ಬೆಳವಣಿಗೆ ಮತ್ತು ಇಳುವರಿಗೆ ಸಂಬಂಧಿಸಿದಂತೆ ಸಸ್ಯದ ಎತ್ತರ (೧೮೨.೨೦ ಸೆ.ಮೀ.), ಎಲೆಗಳ ಸಂಖ್ಯೆ (೧೩.೫೬), ಒಣಪದಾರ್ಥದ ಉತ್ಪಾದನೆ (೨೯೫.೦೦ ಗ್ರಾಂ), ಧಾನ್ಯದ ಇಳುವರಿ (೮೬.೪೦ ಕ್ವಿಂ. ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ), ಮೇವಿನ ಇಳುವರಿ (೧೦೪.೨೦ ಕ್ವಿಂ. ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ) ಮತ್ತು ಧಾನ್ಯ ಹಾಗೂ ಮೇವಿನಲ್ಲಿ ಪೋಷಕಾಂಶಗಳಾದ ಸಾರಜನಕ (ಶೇ. ೧.೬೫ ಮತ್ತು ೧.೦೦), ರಂಜಕ (ಶೇ. ೦.೨೯ ಮತ್ತು ೦.೨೨) ಮತ್ತು ಪೊಟ್ಯಾಷಿಯಂ (ಶೇ. ೦.೪೯ ಮತ್ತು ೧.೦೭) ಹೆಚ್ಚಿನ ಪ್ರಮಾಣದಲ್ಲಿ ಕಂಡುಬಂದಿದೆ.

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# **INTRODUCTION**

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## I INTRODUCTION

In modern agriculture use of fertilizers, especially, inorganic fertilizers have become essential for growing of food crops. But, continuous and indiscriminate use of inorganic fertilizers, little use of organic manures and lack of recycling of crop residues adversely damaged soil fertility and also rapid depletion of mineral nutrients in soil. Moreover, imbalanced use of fertilizers also affected soil physical, chemical and biological properties.

To sustain soil fertility and maintaining good soil properties, use of organic source along with inorganic fertilizers is the best solution. Integrated nutrient management is an integral part of sustainable agriculture which requires management of resources without deteriorating the quality of environment. Increase in awareness is being created on the use of organics including biochar to sustain the soil fertility and productivity. In this regard, biochar is gaining more importance in maintenance of soil fertility as well as soil productivity.

Efficient use of biomass like crop residues and other farm wastes by converting into a useful organic source of nutrients is one way to manage soil health and soil fertility otherwise they are being dumping as wastes materials in nature. Different crop residues like maize stover, grasses, cob rind, animal manure, areca husk *etc.*, could be used for biochar production. Maize biomass waste is the largest agricultural waste after timber and rice waste, conversion of this underutilized maize biomass wastes like corn cob into biochar helps to increase biomass potential use and to conserve the nutrients apart from effective crop residue management. Thus biochar has emerged as an important source of nutrients as that of manures and fertilizers to hold a key role in improvement of crop yield by providing favorable soil environment to crop.

Biochar is a carbon rich solid material produced by incomplete combustion of crop residues through pyrolysis process in an environment with little or no oxygen. During pyrolysis process biomass is heated to 250 °C to 700 °C temperature results in production of volatile compounds, which are condensed to give bio-oil. The other products produced from pyrolysis include a gaseous material called as “syngas” and a carbon (C)-rich charcoal material known as bio-char (Lehmann, 2007a).

The left over solid biochar in the reactor contain C, O, H, N and ash (Ca and K). Biochar produced at low temperatures (250 °C to 400 °C) contain C=O and CH functional groups that can serve as nutrient exchange sites after slow oxidation compared to biochar produced at high temperature (400 °C to 700 °C).

The importance of biochar for soil improvement probably due to its high surface area, presence of more number of micro pores which helps to retain nutrients also provide habitat for beneficial soil microorganisms, promotes storage of organic

carbon (OC) in soil and it has characteristic ability to persist in soil with very little biological decay (Lehmann *et al.*, 2006). Its incorporation in soil had been proposed to increase water holding capacity (Hesu *et al.*, 2014), soil fertility (Samual *et al.*, 2014) and enhance agricultural productivity (Ali *et al.*, 2018). It improves soil physical properties (Chan *et al.*, 2007), soil cation exchange capacity (Chintala *et al.*, 2014) and as a soil additive along with organic and inorganic fertilizers. Biochar has been reported to improve nutrient availability to plants (Glaser *et al.*, 2002).

In recent years biochar is being used as a source of amendment to acid soils and has attracted widespread attention as a method to increase soil carbon sequestration while also reducing atmosphere CO<sub>2</sub> concentrations (Lehmann, 2007a). Increased carbon pools such as, potassium dichromate oxidizable carbon, potassium permanganate oxidizable carbon, microbial biomass carbon and cold water extractable carbon can improve soil quality by playing vital role in soil chemical, biological and physical processes. The research conducted in different parts of the world suggested that biochar has a beneficial role in crop production.

Among cereals, maize (*Zea mays* L.) is an important food crop which ranks third after wheat and rice in the world. It ranks fourth in India after rice, wheat and sorghum. Maize is of American origin having been domesticated about 7000 years ago. It is a versatile crop as it grown across a range of agro ecological zones. It is a multipurpose crop that provides food for humans, feeds for animals and raw materials for the industries. This crop has much higher grain protein content than our staple food rice. Maize is a heavy feeder of nutrients hence it is a very efficient converter of solar energy in to dry matter. Maize being an exhaustive crop also depletes soil fertility.

The application of organics in conjunction with inorganic fertilizers improve the fertility status of soil in terms of higher available nutrients (Anup *et al.*, 2010), but the information on effect of biochar, FYM with inorganic fertilizers on soil fertility and productivity of maize is limiting. Keeping this in view, an experiment was conducted to study the efficacy of biochar with FYM and inorganic fertilizers on productivity of maize crop with the following objectives,

1. To study the effect of different levels of cob rind biochar on soil physical properties
2. To study the effect of different levels of cob rind biochar on carbon pools of soil
3. To study the effect of different levels of cob rind biochar on nutrient status of soil
4. To study the effect of different levels of cob rind biochar on nutrient uptake and yield of maize

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# **REVIEW OF LITERATURE**

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## II REVIEW OF LITERATURE

Biochar is a carbon rich solid material, highly porous in nature and contain nutrients in it. Application of biochar helps to improve the soil physical, chemical and biological properties and can be used as soil amendment. Thus application of biochar holds a key role to improve soil fertility status and crop productivity.

In light of the above, the details of literature pertaining to the effect of biochar on soil physical properties, carbon pools and productivity of maize (*Zea mays* L.) and related crops are briefly reviewed and presented in this chapter under the following headings;

2.1 Characteristics of biochar

2.2 Effect of biochar on physical properties of soil

2.3 Effect of biochar on carbon pools of soil

2.4 Effect of biochar on chemical properties of soil

2.5 Effect of biochar on plant growth, yield and nutrient uptake

### 2.1 Characteristics of biochar

Biochar made from different crop residues are characterized for different morphological and chemical properties. Cob rind biochar is characteristically differ based on pyrolysis temperature. Biochar characterization is essential to understand the production property relationships. The behavior of biochar in soil is related to the characteristics created during the pyrolysis process. Thus, it is important to examine the properties of cob rind biochar and to relate these variables to its function in soil.

Lua and Yang (2004) reported that the variability in physical and chemical properties of biochar depends on the material (feedstock) used to produce biochar, the oxygen supply and the temperature achieved during pyrolysis.

Pastor *et al.* (2006) reported that the characteristics of the wood charcoals as far as their potential carbon adsorbents is concerned depend not only on the wood used, but also the carbonization system.

Chan and Xu (2009) reported that the porosity and surface area of a biochar will have very important effects on nutrient retention capacity by surface binding of both cations and anions to its surface.

Downie *et al.* (2009) found that biochar porosity, which determines its surface area, shows pore size distribution that is highly variable and encompasses nano (< 0.9 nm), micro (< 2 nm) to macro-pores (> 50 nm) and biochars has lower bulk density than mineral soil with values on par with organic soil.

Steinbeiss *et al.* (2009) reported that low-temperature biochars, which have a less condensed carbon structure, are expected to have a greater reactivity in soils than higher temperature biochars and a better contribution to soil fertility.

Keiluweit *et al.* (2010) showed that the low-temperature pyrolysis (< 550 °C), favours greater recovery of C and also of several nutrients (*e.g.* N, K and S) that are increasingly lost at higher temperatures.

Singh *et al.* (2010) found that wood derived biochars had higher carbon content, lower ash content, nutrient content and cation exchange capacity than manure based biochars.

Wang *et al.* (2013) found that increasing pyrolysis temperature of biochar from 500 to 700 °C increased the ash content, BET (Brunauer-Emmet-Teller) surface area, pH, total P and Ca contents and decreased the biochar yield, CEC, total acid and nitrogen. Increase in residence time from 4 to 8 or 16 hours, increased the BET surface area and ash content of biochar but decreased the biochar yield. Fourier-transform infrared spectroscopy (FTIR) analysis showed that more recalcitrant and aromatic structures were formed in the biochar at a higher temperature.

Brewer *et al.* (2014) in a study estimated the BD values of biochars produced from different feedstock and it ranged from 0.25 to 0.6 g cm<sup>-3</sup>.

Jindo *et al.* (2014) reported that low-temperature pyrolysis produced high biochar yields; in contrast, high-temperature pyrolysis led to biochars with a high C content, large surface area, and high adsorption characteristics.

Wan *et al.* (2014) revealed that pH, the content of carbonates, base cation and alkalinity of biochar increased with increase in pyrolysis temperature. The high pH of biochar has been attributed to hydrolysis of salts of Ca, Mg and K (Tryon, 1948).

Bashir *et al.* (2015) conducted experiment and reported that addition of organic manures improved total organic carbon (TOC), total polysaccharide content (TPC) and microbial biomass carbon (MBC).

Rumi *et al.* (2015) reported that biochar is a carbon rich material contains 50 per cent of its original carbon which is highly recalcitrant nature, which are produced during pyrolysis process. Along with the biochar some amount of bio-oil and gases are also produced.

## 2.2 Effect of biochar on physical properties of soil

The physical properties of soils determine their adaptability to cultivation and the level of biological activity that can be supported by the soil. Soil physical properties determine the soil's water and air supplying capacity to plants.

Tryon (1948) reported that application of charcoal increased the percentage of available soil moisture only in sandy soil. No changes were observed in loamy soil, the available soil moisture decreased in the clayey soil with increasing biochar additions and attributed to hydrophobicity of the biochar.

Glaser *et al.* (2000) reported that application of charcoal to Anthrosols having the surface area which was 3 times higher than those of surrounding soils increased the field capacity by 18 per cent.

Briggs *et al.* (2005) reported that addition of charcoal changed the color of dry soil. They found that Munsell value decreased from 5.5 to 4.8 at charcoal concentrations of 10 g kg<sup>-1</sup> and to 3.6 at 50 g kg<sup>-1</sup>.

Gundale and DeLuca (2007) reported that biochar has much lower bulk density than that of mineral soils and therefore concluded that application of biochar can reduce the overall bulk density of soil. Application of biochar increased porosity, available soil water content, organic carbon and soil pH.

Chan *et al.* (2007) showed that with increasing rate of biochar application the tensile strength of the hard setting soil under investigation was decreased and suggested that application of biochar may increase the overall net surface area of soil.

Amonette and Joseph (2009) reported that soil structure, porosity and density of soil influenced by the application of biochar and also air oxygen content, water storage capacity, microbial and nutrient status of soil were potentially altered within plant rooting zone.

Downie *et al.* (2009) reported incorporation of biochar into the soil can alter soil physical properties such as soil structure, pore size distribution and density with logical implications on soil aeration, water holding capacity, plant growth and soil workability. Further, enhance the microbial activities as a result of biochar addition improved soil aggregate formation and stability.

Hesham *et al.* (2013) investigated the effect of conocarpus biochar application on hydraulic properties of sandy loam soil. The result showed a decrease in saturated hydraulic conductivity and infiltration rate, on the other hand, improved the percentage of water stable aggregates and mean weight diameter (MWD). Increase in application rate increased the MWD and reached two folds compared to control.

Mukherjee and Lal (2013) showed that the presence of micropores and large surface area of biochar contribute to potentially alter soil's surface area, pore size distribution, water holding capacity, penetration resistance and bulk density.

Helena and Eila (2014) studied one sandy and two clayey soils were amended with biochar (0, 15 and 30 t ha<sup>-1</sup>) and after three week incubation, a wet sieving method was used to measure the release of colloidal particles and the stability of aggregates. The sorption of P onto soil surfaces was estimated with a Q/I (quantity/intensity) plot technique. By the addition of biochar could reduce clay soil erosion by improving aggregate stability and would change the P sorption affinity of the soil and help to reduce the loss of dissolved P. The biochar thus induced changes in soil properties that could be beneficial for soil erosion control.

Hesu *et al.* (2014) reported that application of biochar reduced the soil bulk density by 12 to 25 per cent after incubation, compared to control. However, porosity of soil increased by 16 to 22 per cent and aggregate size by 0.59 to 0.94 mm, respectively. Because of presence of more micropores in biochar which significantly increased the available water content by 18 to 89 per cent.

Njoku *et al.* (2015) revealed that application of biochar had significantly ( $p < 0.05$ ) increased the aggregate stability and changes in total porosity, saturated hydraulic conductivity and bulk density of soil. Among different rates of biochar application, mean weight diameter and moisture content were found to be non-significant ( $p < 0.05$ ).

Biar *et al.* (2016) reported that application of biochar on a silt loam soil under three different cropping systems significantly increased the available water content.

Pratiwi and Shinogi (2016) reported that application of rice husk biochar to paddy soils decreased bulk density and an increase in saturated hydraulic conductivity, total pore volume as well as the available soil water content. The shoot height of rice plants was significantly higher in 4 per cent biochar amended soil compare to control soil. It was also found that with the application rate of 2 and 4 per cent biochar to soil led to reduction in total CH<sub>4</sub> emission by 45.2 and 54.9 per cent respectively, compared with the control.

Rao *et al.* (2017) reported that with the application of FYM, vermicompost, tank silt and biochar there is no change in the textural class, but clay content of soil increased by 2 per cent with the application of tank silt. Also the application of these amendments significantly increased the porosity compared to control.

Duarte *et al.* (2019) reported that with the application of biochar having three size fractions to two types of soils (loamy and sandy soil), influenced the physical

properties of soil. The biochar with smaller particle size ( $< 0.15$  mm) increased the water retention, porosity and water availability in both the soil, particularly in loamy soil.

Wang *et al.* (2019) showed that application of biochar (0, 0.5, and 1 % weight) having high surface area, increased the field capacity of sandy soil compared to silty clay loam soil in lab scale experiment. In the field trial biochar amendment ( $10 \text{ t ha}^{-1}$ ) nor agricultural management practices altered the water retention capacity of a silty clay loam soil. The study revealed that application of biochar with a high pore volume can increase the field capacity and plant available water in a coarse textured soil and have a limited impact when biochar pore volume is low, or soil texture is fine.

### **2.3 Effect of biochar on carbon pools of soil**

Wardle *et al.* (2008) reported that fire derived charcoal in the forest ecosystem act as an important long-term sink of carbon and it is associated with enhancement of microbial activity.

Jerry and Leenheer (2009) reported that composition of natural organic matter (NOM) in various environments is increasing because of its significance in soil fertility, water quality, the global carbon cycle and the maintenance of life itself.

Kimetu and Lehmann (2010) noticed that biochar addition, particularly in low carbon soils, results in reduced mineralization losses of existing soil carbon and greater stabilization of the pre-existing carbon.

Demise *et al.* (2014) reported that application of three different rates (0.5, 1.0 and 2 %) of oak wood biochar and bamboo biochar improved aggregate stability and enzyme activity of degraded red soil. Microbial biomass carbon positively correlated with all labile organic C and macro-aggregates, indicating that microbial activities result in mineralization of organic matter.

Hartely *et al.* (2016) reported that the addition of several biochar derived from different feed stocks increased the total organic carbon in micro aggregate fraction and also raise in the concentration of dissolved organic carbon in the soil pore water from the biochar treated soil.

Wu *et al.* (2016) showed that cumulative mineralization rates of rice straw (RS) biochar-C incubated with different paddy soils were relatively low (0.17-0.28 %) during 390 days of incubation. The cumulative mineralization rates of RS biochar-C increased with the increasing native soil total organic carbon (TOC) content. These results suggest that RS biochar application could be an effective method for C sequestration in paddy soil. However, the stability of RS biochar in paddy soil would be significantly impacted by soil TOC content. From the perspective of long-term C

sequestration, RS biochar is more suitable for applying in paddy soils with lower TOC content.

Sarma *et al.* (2017) showed that biochar application to acidic sandy loam soils of north-east India has reduced the carbon mineralization and recorded lowest rate of carbon mineralization 9 per cent leading to increased soil organic carbon 12 per cent compared to application of vermicompost and farm yard manure.

Zhang *et al.* (2017) reported that application of straw and straw derived biochar (8 t ha<sup>-1</sup> and 16 t ha<sup>-1</sup>) with inorganic fertilizers significantly increased soil organic carbon by 33.7 to 79.6 per cent and microbial biomass carbon by 18.9 to 46.5 per cent.

Daniel *et al.* (2018) reported that application of cattle manure (0, 13 and 26 t ha<sup>-1</sup>) or biochar (0, 20 and 40 t ha<sup>-1</sup>) and four combined manure-biochar levels (20 or 40 t ha<sup>-1</sup> biochar + 13 or 26 t ha<sup>-1</sup> manure) has increased cumulative carbon mineralization only in sole manure and biochar amended soils by 45-125 per cent.

Naggar *et al.* (2018) showed that organic carbon was increased with the addition of biochar under different soil particle size fraction due to interaction of soil particle with biochar and the increase in organic carbon content was about 37 per cent, 42 per cent and 76 per cent in soil particle size fraction of 53 to 250, < 53, 250 to 2000 µm respectively.

Duarte *et al.* (2019) reported that application of biochar having three size fractions to two types of soil (loamy and sandy soil), influenced the total carbon content of soil, especially in sandy soil compared to control treatment. The highest carbon content was obtained in the biochar size 0.15 to 2 mm in sandy soil.

Petter *et al.* (2019) conducted field experiment and reported that application of biochar (0, 2, 4, 8 and 16 Mg ha<sup>-1</sup>) with or without synthetic fertilizers (0 and 200 kg ha<sup>-1</sup>) were not altered microbial biomass carbon and carbon management index. However, there was an increase in total organic carbon and total nitrogen with the application of biochar.

## **2.4 Effect of biochar on chemical properties of soil**

Soil chemical properties are the most important among the factors that determine nutrient supplying power of the soil to plant. The chemical reaction occur in the soil leading to soil fertility build up. Addition of biochar having high charge per unit area, the occurrence of various surface functional groups and ash content have a positive effect on soil chemical properties.

Glaser *et al.* (2002) stated that charcoal may contribute to an increase in iron retention of soil and decrease in leaching of dissolved organic nutrients as they have an impact on nutrient retention capacity of the tropical soil.

Lehmann *et al.* (2003a) noticed that the immediate beneficial effects of biochar additions for nutrient availability are largely due to higher potassium, phosphorus and zinc availability and to a lesser extent, calcium and copper.

Lehmann *et al.* (2003) studied Lysimeter experiments and reported that the ratio of uptake to leaching for all nutrients increases with charcoal application to the soil. Therefore, nutrients must have been retained on electrostatic adsorption complexes created by the charcoal. Potential of biochar in reducing leaching losses of essential elements and greenhouse gas (GHG) fluxes were also reported by Major *et al.* (2009).

Keech *et al.* (2005) stated that biochar has the higher surface area, porosity and a charge that has the potential to increase soil water-holding capacity, cation exchange capacity, surface sorption capacity and base saturation when added to the soil.

Steiner *et al.* (2007) observed that addition of biochar to poultry litter during composting reduced ammonia emissions by 64 per cent and reduced total nitrogen (TN) loss by 52 per cent.

Rodriguez *et al.* (2009) reported that the biochar produced from sugarcane bagasse increased the pH of soil from 4.0 to 4.5 and 6.0 to 6.5 in a maize trial in Colombia. Biochar is predominately found in fractions of soil organic matter (SOM) that resides in small clusters of soil particles, or soil aggregates, rather than as free organic matter (Liang *et al.*, 2006).

Hina *et al.* (2010) discussed the role of activated biochar in the treatment of waste streams. Also, biochar saturated with  $\text{NH}_4^+$  could also be used as a slow-release fertilizer.

Yuan *et al.* (2011) revealed that alkalinity of biochar was a key factor affecting their liming potential and the greater alkalinity of biochars led to greater reductions in soil acidity. The incorporation of biochars decreased soil exchangeable acidity and increased soil exchangeable base cations and base saturation, thus improving soil fertility.

Hass *et al.* (2012) observed that biochar produced at higher pyrolysis temperature increased soil pH more than the biochar produced at lower pyrolysis temperature at same application rate. Also, steam activation increased the liming capacity of biochar.

Victoria *et al.* (2012) showed that addition of biochar produced at two temperature range has significantly increased the N availability by several transformation process with in short time. With the increase in N mineralization by 185 to 221 per cent, nitrification by 10 to 69 percent and ammonia consumption rate by 333 to 508 per cent, the nitrogen from recalcitrant soil organic pool was transformed to a more labile soil organic pool thereby increased the nitrogen bio-availability.

Chintala *et al.* (2014) conducted incubation study for acid soils using corn stover and switch grass biochar to determine the liming potential of biochar. The result revealed that use of biochar, application rate has significant effects ( $p < 0.05$ ) on soil pH, EC and cation exchange capacity of acidic soil.

Nurhidayati and Mariati (2014) conducted a field experiment using maize cob biochar, rice husk charcoal and lime with three levels 3, 6 and 9 t ha<sup>-1</sup> as amendment to acid soil. The results revealed that application of soil amendments increased soil pH by 23 per cent (lime), 20 per cent (rice husk charcoal) and 23 per cent (biochar) as compared with control. The increase in soil pH also increased the availability of soil N, P and K.

Rajesh *et al.* (2014) reported that exchangeable acidity was significantly affected by amendment type. Application of corn stover biochar had shown a relatively larger increase in soil pH than switchgrass biochar at all application rates. The ameliorating effect of biochars on chemical properties of acidic soil was consistent with their chemical composition.

Samual *et al.* (2014) conducted greenhouse experiment with combined application of green manure or fertilizer with biochar. The results showed a positive comparable synergistic effect on soil microbial biomass C, mineral N, available P and pH by the application of manure or fertilizer with biochar.

Zhu *et al.* (2014) reported that incorporation of biochar to acid red soil in the 46 days of pot experiment has increased the soil pH and available phosphorus and no significant effect on the nitrogen use efficiency and nitrogen retained in the soil.

Danish *et al.* (2015) studied the effect of biochar application on SAR and RSC of sandy soil. Application at a higher rate significantly increased SAR (2.6 folds) and RSC (1.84 folds) of sandy soil as compared to control and thus discouraged the application of biochar with high Na<sup>2+</sup> as an amendment in saline and sodic soils.

Purakayastha (2015) reported that biochar was prepared from maize stover, pearl millet stalk, rice straw and wheat straw in a pyrolysis kiln at the temperature of 400 °C. The biochar was characterized for various physical, chemical and structural

properties. The wheat and rice biochar exhibited higher CEC than the other biochar materials, while the pH values of maize and pearl millet biochar were higher over rice and wheat biochar. The maize biochar was richer in C, N and P contents. Maize biochar with higher nutrient values especially N and P and C stability could be advocated for enhancing soil fertility and long-term C sequestration. Rice biochar might be advocated for higher microbial activities in restoring the biological fertility of degraded soils.

Feng *et al.* (2017) conducted the experiment in cold waterlogged paddy soils of North China. The results showed that the straw and biochar amendments improved total nitrogen and organic carbon content of the soil reduced N<sub>2</sub>O emissions and had little influence on nitrogen retention, nitrogen density, and CO<sub>2</sub> emissions. Increased soil nitrogen and carbon content, improved soil carbon sequestration and reduced GHG emission without affecting the yield of super rice.

Gokila and Basker (2017) reported that the combined application of biochar (5t ha<sup>-1</sup>) with 100 per cent recommended dose of fertilizer and biofertilizer increased the soil fertility status in maize growing soil.

Ondo *et al.* (2017) conducted a field experiment to assess the influence of biochar and organic compost on soil properties. The results revealed that the combined application of biochar and compost amendment significantly increased the pH of soil.

Arif *et al.* (2018) conducted a field experiment and reported that application of biochar with FYM and nitrogen fertilizer increased soil properties like carbon content, nitrogen and phosphorous status in biochar treatment over no biochar treatment soil.

## **2.5 Effect of biochar on plant growth, yield and nutrient uptake**

Studies in both tropical and temperate climates have demonstrated biochars ability to increase plant growth, reduce leaching of nutrients, increase water retention and increase microbial activity.

Adekayode and Olojugba (2010) investigated with 4 t ha<sup>-1</sup> wood ash, 300 kg ha<sup>-1</sup> NPK 15-15-15, 200 kg ha<sup>-1</sup> NPK with 2 t ha<sup>-1</sup> wood ash mixture and a control plot with manure. The results revealed that chlorophyll content of 1.50 mg 100 g<sup>-1</sup> and the grain yield 1.97 mg ha<sup>-1</sup> were significantly higher in 200 kg ha<sup>-1</sup> NPK 15-15-15 with 2 t ha<sup>-1</sup> wood ash mixture as compared to other treatments.

Blackwell *et al.* (2010) conducted a field experiment and revealed that the interaction of water soluble phosphorus @ 7 kg ha<sup>-1</sup> and biochar 5 t ha<sup>-1</sup> significantly increased the grain yield from 0.570 to 0.804 t ha<sup>-1</sup>.

Jha *et al.* (2010) reported that increase in crop yield to the tune of 45 to 250 per cent by the application of biochar along with chemical fertilizers. Soil nutrients availability increased with the application of biochar.

Major *et al.* (2010) conducted a field experiment and reported that the concentration of calcium and magnesium in the maize leaves at tasselling stage were 1.36 and 1.03 g kg<sup>-1</sup> dry matter, respectively with the application of biochar @ 4 t ha<sup>-1</sup> which was significantly higher as compared to control (1.08 and 0.92 g kg<sup>-1</sup> dry matter).

Namgay *et al.* (2010) conducted pot culture experiment on maize and reported that the maize dry matter was not influenced significantly by the application of biochar at different rates *i.e.*, 0, 5, 15 g kg<sup>-1</sup>.

Zhang *et al.* (2010) reported that application of wheat straw biochar @ 10 and 40 t ha<sup>-1</sup> increased rice yields by 12 and 14 per cent in soils amended with nitrogen fertilization, respectively.

Sukartono *et al.* (2011) reported that application of biochar @ 15 t ha<sup>-1</sup> significantly increased the maize yield and nitrogen, phosphorous, potassium uptake by maize crop.

Uzoma *et al.* (2011) found that application of cow manure biochar @ 15 and 20 t ha<sup>-1</sup> significantly increased maize grain yield by 150 and 98 per cent as compared with the control.

Arif *et al.* (2012) conducted a field experiment and reported that the integrated use of mineral nitrogen, 150 kg ha<sup>-1</sup> and biochar @ 30 t ha<sup>-1</sup> resulted in lengthy cobs (16 cm) which was at par with mineral nitrogen application (15 cm). Whereas control plots resulted in shorter ears (8 cm).

Widowati *et al.* (2012) conducted a field experiment and revealed that the dry matter production of maize at the end of vegetative stage was significantly higher (3.11 t ha<sup>-1</sup>) with the integral application of nitrogen fertilizer @ 145 kg ha<sup>-1</sup> and city waste biochar @ 30 t ha<sup>-1</sup> when compared to the sole use of nitrogen fertilizer @ 145 kg ha<sup>-1</sup> (3.06 t ha<sup>-1</sup>).

Cornelissen *et al.* (2013) reported that grain yields of maize were increased significantly from 0.9 ± 0.1 t ha<sup>-1</sup> in control compared to 3.8 ± 0.5 t ha<sup>-1</sup> in soil treated with biochar 4 t ha<sup>-1</sup>.

Karer *et al.* (2013) conducted a field experiment in two season with the application of biochar @ 0, 24, 72 t ha<sup>-1</sup> and revealed that with the application of

biochar @ 24 t ha<sup>-1</sup>, the nitrogen uptake was significantly higher (131 t ha<sup>-1</sup>) as compared to no biochar application at same rate of nitrogen application.

Masto *et al.* (2013) conducted a field experiment and revealed that maize grain yield was significantly higher on application of biochar @ 4 t ha<sup>-1</sup> as compared to control (3.59 t ha<sup>-1</sup>).

Alie *et al.* (2014) reported that application of biochar  $\geq 8.3$  g kg<sup>-1</sup> soil significantly ( $p < 0.05$ ) increased plant height, stem girth, fresh and dry-shoot weight of both maize and rice plants at seedling stage of crops.

Imran *et al.* (2014) reported that the maize 1000 seed weight was significantly increased with increase in biochar levels. They also reported that the maximum maize grain yield (4013 kg ha<sup>-1</sup>) was obtained with application of biochar @ 24 t ha<sup>-1</sup> while minimum in control (3660 kg ha<sup>-1</sup>).

Mau and Utami (2014) conducted a greenhouse experiment on study of interaction effects of biochar amendment and arbuscular mycorrhizal fungi inoculation on phosphorus uptake, the result revealed that highest available P was in the soils incubated with 7.5 g biochar kg<sup>-1</sup> and AMF (Arbuscular Mycorrhizal Fungus) spores kg<sup>-1</sup> after 8 weeks incubation.

Party *et al.* (2014) conducted greenhouse experiment with combined application of green manure or fertilizer with biochar. The results showed increased maize yield by 35 and 25 per cent, respectively for application of biochar and *V. faba* or *T. diversifolia*. Relative to sole fertilizer application, there was a 27 per cent increase in maize grain yield when fertilizer was combined with biochar.

Coumaravel *et al.* (2015) conducted a field experiment with maize hybrid, the result revealed that application of biochar at 10 t ha<sup>-1</sup> along with the recommended dose of fertilizer + FYM 12 t ha<sup>-1</sup> and azospirillum at 2 kg ha<sup>-1</sup> significantly increased yield and nutrient uptake by maize crop.

Kalyani *et al.* (2016) reported increased plant height, number of leaves and yield of the bean, fenugreek and mint with biochar in the combination of organic manure than biochar alone or compost alone.

Gokila and Basker (2017) reported that application of biochar (5 t ha<sup>-1</sup>) with recommended dose of inorganic fertilizers and biofertilizers increased the yield components of maize also soil quality trait such as crude protein content.

Naeem *et al.* (2017) conducted a trail on maize in Pakistan with biochar (1 % w/w), compost (1.5 % w/w) and RDF with following treatments: biochar alone, RDF (Recommended nitrogen, phosphorus and potassium) alone, compost alone,

compost + RDF, biochar + RDF, biochar + compost, biochar + compost + RDF along with a control (C) without biochar, compost and RDF. They stated that maize yield significantly increased by the application of biochar + compost + RDF compared with control and other treatments.

Ali *et al.* (2018) conducted a field experiment and reported that application of biochar (0, 25 and 50 t ha<sup>-1</sup>) with FYM (5 and 10 t ha<sup>-1</sup>) and nitrogen (75 and 150 kg ha<sup>-1</sup>) increased grain yield by 21 and 11 per cent over no biochar treatments. Similarly, maize biological yield was increased by 14 and 39 per cent over no biochar and control treatments.

Dagnija *et al.* (2018) found that the addition of biochar leads to a significant ( $P < 0.05$ ) increase in the concentrations of Ca<sup>2+</sup> and Mg<sup>2+</sup>, as well as a decrease in the concentration of Al<sup>3+</sup>, irrespective of biochar particle size and the presence of *T. viride*. Plant growth was stimulated in the presence of small (< 2 mm) particle-sized biochar.

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# **MATERIAL AND METHODS**

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### III MATERIAL AND METHODS

An investigation entitled “Effect of biochar on soil physical properties, carbon pools and productivity of maize (*Zea mays* L.)” was conducted during *kharif* season of 2018 at Agricultural and Horticultural Research Station, Bavikere, UAHS, Shivamogga. The materials used and methods adopted for the investigation are described in this chapter.

#### 3.1 Production and characterization of biochar

Maize cob rinds were collected from the farmers field and were heated using kiln apparatus, which consists of outer ring having height of 1.5 m with diameter of 76 cm and inner ring having height of 1.2 m with diameter of 63 cm. The collected cob rind is pyrolysed in the absence or limited supply of oxygen at temperature of 350 to 500 °C for four hours. These pyrolysed materials are allowed to cool for three to four hours, half burnt biochar material were finely ground to pass through 2 mm sieve to get fine powder. Biochar was analyzed for different parameters as per the methods given in Table 1 and used for field application (Plate 1).

#### 3.2 Location of the experimental site

The field experiment was conducted at PG research center, Agriculture and Horticulture Research Station, Bavikere. The station is situated between 13°42’ N latitude and 75°51’ E longitude with an altitude of 667.5 m above mean sea level (MSL), It falls under the Southern Transitional Agro-climatic zone of Karnataka (Zone No.7). The topography of land was very gently sloppy with moderately well drained nature soil.

#### 3.3 Weather conditions during crop growth period

During crop growth period, a total rainfall of 722.6 mm was received from July to December, with highest rainfall in the month of July (254.20 mm). The mean monthly maximum temperature was highest during July (39.2 °C), while it was lowest in the month of December (20.1 °C). The monthly meteorological data (rainfall, maximum and minimum temperature) of the experimental site during crop growth period are presented in Appendix-I.

#### 3.4 Initial soil sample collection and analysis

Initial soil sample was collected from 0 to 15 cm depth before start of the experiment. Soil sample was processed and analyzed for various physical and chemical properties by following standard procedure. The properties of initial soil sample was presented in the Table 2.

**Table 1: Methods followed for characterization of biochar and FYM**

<b>Parameters</b>	<b>Methods</b>	<b>References</b>
<b>pH</b>	Potentiometry	Jackson (1973)
<b>EC (dS m<sup>-1</sup>)</b>	Conductometry	Jackson (1973)
<b>Bulk density (Mg m<sup>-3</sup>)</b>	Glass vial method	Black (1965)
<b>MWHC (%)</b>	Keen's cup method	Piper (1966)
<b>Nitrogen (%)</b>	Kjeldahl digestion distillation method	Jackson (1973)
<b>Phosphorus (%)</b>	Vanadomolybdate method	Jackson (1973)
<b>Potassium (%)</b>	Flame photometer method	Jackson (1973)
<b>Total carbon (g kg<sup>-1</sup>)</b>	TOC analyser	
<b>Calcium (%)</b>	Complexometric titration method	Jackson (1973)
<b>Magnesium (%)</b>	Complexometric titration method	Jackson (1973)
<b>Sulphur (ppm)</b>	0.15% CaCl <sub>2</sub> extraction and turbidity	Black (1965)
<b>Zinc (ppm)</b>	Atomic absorption spectrophotometry	Lindsay and Norwell (1978)
<b>Iron (ppm)</b>		
<b>Manganese (ppm)</b>		
<b>Copper (ppm)</b>		



Kiln apparatus



Preparation of biochar using cob rind



Biochar after pyrolysis process



Powdering and sieving of biochar



Field application

**Plate 1. Biochar production and field application**

**Table 2: Physical and chemical properties of experimental site**

<b>Physical properties</b>	
<b>Parameters</b>	<b>Value</b>
Soil taxonomy	<i>Typic Rhodustalfs</i>
Sand (%)	70.03
Silt (%)	15.50
Clay (%)	14.10
Textural class of soil	Sandy loam
Bulk density (Mg m <sup>-3</sup> )	1.40
Porosity (%)	24.10
WHC (%)	30.20
<b>Chemical properties</b>	
pH (1: 2.5)	5.51
EC (dS m <sup>-1</sup> at 25° C)	0.13
Avail. N (kg ha <sup>-1</sup> )	290.14
Avail. P <sub>2</sub> O <sub>5</sub> (kg ha <sup>-1</sup> )	51.80
Avail. K <sub>2</sub> O (kg ha <sup>-1</sup> )	225.10
Exchangeable Ca (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	5.60
Exchangeable Mg (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	2.40
Avail. S (mg kg <sup>-1</sup> )	12.25
DTPA-Fe (mg kg <sup>-1</sup> )	10.72
DTPA-Mn (mg kg <sup>-1</sup> )	5.41
DTPA -Zn (mg kg <sup>-1</sup> )	0.71
DTPA -Cu (mg kg <sup>-1</sup> )	1.10
Total organic carbon ( g kg <sup>-1</sup> )	9.30
Total carbon (g kg <sup>-1</sup> )	9.50
Total inorganic carbon ( g kg <sup>-1</sup> )	0.20
<b>Carbon pools</b>	
Potassium dichromate oxidizable carbon (g kg <sup>-1</sup> )	8.01
Potassium permanganate oxidizable carbon ( mg kg <sup>-1</sup> )	403
Microbial biomass carbon ( mg kg <sup>-1</sup> )	245
Cold water extractable carbon ( mg kg <sup>-1</sup> )	115

### 3.5 Design and layout of the experiment

The experiment consists of nine treatments combinations and were replicated thrice. The details, plan and layout of experiment is presented in Fig 1.

#### 3.5.1 Details of the experiment

<b>Location</b>	:	PG Center, AHRS, Bavikere.
<b>Crop</b>	:	Maize
<b>Hybrid</b>	:	CP-818
<b>Design</b>	:	Randomized Complete Block Design (RCBD)
<b>Replication</b>	:	3
<b>Treatments</b>	:	9
<b>Spacing</b>	:	45 cm × 30 cm
<b>Gross plot</b>	:	4.5 m × 3.6 m
<b>Net plot</b>	:	2.7 m × 2.4 m

#### 3.5.2 Treatment details

**T<sub>1</sub>**: Control (RDF) + RD-FYM

**T<sub>2</sub>**: Cob rind biochar @ 2 t ha<sup>-1</sup>

**T<sub>3</sub>**: Cob rind biochar @ 4 t ha<sup>-1</sup>

**T<sub>4</sub>**: Cob rind biochar @ 2 t ha<sup>-1</sup> + 100 % RD-FYM

**T<sub>5</sub>**: Cob rind biochar @ 2 t ha<sup>-1</sup> + 75 % RD-FYM

**T<sub>6</sub>**: Cob rind biochar @ 2 t ha<sup>-1</sup> + 50 % RD-FYM

**T<sub>7</sub>**: Cob rind biochar @ 4 t ha<sup>-1</sup> + 100 % RD-FYM

**T<sub>8</sub>**: Cob rind biochar @ 4 t ha<sup>-1</sup> + 75 % RD-FYM

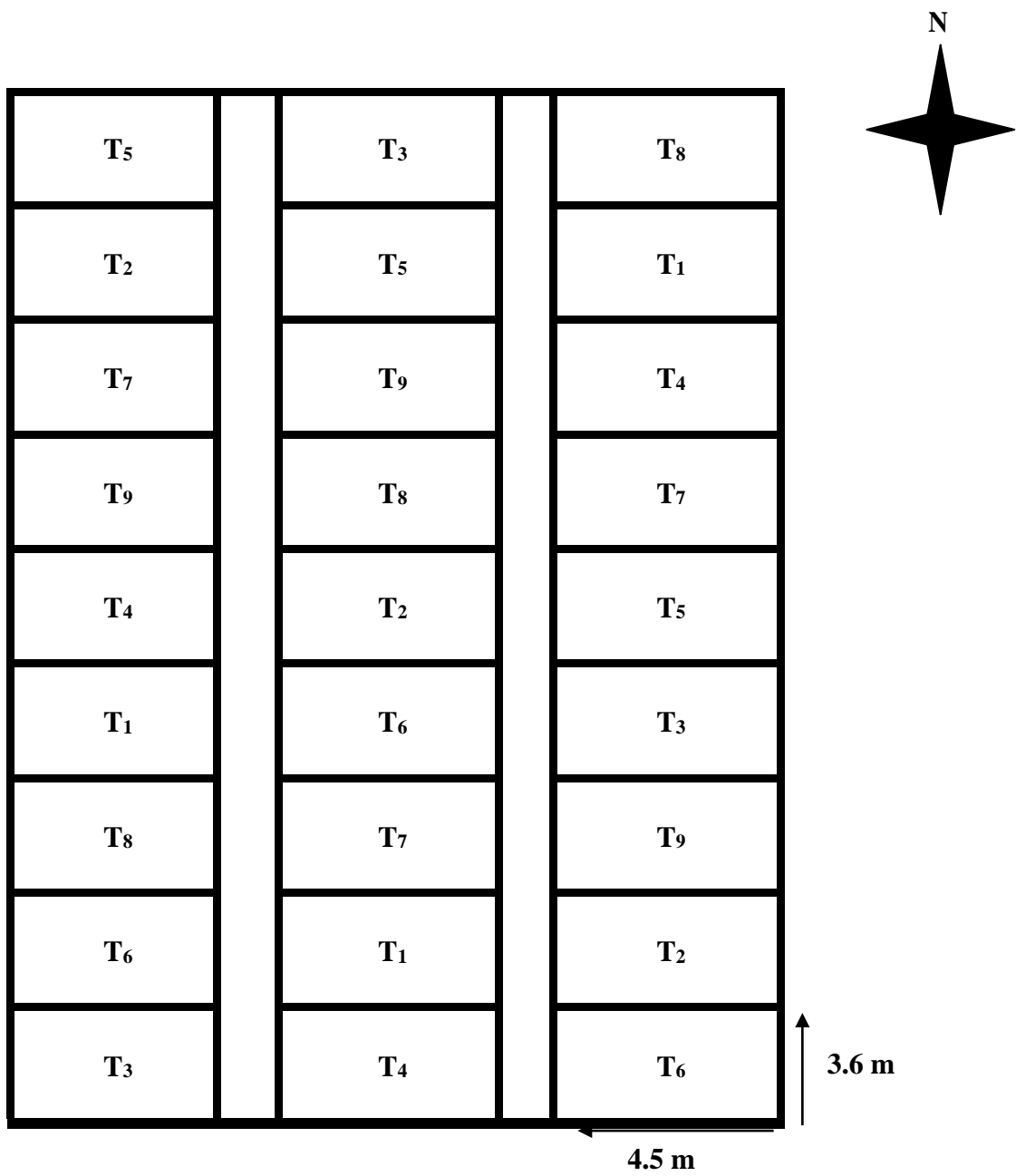
**T<sub>9</sub>**: Cob rind biochar @ 4 t ha<sup>-1</sup> + 50 % RD-FYM

Recommended dose of fertilizers (RDF) is common for all the treatments

### 3.6 Crop husbandry

#### 3.6.1 Land preparation

The land preparation was done using tractor drawn disc plough, cultivator and leveled with harrow. The experimental layout was laid out for 9 treatments with 3 replications having individual plot size of 4.5 m × 3.6 m. Irrigation channel provision was made between the replications.



**Fig 1. Plan and layout of the experimental site**

### 3.6.2 Application of biochar and FYM

As per treatment the calculated quantity of biochar and FYM were applied per plot, 15 days prior to sowing.

### 3.6.3 Application of chemical fertilizers

As per recommended dose of fertilizers (100:50:25 NPK kg ha<sup>-1</sup>) calculated quantity of N (50 %) through urea, 100 per cent of P and K through single super phosphate and muriate of potash were applied as basal dose to the treatments.

### 3.6.4 Sowing

Required quantity of seeds for plots were calculated and used for sowing. Maize seeds were dibbled at 30 cm interval in 45 cm row to row spacing.

### 3.6.5 Gap filling

Gap filling was done seven days after sowing in order to maintain 100 per cent plant population.

### 3.6.6 Thinning

Thinning was done fifteen days after sowing by maintaining one seedling per hill in order to maintain optimum plant population in each plot.

### 3.6.7 Weed management

Hand weeding was done thrice at 25, 45, 70 days after sowing by manually and two time inter cultivation was done by passing hoe at 30 and 45 days after sowing, to keep plots weed free throughout the crop growth period.

### 3.6.8 Top dressing

Remaining 50 per cent of N was top dressed through urea after 30 days of sowing.

### 3.6.9 Earthing up

After 45 days of sowing earthing up was done using spade for better crop establishment.

### 3.6.10 Harvesting and threshing

The crop was harvested after attaining physiological maturity. Two rows in all sides of each plot harvested separately as a boarder rows and the remaining area is considered as a net plot. The cobs in each net plot harvested and threshed separately.

Grains and straw were sun dried separately and weighed and expressed in quintal per hectare.

### **3.7 Growth parameters**

From each net plot five plants were randomly selected and labeled for recording observations in each treatment. The growth and yield parameters were recorded at different days after sowing *viz.*, 30, 60, 90 DAS and at harvest of crop.

#### 3.7.1 Plant height

The plant height was recorded for the labeled plants from base of plant to the collar of flag leaf. The average height of five plants was worked out and expressed in centimeter.

#### 3.7.2 Number of leaves

From labeled plants total fully opened leaves produced were counted and expressed as number of leaves per plant.

General view of experimental site presented in plate 2.

### **3.8 Yield attributes**

After attaining physiological maturity the tagged plants were used for recording yield and yield components.

#### 3.8.1 Cob length

Length of cob was measured from base to tip of cob with the help of measuring scale and expressed in centimeter.

#### 3.8.2 Cob girth

Cob girth was measured with the help of thread at middle of cob and expressed in centimeter.

#### 3.8.3 Number of grains per cob

From the five randomly selected cobs, number of grains in each cob was counted and average of them is taken as total number of grains per cob.

#### 3.8.4 Test weight (100 seed weight)

The weight of hundred kernels was recorded from the kernel samples drawn from produce obtained from each net plot and expressed in grams.



Plate 2. General view of experimental site

### 3.8.5 Grain yield

From the corresponding net plots grains were threshed later sun dried for four to six days and weighed separately. Finally grain yield was worked out and expressed in quintal per hectare.

### 3.8.6 Stover yield

Stover yield was recorded after complete sun drying stalks from each net plot for four to six days and weighed then expressed in quintal per hectare.

### 3.8.7 Dry matter production

From the rows adjacent to net plot rows excluding border rows five plants were uprooted at 30, 60 days after sowing and at harvest of maize. The uprooted plants were dried under shade and separated into leaves, stem, tassel and cob then dried in a hot air oven at 65 °C until a constant weight was obtained and oven dry weight of all parts were taken and dry weight per plant was worked out.

## **3.9 Soil sample collection and preparation**

The soil samples were collected before initiation of experimentation and during crop growth and after harvest of the crop from each treatment plots in all the three replications. Soil samples were dried under shade, powdered and passed through 2 mm sieve. The fine earth was stored in plastic bags for further analysis.

## **3.10 Soil properties**

### 3.10.1 Soil pH

Soil pH was determined in 1:2.5 ratio of soil: water suspension by potentiometric method using glass electrode (Jackson, 1973).

### 3.10.2 Electrical conductivity

Electrical conductivity of soil sample was measured in the supernatant solution of 1:2.5 ratio of soil: water extract using conductivity meter and expressed as dS m<sup>-1</sup> (Jackson, 1973).

### 3.10.3 Soil physical properties

#### 3.10.3.1 Particle size analysis

The particle size distribution in soil samples was determined by adopting International pipette method as described by Piper (1966) using sodium hydroxide as a dispersing agent. From the dispersed suspension an aliquot of clay + silt and clay

were pipetted out from specified depth at their specific time intervals depending on the suspension temperature. The total sand obtained by repeated decantation of silt and clay was passed through 0.05 mm sieve. The fraction that was finer than 0.05 mm was added to silt determined initially by pipetting to have particle size classes as per USDA system.

#### 3.10.3.2 Bulk density

The bulk density of soil was determined by core method. A metallic core of known volume is driven into the undisturbed soil and sample was taken. The weight of field moist sample and oven dried soil sample were determined. The volume is calculated from the core dimensions used for drawing the sample. By substituting the values in the formula bulk density is calculated (Black, 1965).

#### 3.10.3.3 Water holding capacity and porosity

The maximum water holding capacity and porosity of soil were determined using Keen's cup as explained by Bernard A, Keen and Henry Raczkowaski brass cup described by Piper (1966).

#### 3.10.4 Available nutrients

##### 3.10.4.1 Available nitrogen

Available nitrogen in the soil was determined by alkaline potassium permanganate distillation method as described by Subbiah and Asija (1956) and expressed as kg ha<sup>-1</sup>.

##### 3.10.4.2 Available phosphorus

Available phosphorus was extracted from the soil using Bray's No.1 extractant and the concentration of phosphorus in the extract was determined by chlorostannous reduced molybdophosphoric acid blue color in HCl system by using Spectrophotometer (Jackson, 1973) and results were expressed in kg ha<sup>-1</sup>.

##### 3.10.4.3 Available potassium

Available potassium was extracted from the soil using neutral normal ammonium acetate (pH 7.0) in 1:5 soil to extractant ratio and the concentration of potassium present in the extract was determined by flame photometer (Jackson, 1973) and results were expressed in kg ha<sup>-1</sup>.

##### 3.10.4.4 Exchangeable calcium and magnesium

The exchangeable calcium and magnesium were estimated by extracting the soil with neutral N ammonium acetate solution and calcium and magnesium in the

filtrate were determined by Versenate titration method (Jackson, 1973) and results were expressed as  $\text{cmol (p}^+) \text{ kg}^{-1}\text{soil}$ .

#### 3.10.4.5 Soil available sulphur

Available sulphur was extracted from the soil by 0.15 per cent calcium chloride solution and sulphur in solution was determined by turbidometry and turbidity was measured at 420 nm (Black, 1965) and the results were expressed as  $\text{mg kg}^{-1}$ .

### **3.11 Carbon pools**

#### 3.11.1 Potassium Dichromate Oxidizable Carbon (PDOC) / Soil Organic Carbon (SOC)

The air dried soil was finely ground and passed through 0.2 mm sieve and used to determine potassium dichromate oxidizable carbon by wet-oxidation method by (Walkley and Black, 1934) and expressed in  $\text{g kg}^{-1}$  of soil.

About 0.5 g of 0.2 mm sieved soil sample was taken into a 500 ml capacity conical flask. 10 ml of 1N  $\text{K}_2\text{Cr}_2\text{O}_7$  solution and 20 ml of concentrated  $\text{H}_2\text{SO}_4$  were gently mixed and contents were kept for a half an hour. After half an hour 200 ml of distilled water, 10 ml  $\text{H}_3\text{PO}_4$ , about 0.2 g of NaF and 8 to 10 drops of diphenylamine indicator were added. Contents were titrated against standard ferrous ammonium sulphate until it becomes bright green in colour. Blank titration was run by following all the above steps without soil.

After recording the burette readings of both blank and sample titrations, potassium dichromate oxidizable carbon present in the soil was calculated using the following formula.

$$\% \text{ PDOC} = \frac{10 \times 1 (\text{Blank titre value} - \text{Sample titre value}) \times 0.003}{\text{Blank value} \times \text{Weight of soil (g)}} \times 100$$

#### 3.11.2 Potassium Permanganate Oxidizable Carbon (PPOC)

Potassium permanganate oxidizable carbon was carried out as per the procedure described by Blair *et al.* (1995).

Three gram of air-dried (< 2 mm) soil was weighed in 50 ml centrifuge tube and 30 ml of 20 mM  $\text{KMnO}_4$  was added and a blank was run. Contents were shaken for 15 minutes and centrifuged for five minutes at 2000 rpm. 2 ml aliquot of supernatant was transferred into 50 ml volumetric flask and made up to 50 ml. Read the absorbance at 560 to 565 nm and determine the concentration of  $\text{KMnO}_4$  from the standard calibration curve (plot concentration versus absorbance).

$$\text{PPOC (mg kg}^{-1}\text{)} = (B - S) \times 50/2 \times \frac{\text{volume of KMnO}_4 \times 100}{1000 \times \text{weight of soil (g)}} \times 9$$

Where,

B= concentration (m molar) of KMnO<sub>4</sub> in blank

S= concentration (m molar) of KMnO<sub>4</sub> in the sample

50/ 2= dilution factor

9= mg carbon oxidized by 1 m mole KMnO<sub>4</sub>

### 3.11.3 Cold Water Extractable Carbon (CWEC)

Cold water extractable carbon was estimated as per the method described by McGill *et al.* (1986).

About 20 ml of de-ionized water was added to 10 gram of field moist soil taken in a 50 ml centrifuge tube. Contents were centrifuged at 1000 rpm for 30 minutes and supernatant was filtered. 10 ml of filtered extract was digested with 0.4N K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> (2 ml), HgO (70 mg), 10 ml of concentrated H<sub>2</sub>SO<sub>4</sub> and 5 ml of H<sub>3</sub>PO<sub>4</sub> taken in 500 ml conical flask. Similarly two blanks were run with 10 ml of distilled water along with the acid mentioned above. This mixture is boiled gently on a hot plate at 105 °C for an hour under reflex condition.

250 ml of distilled water was added and cooled at room temperature. The excess potassium dichromate is determined by back titration against 0.35N ferrous ammonium sulphate to get a brick-red end point.

$$\text{CWEC (mg kg}^{-1}\text{)} = \frac{\text{Cold water extractable carbon (BTV - STV)}}{X \text{ (g)}}$$

$$X \text{ (g)} = \frac{\text{weight of wet soil (g)}}{100 + \text{moisture (\%)}} \times 100$$

BTV= blank titre value

STV = sample titre value

### 3.11.4 Soil Microbial Biomass Carbon (SMBC)

The soil microbial biomass carbon was determined by following chloroform fumigation method described by Vance *et al.* (1987).

In vacuum desiccators about ten gram of soil sample was fumigated for 24 hrs. Under vacuum condition using ethanol free chloroform. After fumigation, fumes were removed by evacuation. The microbial biomass carbon of fumigated and non-

fumigated soils were extracted using 50 ml of 0.5 M K<sub>2</sub>SO<sub>4</sub> and extracts were used for estimation of carbon.

$$\text{SMBC (mg kg}^{-1}\text{)} = \frac{(E_{\text{CF}} - E_{\text{CNF}})}{K_{\text{EC}}}$$

$E_{\text{CF}}$  = Total weight of extractable carbon in the fumigated soil samples

$E_{\text{CNF}}$  = Total weight of extractable carbon in non-fumigated soil samples

$K_{\text{EC}} = 0.25 \pm 0.05$  and it represents the efficiency of microbial biomass carbon.

### 3.11.5 Total carbon, Total Inorganic Carbon and Total Organic Carbon

Estimation of total carbon, total inorganic carbon and total organic carbon was carried out using total organic carbon (TOC) analyzer. The commonly used method is catalytic combustion or oxidation method.

The catalytic combustion method achieves total combustion of samples by heating them to 680 °C temperature in an oxygen-rich environment inside total carbon combustion tubes in the presence of a platinum catalyst. One of the important features of this method is the capacity to efficiently oxidize hard to decompose organic compounds, including insoluble and macromolecular organic compounds. The carbon dioxide generated by oxidation is detected using an infrared gas analyzer (NDIR-non-dispersive infrared) which has high detection sensitivity with a detection limit of 4 µg L<sup>-1</sup> the highest level for the combustion catalytic oxidation method.

The sample was delivered at the combustion furnace which was supplied with purified air. There, it undergoes combustion through heating up to 680 °C with a platinum catalyst. It was decomposed and converted to carbon dioxide. The carbon dioxide generated was cooled and dehumidified and then detected by the NDIR. The concentration of total carbon (TC) in the soil sample was obtained through comparison with calibration curve.

#### 3.11.5.1 Total Carbon

About 50 mg of soil sample was weighed into a tin/ silver boat. The boat was then placed into a quartz ladle which is introduced to the high temperature and oxygen atmosphere (typically 900 °C) within the sample combustion zone. At higher temperature, all the carbon within the soil sample got rapidly oxidized to CO<sub>2</sub>. Interfering reaction products two (including sulphur oxides, halides, water and nitrous oxides) were removed by the post-combustion scrubbers. The resulting carbon dioxide was then swept into the coulometer or detector where it was automatically measured.

#### 3.11.5.2 Total Inorganic Carbon (TIC)

About 50 mg of soil sample was weighed into a silver boat then the soil sample was treated with the acid ( $\text{HNO}_3$  80 %) then the boat was placed into a quartz ladle which is introduced to high temperature (typically 200 °C) within the soil sample combustion zone. At higher temperature, all the carbon within the sample got rapidly oxidized to  $\text{CO}_2$  and evolved  $\text{CO}_2$  was carried to the detector two by the carrier gas and the concentration of  $\text{CO}_2$  was read through the infrared detector.

#### 3.11.5.3 Total Organic Carbon (TOC)

The total organic carbon was determined by subtracting the soil total inorganic carbon from the total carbon content as below.

Total Organic Carbon (TOC) = Total Carbon (TC) - Total Inorganic Carbon (TIC)

### **3.12 Biochar, FYM and plant sample analysis**

From each net plot five plants were randomly selected at different stages were oven dried, powdered and stored in polythene bags for further chemical analysis. Similarly powdered biochar and FYM also stored and used for analysis

#### 3.12.1 Total nitrogen

Total nitrogen in the biochar, FYM and plant sample was determined by Kjeldahl's digestion distillation method as described by (Piper, 1966). The powdered sample of 0.5 g was digested with concentrated  $\text{H}_2\text{SO}_4$  in presence of digestion mixture and distilled under alkaline medium. The liberated ammonia was trapped in four percent boric acid containing mixed indicator and titrated against standard  $\text{H}_2\text{SO}_4$ .

#### 3.12.2 Digestion of biochar, FYM and plant samples with di-acid mixture

Powdered biochar, FYM and plant sample of 0.5 g was predigested with  $\text{HNO}_3$  and digested with di-acid mixture containing  $\text{HNO}_3$  and  $\text{HCl}_4$  in the ratio of 10:4 on sand bath till a snow white residue was obtained. The volume of digest was made up to 100 ml with distilled water and used for analysis of various nutrients (Piper, 1966) as detailed below.

#### 3.12.3 Total phosphorus

Vanadomolybdate was added to a known volume of the di-acid extract to develop yellow color of vanadomolybdophosphoric acid in nitric acid medium. The color intensity was measured at 430 nm wavelength using spectrophotometer (Piper, 1966).

#### 3.12.4 Total potassium

Total potassium content in digested sample was determined by flame photometric method after diluting 1 ml of the di-acid digest to 25 ml with distilled water. The flame photometer readings of the sample were compared with the calibration curve of potassium and percent potassium content in the plant sample was calculated (Piper, 1966).

#### 3.12.5 Total calcium and magnesium

In an aliquot of the diacid digested biochar and FYM extract, calcium and magnesium was estimated by titrating against standard Versenate (EDTA) solution (Jackson, 1973).

#### 3.12.6 Total sulphur

In an aliquot of diacid digested biochar and FYM extract sulphur content was determined by turbidometric method. The light transmittance was read on spectrophotometer at 420 nm (Black, 1965).

#### 3.12.7 Total micronutrient

In an aliquot of diacid digested biochar and FYM extract, the total Zn, Cu, Mn and Fe were estimated using Atomic Absorption Spectrophotometer at different wave lengths.

#### 3.12.8 Total organic carbon, Total inorganic and total carbon

The powdered biochar and FYM samples were used for analysis of total organic carbon, total inorganic carbon and total carbon by following the same procedure as followed in soil sample analysis (3.11.5).

### **3.13 Uptake of Nutrients**

Nutrient uptake by maize was calculated by multiplying the nutrient content in plants with the total dry matter production and expressed in kg ha<sup>-1</sup> (Robinson, 1986).

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)} \times \text{Biomass (kg ha}^{-1}\text{)}}{100}$$

### **3.14 Statistical analysis**

The experimental data obtained was subjected to statistical analysis by adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984). The level of significance used in 'F' test was given at 5 per cent. Critical difference (CD) values given in the Table at 5 per cent level of significance, wherever the 'F' test was found significant.

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# **EXPERIMENTAL RESULTS**

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## IV EXPERIMENTAL RESULTS

An experiment was conducted during *kharif* season of 2018 at Agriculture and Horticulture Research Station (AHRS), Bavikere, UAHS, Shivamogga to study the “Effect of cob rind biochar on soil physical properties, carbon pools and productivity of maize (*Zea mays* L.)”. The results of the investigation are presented under following headings in this chapter;

- 4.1 Characterization of biochar and FYM
- 4.2 Effect of biochar levels on physical properties of soil at different growth stages of maize
- 4.3 Effect of biochar levels on carbon pools of soil after harvest of maize
- 4.4 Effect of biochar levels on total carbon status of soil after harvest of maize
- 4.5 Effect of biochar levels on chemical properties of soil at different growth stages of maize
- 4.6 Effect of biochar levels on available nitrogen status of soil at different growth stages of maize
- 4.7 Effect of biochar levels on available phosphorus status of soil at different growth stages of maize
- 4.8 Effect of biochar levels on available potassium status of soil at different growth stages of maize
- 4.9 Effect of biochar levels on growth parameters of maize
- 4.10 Effect of biochar levels on yield and yield attributes of maize
- 4.11 Effect of biochar levels on dry matter production at different growth stages of maize
- 4.12 Effect of biochar levels on concentration and uptake of primary nutrients by maize at 60 days after sowing
- 4.13 Effect of biochar levels on primary nutrients concentration of stover and grain of maize at harvest
- 4.14 Effect of biochar levels on primary nutrients uptake by stover and grain of maize at harvest.

### 4.1 Characterization of biochar and FYM

Maize cob rinds collected from farmers field was used for preparation of biochar through pyrolysis process. The powdered biochar was sieved and analyzed for different parameters and results are presented in Table 3.

**Table 3: Characterization of biochar and FYM**

<b>Physical properties</b>		
	<b>Biochar</b>	<b>FYM</b>
<b>Parameters</b>	<b>Value</b>	<b>Value</b>
Bulk density (Mg m <sup>-3</sup> )	0.57	0.46
WHC (%)	70.5	23.62
<b>Chemical properties</b>		
<b>Parameters</b>	<b>Value</b>	<b>Value</b>
pH (1: 2.5)	8.03	7.20
EC (dS m <sup>-1</sup> ) (1: 2.5)	1.22	0.41
Total carbon (g kg <sup>-1</sup> )	74.08	13.80
Total organic carbon (g kg <sup>-1</sup> )	73.36	13.21
Total inorganic carbon (g kg <sup>-1</sup> )	0.72	0.59
Nitrogen (%)	0.56	0.63
Phosphorus (%)	0.05	0.24
Potassium (%)	1.02	0.56
Calcium (%)	0.60	0.08
Magnesium (%)	0.41	0.05
Sulphur (%)	0.12	0.02
Fe (mg kg <sup>-1</sup> )	121.50	1.45
Mn (mg kg <sup>-1</sup> )	32.30	70.00
Zn (mg kg <sup>-1</sup> )	16.40	61.00
Cu (mg kg <sup>-1</sup> )	2.90	3.00

The data revealed that, the biochar has recorded the water holding capacity of 70.5 per cent and bulk density of  $0.57 \text{ Mg m}^{-3}$ . The chemical composition of biochar found to be alkaline in nature with a pH of 8.03 and the electrical conductivity of  $1.22 \text{ dS m}^{-1}$ . The total carbon content of  $74.08 \text{ g kg}^{-1}$  was recorded, the nitrogen, phosphorus and potassium recorded at 0.56, 0.05 and 1.02 per cent, respectively. It also showed good amount of calcium, magnesium and sulphur with the tune of 0.6, 0.41 and 0.12 per cent, respectively. Biochar also recorded appreciable quantities of iron, manganese, zinc and copper to an extent of 121.5, 32.3, 16.4 and  $2.9 \text{ mg kg}^{-1}$ , respectively.

Similarly FYM also analyzed for different parameters and results are presented in the Table 3. The data revealed that, the FYM has recorded the water holding capacity of 23.62 per cent and bulk density of  $0.46 \text{ Mg m}^{-3}$ . The pH of FYM was found to be 7.2 and recorded electrical conductivity of  $0.41 \text{ dS m}^{-1}$ . The total carbon content of  $13.8 \text{ g kg}^{-1}$  was recorded, the nitrogen, phosphorus and potassium recorded at 0.63, 0.24 and 0.56 per cent, respectively. It also recorded calcium, magnesium and sulphur with the tune of 0.08, 0.05 and 0.02 per cent, respectively. FYM also recorded appreciable quantities of iron, manganese, zinc and copper to an extent of 1.45, 70.00, 61.00 and  $3 \text{ mg kg}^{-1}$ , respectively.

#### **4.2 Effect of biochar levels on physical properties of soil at different growth stages of maize**

The data pertaining to effect of biochar levels on physical properties *viz.*, bulk density, porosity and water holding capacity recorded at different crop growth stages are presented in the Table 4.

The data showed that at a given level of biochar and with decrease in recommended dose of FYM, there was an increase in BD, but decrease in porosity and WHC of soil was observed. Combined use of higher dose of biochar and RD of FYM resulted in drastic decrease in BD of soil but not significantly and significantly higher porosity and WHC of soil was noticed.

##### **4.2.1 Bulk density**

The data on effect of levels of biochar on bulk density of soil (Table 4) revealed that there was no significant changes in the bulk density of soil at 60 days after sowing. However remarkable decrease in bulk density of soil ( $1.29 \text{ Mg m}^{-3}$ ) especially in the treatment T<sub>7</sub> received combination of biochar and FYM. Whereas, the control treatment (T<sub>1</sub>) received 100 per cent RDF + FYM recorded higher BD value ( $1.36 \text{ Mg m}^{-3}$ ) followed by biochar alone application.

**Table 4: Effect of biochar levels on physical properties of soil at different growth stages of maize**

Treatments	Bulk density ( $\text{Mg m}^{-3}$ )		Porosity (%)		WHC (%)	
	60 DAS	Harvest	60 DAS	Harvest	60 DAS	Harvest
	T <sub>1</sub> : Control (RDF)+ RD-FYM	1.36	1.33	24.92	25.16	31.15
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	1.34	1.32	25.89	26.62	33.28	33.97
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	1.33	1.30	27.78	27.85	34.64	35.01
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	1.30	1.29	30.77	30.94	35.48	36.08
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	1.32	1.31	28.96	29.09	34.77	35.17
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	1.33	1.32	27.97	28.05	33.97	34.59
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	1.29	1.28	32.61	32.93	36.86	37.41
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	1.31	1.30	30.46	31.52	36.31	36.96
T <sub>9</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 50 % RD-FYM	1.32	1.31	29.67	30.70	35.54	35.60
S.Em±	0.03	0.03	0.86	0.85	0.86	0.82
CD (0.05)	NS	NS	2.58	2.55	2.58	2.46

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM, NS: Non significant

Similarly at harvest stage no significant changes were observed in bulk density of soil. Among the treatments, lower BD value ( $1.28 \text{ Mg m}^{-3}$ ) was recorded in the treatment received biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM ( $T_7$ ), compared to control treatment ( $T_1$ ) received 100 per cent RDF + 100 per cent FYM, which showed higher BD value ( $1.33 \text{ Mg m}^{-3}$ ) in soil.

#### 4.2.2 Porosity

The result of biochar and FYM effect on porosity of soil at 60 days after sowing is presented in Table 4. The results revealed that compared to alone application of biochar and FYM, the combined application of different levels of biochar and FYM showed significant increase in porosity of soil. Among the treatments higher porosity value (32.61 %) was recorded in  $T_7$  with the application of biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM and it was on par with the treatment ( $T_4$ ) which received biochar  $2 \text{ t ha}^{-1}$  + 100 per cent FYM showed porosity of 30.77 per cent and the treatment ( $T_8$ ) which received biochar  $4 \text{ t ha}^{-1}$  + 75 per cent FYM, which recorded 26.55 per cent. Lower porosity (24.92 %) was recorded in control treatment received 100 per cent RDF + 100 per cent FYM.

Similarly at harvest stage significantly higher porosity values were obtained due to combined application of biochar and FYM compare to alone application of biochar and FYM. Among the treatments  $T_7$  (biochar @  $4 \text{ t ha}^{-1}$  + 100 % FYM) recorded higher porosity (32.93 %) compared to control (25.16 %) which supplied with 100 per cent RDF + RD of FYM.

#### 4.2.3 Water holding capacity

The results of effect of biochar levels on water holding capacity of soil at 60 days after sowing (Table 4) showed that combined application of biochar and FYM significantly increased water holding capacity of soil compared to biochar and FYM alone application. Among the treatments, application of higher dose of biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM ( $T_7$ ) recorded higher WHC (36.86 %) compared to control  $T_1$  (31.15 %) which supplied with 100 per cent RDF + RD of FYM.

Similar results were obtained at harvest of maize. Significant increase in water holding capacity of soil was observed due to combined application of biochar and FYM. Among the treatments, application of biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM ( $T_7$ ) recorded higher WHC (37.41 %) in soil and lower WHC (32.07 %) was recorded in the control treatment ( $T_1$ ) which received 100 per cent RDF + RD of FYM.

### **4.3 Effect of biochar levels on carbon pools of soil after harvest of maize**

The data related to carbon pools of soil *viz.*, potassium dichromate oxidizable carbon (PDOC), potassium permanganate oxidizable carbon (PPOC), microbial

biomass carbon (MBC) and cold water extractable carbon (CWEC) as influenced by levels of biochar and FYM is presented in Table 5.

The data depicted in the Table 5 clearly showed that at a given level of biochar with decrease in dose of FYM, there was a decrease in carbon pools of soil viz., PDOC, PPOC, MBC and CWEC. However combined application of higher dose of biochar and FYM showed significantly higher carbon pools in soil compare to lower dose of biochar and FYM and control treatment.

#### 4.3.1 Potassium dichromate oxidizable carbon (PDOC)

The data (Table 5) pertaining to effect of biochar on potassium dichromate oxidizable carbon clearly revealed that application of biochar in combination with FYM significantly increased potassium dichromate oxidizable carbon compare to control and application of biochar alone. Among the treatments, the treatment (T<sub>7</sub>) received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM recorded significantly higher value (10.89 g kg<sup>-1</sup>), followed by the application of biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM (T<sub>8</sub>) recorded 9.72 g kg<sup>-1</sup> and treatment (T<sub>4</sub>) received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM which recorded 9.61 g kg<sup>-1</sup> compare to control treatment (T<sub>1</sub>) which recorded lower value of 8.16 g kg<sup>-1</sup> of PDOC due to application of 100 per cent RDF + RD FYM.

#### 4.3.2 Potassium permanganate oxidizable carbon (PPOC)

Perusal of the data with respect to potassium permanganate oxidizable carbon presented in Table 5 revealed that compare to control, application of biochar in combination with FYM significantly increased potassium permanganate oxidizable carbon. However, higher value of PPOC (494.01 mg kg<sup>-1</sup>) was recorded in the treatment (T<sub>7</sub>) which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, followed by treatment (T<sub>8</sub>) recorded 467.10 mg kg<sup>-1</sup> which received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and treatment (T<sub>4</sub>) recorded 466.69 mg kg<sup>-1</sup> with the application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM, compared to control treatment (T<sub>1</sub>) recorded 446.67 mg kg<sup>-1</sup> which supplied with 100 per cent RDF + RD FYM. The lowest PPOC value (424.65 mg kg<sup>-1</sup>) was recorded due to application of biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

#### 4.3.3 Microbial biomass carbon (MBC)

Influence of biochar on microbial biomass carbon of soil at harvest are presented in Table 5 revealed that application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded significantly higher MBC (365.77 mg kg<sup>-1</sup>), followed by treatment (T<sub>8</sub>) recorded 331.27 mg kg<sup>-1</sup> of MBC which supplied with biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and treatment (T<sub>4</sub>) received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM recorded 329.67 mg kg<sup>-1</sup> compared to control treatment (T<sub>1</sub>) recorded 298.91 mg kg<sup>-1</sup>. The treatment (T<sub>2</sub>) which received biochar @ 2 t ha<sup>-1</sup> recorded lowest value (268.77 mg kg<sup>-1</sup>) of MBC at harvest stage.

**Table 5: Effect of biochar levels on carbon pools of soil after harvest of maize**

Treatments	PDOC/SOC (g kg <sup>-1</sup> )	PPOC	MBC (mg kg <sup>-1</sup> )	CWEC
T <sub>1</sub> : Control (RDF)+ RD-FYM	8.16	446.67	298.91	141.20
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	8.22	424.65	268.77	135.63
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	8.86	436.00	297.90	140.80
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	9.61	466.69	329.67	157.66
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	9.10	458.10	315.27	149.33
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	8.96	443.00	307.63	147.66
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	10.89	494.01	365.77	160.64
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	9.72	467.10	331.27	154.67
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	9.03	450.00	318.30	140.70
S.Em±	0.43	5.37	8.80	8.73
CD (0.05)	1.20	16.11	26.4	NS

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM, NS: Non significant, PDOC: Potassium dichromate oxidizable carbon, SOC: Soil organic carbon PPOC: Potassium permanganate oxidizable carbon, MBC: Microbial biomass carbon, CWEC: Cold water extractable carbon

#### 4.3.4 Cold water extractable carbon (CWEC)

The data pertaining to effect of biochar on cold water extractable carbon (CWEC) is presented in Table 5 showed that there was no significant change observed among the treatments with respect to CWEC due to application of different levels of biochar and FYM. However, remarkable increase was noticed with the application of biochar and FYM, The highest CWEC value ( $160.64 \text{ mg kg}^{-1}$ ) was recorded due to application of biochar @  $4 \text{ t ha}^{-1} + 100 \% \text{ FYM}$  ( $T_7$ ) and  $T_2$  which received biochar @  $2 \text{ t ha}^{-1}$  recorded lowest CWEC value ( $135.63 \text{ mg kg}^{-1}$ ) in soil.

#### **4.4 Effect of biochar levels on total carbon status of soil after harvest of maize**

The results pertaining to effect of biochar levels on, total organic carbon (TOC), total inorganic carbon (TIC) and total carbon (TC) content are presented in the Table 6.

The data showed that at a given level of biochar, with decrease in recommended dose of FYM, there was a decrease in total organic carbon, total inorganic carbon and total carbon of soil was observed. However, combined and higher dose of biochar and RD FYM, resulted in increase in carbon fractions (except total inorganic carbon) of soil significantly compare to control treatment.

##### 4.4.1 Total organic carbon (TOC)

The results (Table 6) revealed that combined application of biochar and FYM significantly influenced the total organic fraction of soil compare to control treatment. The highest TOC value ( $11.17 \text{ g kg}^{-1}$ ) was recorded by the application of biochar @  $4 \text{ t ha}^{-1} + 100 \% \text{ RD FYM}$  ( $T_7$ ) and it is on par with treatment ( $T_8$ ) which received biochar @  $4 \text{ t ha}^{-1} + 75 \% \text{ RD FYM}$  and recorded  $10.89 \text{ g kg}^{-1}$  and treatment ( $T_4$ ) recorded  $10.78 \text{ g kg}^{-1}$  which supplied with biochar  $2 \text{ t ha}^{-1} + 100 \text{ per cent FYM}$  compare to control treatment ( $T_1$ ) received  $100 \% \text{ RDF} + \text{RD FYM}$ , which recorded minimum TOC content of  $10.42 \text{ g kg}^{-1}$  of soil. Lowest value ( $9.10 \text{ g kg}^{-1}$ ) was recorded in the treatment ( $T_2$ ) which received only biochar @  $2 \text{ t ha}^{-1}$ .

##### 4.4.2 Total inorganic carbon (TIC)

The total inorganic carbon of post-harvest soil did not differ significantly (Table 6) due to application of biochar and FYM. However, remarkably higher TIC value was recorded due to combined application of biochar and FYM. Among the treatments the  $T_7$  which received biochar @  $4 \text{ t ha}^{-1} + 100 \% \text{ RD FYM}$  recorded higher TIC value ( $0.82 \text{ g kg}^{-1}$ ) and treatment ( $T_2$ ) recorded lower value ( $0.61 \text{ g kg}^{-1}$ ) which supplied biochar @  $2 \text{ t ha}^{-1}$ .

**Table 6: Effect of biochar levels on total carbon status of soil after harvest of maize**

Treatments	TOC	TIC	TC
	(g kg <sup>-1</sup> )		
T <sub>1</sub> : Control (RDF) + RD-FYM	10.42	0.70	11.12
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	9.10	0.61	9.71
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	9.51	0.63	10.14
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100% RD-FYM	10.78	0.78	11.56
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75% RD-FYM	10.42	0.72	11.14
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50% RD-FYM	9.11	0.65	9.76
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100% RD-FYM	11.17	0.82	11.99
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75% RD-FYM	10.89	0.75	11.64
T <sub>9</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 50% RD-FYM	10.15	0.71	10.86
SE.m±	0.24	0.07	0.23
CD(0.05)	0.72	NS	0.70

Note: RDF-Recommended dose of fertilizer  
RD-FYM: Recommended dose of FYM  
NS: Non significant  
TC: Total carbon  
TOC: Total organic carbon  
TIC: Total inorganic carbon

#### 4.4.3 Total carbon (TC)

The data presented in the Table 6 revealed that application of biochar with FYM influenced the total carbon content of soil significantly compare to control treatment. Highest TC value (11.99 g kg<sup>-1</sup>) was recorded in soil in the treatment (T<sub>7</sub>) received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM and found on par with treatment (T<sub>8</sub>) which recorded 11.64 g kg<sup>-1</sup> when supplied with biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and treatment (T<sub>4</sub>) recorded 11.56 g kg<sup>-1</sup> which supplied with biochar @ 2 t ha<sup>-1</sup> + 100 % RD FYM compare to control treatment (T<sub>1</sub>) which received 100 per cent RDF + RD FYM and recorded 11.12 g kg<sup>-1</sup> of soil. Lowest TC value was recorded due to application of biochar alone @ 2 t ha<sup>-1</sup> which recorded 9.71 g kg<sup>-1</sup> of soil.

### **4.5 Effect of biochar levels on chemical properties of soil at different growth stages of maize**

#### 4.5.1 Soil pH

The data pertaining to effect of biochar application on soil pH are presented in the Table 7. The results revealed that combined application of biochar and FYM, there was no significant change was observed in the soil reaction at 30, 60 days after sowing and at harvest of maize. However, remarkable increase in soil pH was noticed in the biochar and FYM treated plots at all the growth stages.

At 30 days after sowing remarkable increase in soil pH was observed due to application of biochar and FYM. Among the treatments, the treatment (T<sub>9</sub>) which received biochar @ 4 t ha<sup>-1</sup> + 50 per cent FYM recorded higher pH value of 5.93 and lowest pH value (5.54) was recorded in the control treatment which supplied with 100 per cent RDF + RD FYM (T<sub>1</sub>).

Similarly at 60 days after sowing, application of biochar and FYM influenced the soil pH. Among the treatments higher soil pH (6.06) was recorded in T<sub>9</sub> which received biochar @ 4 t ha<sup>-1</sup> + 50 per cent FYM and lower value (5.62) was recorded in control treatment (T<sub>1</sub>) which received 100 per cent RDF + 100 per cent FYM (T<sub>1</sub>).

At harvest stage slight increase in soil reaction (pH) was observed in the biochar and FYM treated plots. The treatment which received biochar @ 4 t ha<sup>-1</sup> + 50 per cent FYM (T<sub>9</sub>) recorded high soil pH value (6.07) and lower value (5.58) was recorded in control treatment T<sub>1</sub> which received 100 per cent RDF + 100% RD FYM.

#### 4.5.2 Electrical conductivity

The data pertaining to effect of biochar and FYM application on electrical conductivity (Table 7) revealed that application of biochar in combination with FYM showed significant difference among the treatments at different growth stages.

**Table 7: Effect of biochar levels on chemical properties of soil at different growth stages of maize**

Treatments	pH			EC (dSm <sup>-1</sup> )		
	30 DAS	60 DAS	HARVEST	30 DAS	60 DAS	HARVEST
	T <sub>1</sub> : Control (RDF)+ RD-FYM	5.54	5.62	5.58	0.17	0.19
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	5.61	5.69	5.74	0.21	0.23	0.27
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	5.89	5.94	6.01	0.25	0.28	0.31
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	5.65	5.84	5.93	0.20	0.23	0.31
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	5.68	5.75	5.89	0.21	0.26	0.32
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	5.75	5.82	5.92	0.22	0.26	0.34
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	5.79	5.85	6.02	0.23	0.29	0.36
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	5.81	5.91	5.99	0.25	0.31	0.39
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	5.93	6.06	6.07	0.28	0.34	0.40
S.Em.±	0.19	0.17	0.19	0.02	0.02	0.03
CD (0.05)	NS	NS	NS	0.06	0.07	0.09

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM, NS: Non significant

At 30 days after sowing application of biochar and FYM significantly influenced the EC of soil. Among treatments highest value of  $0.28 \text{ dS m}^{-1}$  was recorded in T<sub>9</sub> (biochar @  $4 \text{ t ha}^{-1}$  + 50 % FYM), followed by T<sub>8</sub> (biochar @  $4 \text{ t ha}^{-1}$  + 75 % FYM), which recorded  $0.25 \text{ dS m}^{-1}$  and T<sub>3</sub> recorded  $0.25 \text{ dS m}^{-1}$  due to application of biochar @  $4 \text{ t ha}^{-1}$  compared to control treatment T<sub>1</sub> which received 100 per cent RDF + 100 % RD FYM ( $0.17 \text{ dS m}^{-1}$ ).

Similarly at 60 days after sowing significantly higher EC value of  $0.34 \text{ dS m}^{-1}$  was recorded in T<sub>9</sub> (biochar @  $4 \text{ t ha}^{-1}$  + 50 % FYM), followed by T<sub>8</sub> (biochar @  $4 \text{ t ha}^{-1}$  + 75 % FYM) recorded  $0.31 \text{ dS m}^{-1}$ , treatment T<sub>7</sub> recorded  $0.29 \text{ dS m}^{-1}$  with the application of biochar @  $4 \text{ t ha}^{-1}$  + 100 % FYM and T<sub>3</sub> treatment recorded  $0.28 \text{ dS m}^{-1}$  which supplied with biochar @  $4 \text{ t ha}^{-1}$  compared to control treatment which received 100 per cent RDF + 100 % RD FYM (T<sub>1</sub>) and recorded  $0.19 \text{ dS m}^{-1}$ .

Similarly at harvest stage highest EC ( $0.40 \text{ dS m}^{-1}$ ) was recorded due to application of biochar @  $4 \text{ t ha}^{-1}$  + 50 per cent FYM (T<sub>9</sub>), followed by T<sub>8</sub> (biochar @  $4 \text{ t ha}^{-1}$  + 75 % FYM) recorded  $0.39 \text{ dS m}^{-1}$ , treatment T<sub>7</sub> recorded  $0.36 \text{ dS m}^{-1}$  with the application of biochar @  $4 \text{ t ha}^{-1}$  + 100 % FYM and treatment (T<sub>6</sub>) recorded  $0.34 \text{ dS m}^{-1}$  due to application of biochar @  $2 \text{ t ha}^{-1}$  + 50 % FYM, compare to control treatment which received 100 per cent RDF + 100 % RD FYM (T<sub>1</sub>) which recorded  $0.24 \text{ dS m}^{-1}$ .

#### **4.6 Effect of biochar levels on available nitrogen status of soil at different growth stages of maize**

The data (Table 8) clearly explained that, the available N status of soil significantly varied at all the growth stages due to the effect of levels of biochar and FYM and their combinations.

At 30 days after sowing, significantly higher available nitrogen ( $395.00 \text{ kg ha}^{-1}$ ) in soil was recorded in the treatment T<sub>7</sub> which received biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM, followed by treatment T<sub>8</sub> which received biochar @  $4 \text{ t ha}^{-1}$  + 75 per cent FYM recorded  $374.00 \text{ kg ha}^{-1}$  and treatment T<sub>4</sub> recorded  $375 \text{ kg ha}^{-1}$  due to application of biochar @  $2 \text{ t ha}^{-1}$  + 100 % RD FYM, compare to control treatment (T<sub>1</sub>) supplied with 100 per cent RDF + 100 % RD FYM which registered  $336.00 \text{ kg ha}^{-1}$ . The lowest available nitrogen ( $327.00 \text{ kg ha}^{-1}$ ) was recorded in the treatment (T<sub>2</sub>) supplied with biochar alone @  $2 \text{ t ha}^{-1}$ .

Similarly at 60 days after sowing, application of biochar with FYM significantly increased the available nitrogen in the soil. The highest available nitrogen ( $346.97 \text{ kg ha}^{-1}$ ) content recorded in the treatment T<sub>7</sub> having the biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM, followed by treatment (T<sub>8</sub>) recorded  $331.30 \text{ kg ha}^{-1}$ , which received biochar @  $4 \text{ t ha}^{-1}$  + 75 % RD FYM and treatment which received

**Table 8: Effect of biochar levels on available nitrogen status of soil at different growth stages of maize**

Treatments	Available N ( kg ha <sup>-1</sup> )		
	30 DAS	60 DAS	HARVEST
T <sub>1</sub> : Control (RDF)+ RD-FYM	336.00	304.30	297.25
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	327.00	287.63	266.73
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	344.00	305.63	281.37
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	375.00	332.97	301.67
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	354.33	316.30	297.85
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	338.67	309.70	287.97
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100% RD-FYM	395.00	346.97	316.10
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	374.00	331.30	302.30
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	356.80	323.00	295.67
SE.m±	7.61	6.79	5.87
CD(0.05)	22.83	20.37	17.61

Note: RDF-Recommended dose of fertilizer  
RD-FYM: Recommended dose of FYM

biochar @ 2 t ha<sup>-1</sup> + 100 % RD FYM (T<sub>4</sub>) which recorded 332.97 kg ha<sup>-1</sup>, compare to control treatment (T<sub>1</sub>) which recorded 304.30 kg ha<sup>-1</sup> where supplied with 100 per cent RDF + 100 % RD FYM. The lowest available nitrogen of 287.63 kg ha<sup>-1</sup> was recorded due to application of biochar @ 2 t ha<sup>-1</sup>.

Combined application of biochar and FYM at harvest of maize significantly influenced the available nitrogen status of soil and the highest value (316.10 kg ha<sup>-1</sup>) was recorded due to application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) which found on par with treatment T<sub>8</sub> which received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and recorded 302.30 kg ha<sup>-1</sup> and treatment T<sub>4</sub> which received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM and recorded 301.67 kg ha<sup>-1</sup> compare to control treatment (T<sub>1</sub>) recorded 297.25 kg ha<sup>-1</sup> which supplied with 100 per cent RDF + 100 per cent FYM. Lowest value of 266.73 kg ha<sup>-1</sup> of available nitrogen was recorded in the treatment (T<sub>2</sub>) which received lower dose of only biochar at 2 t ha<sup>-1</sup>.

#### **4.7 Effect of biochar levels on available phosphorus status of soil at different growth stages of maize**

The available phosphorus status of soil (Table 9) at different stages of maize increased due to combined application of levels of biochar and FYM compare to control.

At 30 days after sowing the results (Table 9) revealed that numerically high available phosphorus content (64.60 kg ha<sup>-1</sup>) in soil was recorded in the treatment T<sub>7</sub> applied with biochar @ 4 t ha<sup>-1</sup> + 100 % RD FYM but it found on par with treatment T<sub>8</sub> received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM recorded 61.70 kg ha<sup>-1</sup>, followed by application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>4</sub>) which recorded 60.80 kg ha<sup>-1</sup> compare to control treatment (T<sub>1</sub>) which recorded 62.90 kg ha<sup>-1</sup> due to application of 100 per cent RDF + 100 per cent FYM. The lowest available phosphorus status (53.48 kg ha<sup>-1</sup>) was recorded due to application of biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

Similarly, at 60 days after sowing application of biochar with FYM significantly influenced the soil available phosphorus status of soil, but its content declined. Among the different treatments, the treatment T<sub>7</sub> recorded high available phosphorus (60.97 kg ha<sup>-1</sup>) due to application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, followed by treatment T<sub>4</sub> which recorded 57.97 kg ha<sup>-1</sup> which containing biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM and treatment (T<sub>8</sub>) received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM (57.77 kg ha<sup>-1</sup>), compare to control treatment (T<sub>1</sub>) recorded 53.90 kg ha<sup>-1</sup> supplied with 100 per cent RDF + 100 per cent FYM. The lowest available phosphorus was recorded (50.30 kg ha<sup>-1</sup>) due to application of biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

**Table 9: Effect of biochar levels on available phosphorus status of soil at different growth stages of crop**

Treatments	Available P <sub>2</sub> O <sub>5</sub> ( kg ha <sup>-1</sup> )		
	30 DAS	60 DAS	HARVEST
T <sub>1</sub> : Control (RDF)+ RD-FYM	62.90	53.90	50.93
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	53.48	50.30	47.95
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	56.93	56.60	50.84
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	60.80	57.97	53.05
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	59.08	54.11	49.97
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	57.81	50.93	48.73
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	64.60	60.97	55.18
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	61.70	57.77	53.23
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	58.32	53.14	49.15
SE.m±	1.27	1.17	1.08
CD(0.05)	3.82	3.51	3.24

Note: RDF-Recommended dose of fertilizer  
RD-FYM: Recommended dose of FYM

At harvest high available phosphorus status ( $55.18 \text{ kg ha}^{-1}$ ) in soil was noticed due to application of biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM ( $T_7$ ) which differ significantly compare to control treatment ( $T_1$ ) which received 100 per cent RDF + 100 per cent FYM and showed  $50.93 \text{ kg ha}^{-1}$  but found on par with treatment  $T_8$  which received biochar @  $4 \text{ t ha}^{-1}$  + 75 per cent FYM and recorded to the tune of  $53.23 \text{ kg ha}^{-1}$ . The application of biochar @  $2 \text{ t ha}^{-1}$  + 100 per cent FYM ( $T_4$ ) recorded  $53.05 \text{ kg ha}^{-1}$ . Among the treatments, the lower available phosphorus ( $47.95 \text{ kg ha}^{-1}$ ) in soil was recorded in  $T_2$  which received only biochar @  $2 \text{ t ha}^{-1}$ .

#### **4.8 Effect of biochar levels on available potassium status of soil at different growth stages of maize**

The data (Table 10) clearly explained that, the available K status of soil significantly varied at all the growth stages due to due to the effect of levels of biochar and FYM and their combinations.

At 30 days after sowing available potassium status of soil significantly higher in the treatment which received biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM which showed  $294.92 \text{ kg ha}^{-1}$ , compare to control ( $T_1$ ) which recorded  $266.78 \text{ kg ha}^{-1}$  due to the application of 100 per cent RDF + 100 % RD FYM and found on par with treatment ( $T_8$ ) which recorded  $282.30 \text{ kg ha}^{-1}$  with the application of biochar @  $4 \text{ t ha}^{-1}$  + 75 per cent FYM and treatment  $T_4$  which received biochar @  $2 \text{ t ha}^{-1}$  + 100 per cent FYM recorded  $278.67 \text{ kg ha}^{-1}$ . Lowest available potassium ( $247.00 \text{ kg ha}^{-1}$ ) was recorded in  $T_2$  which received biochar @  $2 \text{ t ha}^{-1}$ .

Similarly at 60 days after sowing the highest available potassium status ( $266.78 \text{ kg ha}^{-1}$ ) was recorded due to application of biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent RDF but found on par with the treatment ( $T_8$ ) which received biochar @  $4 \text{ t ha}^{-1}$  + 75 per cent FYM and registered  $254.19 \text{ kg ha}^{-1}$  and treatment  $T_4$  recorded  $252.46 \text{ kg ha}^{-1}$  supplied with biochar @  $2 \text{ t ha}^{-1}$  + 100 per cent FYM, compare to control treatment ( $T_1$ ) which received 100 per cent RDF + 100 per cent FYM which recorded  $247.90 \text{ kg ha}^{-1}$ . Low available potassium ( $221.42 \text{ kg ha}^{-1}$ ) in soil was recorded due to application of biochar @  $2 \text{ t ha}^{-1}$ .

At harvest of maize the results (Table 10) revealed that application of biochar @  $4 \text{ t ha}^{-1}$  + 100 per cent FYM ( $T_7$ ) recorded significantly higher ( $253.33 \text{ kg ha}^{-1}$ ) available potassium and was on par with treatment ( $T_4$ ) received biochar @  $2 \text{ t ha}^{-1}$  + 100 per cent FYM, which recorded  $247.18 \text{ kg ha}^{-1}$  and  $T_8$  which received biochar @  $4 \text{ t ha}^{-1}$  + 75 per cent FYM and recorded  $241.34 \text{ kg ha}^{-1}$  of potassium, compare to control treatment ( $T_1$ ) recorded  $233.63 \text{ kg ha}^{-1}$  due to application 100 per cent RDF + 100 per cent FYM. Lower potassium status ( $219.00 \text{ kg ha}^{-1}$ ) was obtained due to application of biochar @  $2 \text{ t ha}^{-1}$  ( $T_2$ ).

**Table 10: Effect of biochar levels on available potassium status of soil at different growth stages of maize crop**

Treatments	Available K <sub>2</sub> O ( kg ha <sup>-1</sup> )		
	30 DAS	60 DAS	HARVEST
T <sub>1</sub> : Control (RDF)+ RD-FYM	266.78	247.90	233.63
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	247.00	221.42	219.00
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	251.67	228.05	227.33
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	278.67	252.46	247.18
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	266.63	246.98	237.00
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	260.40	240.94	231.87
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	294.92	266.78	253.33
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	282.30	254.19	241.34
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	264.70	243.47	238.33
SE.m±	5.75	4.93	4.63
CD(0.05)	17.25	14.79	13.89

Note: RDF-Recommended dose of fertilizer  
RD-FYM: Recommended dose of FYM

#### **4.9 Effect of biochar levels on growth parameters of maize.**

Average data of five plants per plot and three replications data pertaining to growth parameters of maize *viz.*, plant height and number of leaves of maize as influenced by levels of biochar and FYM at different growth stages are presented in Table 11.

The data revealed that at a given level of biochar (2 and 4 t ha<sup>-1</sup>) with reduced dose of FYM decrease in plant height and number of leaves were noticed. Further, combined and higher levels of biochar and FYM registered significantly increase plant growth parameters like plant height and number of leaves at different growth stages of maize compare to control treatment and application of biochar alone.

##### 4.9.1 Plant height

Plant height of maize increased progressively at all the growth stages with increased levels of biochar and FYM.

At 30 days after sowing combined application of levels of biochar and FYM significantly increased the plant height (Table 11) compare to control (100 % RDF + 100 % RD FYM). Significantly higher plant height (46.67 cm) was recorded due to application of biochar @ 4 t ha<sup>-1</sup> + 100 % RD FYM (T<sub>7</sub>) compare to biochar alone (T<sub>2</sub> and T<sub>3</sub>) and control (T<sub>1</sub>), but it found to be on par with the treatment received biochar 4 t ha<sup>-1</sup> + 75 per cent FYM (T<sub>8</sub>) which recorded 45.77 cm and T<sub>4</sub> which received 2 t ha<sup>-1</sup> biochar + 100 per cent FYM recorded 44.97 cm. Significantly lower plant height of 36.17 cm was recorded due to application of biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

Similarly, significant increase in plant height was noticed at 60 days after sowing due to biochar and FYM application. However, the treatment received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded significantly higher plant height (154.00 cm) but found on par with biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM (T<sub>8</sub>) application which recorded 149.10 cm and treatment (T<sub>4</sub>) with application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM recorded 147.20 cm, compare to control (T<sub>1</sub>) treatment which received 100 per cent RDF + 100 per cent FYM (140.39 cm). Significantly lower plant height was recorded in the treatment T<sub>2</sub> (biochar @ 2 t ha<sup>-1</sup>) and T<sub>3</sub> (biochar @ 4 t ha<sup>-1</sup>) which recorded 108.45 and 114.01 cm, respectively.

At 90 days after sowing application of levels of biochar and FYM significantly influenced the plant height over control. Significantly higher plant height (179.48 cm) was recorded in the treatment which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) and it was on par with the treatment (T<sub>8</sub>) recorded 173.37 cm supplied with biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and treatment (T<sub>4</sub>) received biochar @ 2 t ha<sup>-1</sup>

**Table 11: Effect of biochar levels on growth parameters of maize**

Treatments	Plant height (cm)				Number of leaves per plant			
	30 DAYS	60 DAYS	90 DAYS	At harvest	30 DAYS	60 DAYS	90 DAYS	At harvest
T <sub>1</sub> : Control (RDF)+ RD-FYM	43.15	140.39	164.54	167.67	5.65	12.58	12.74	12.45
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	36.17	108.45	133.10	135.20	5.30	10.26	10.54	10.17
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	36.96	114.01	137.84	140.07	5.37	10.48	10.76	10.33
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	44.97	147.20	171.97	176.53	5.93	13.10	13.26	12.77
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	42.00	139.98	162.11	163.90	5.90	12.27	12.62	12.20
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	41.07	130.00	155.17	157.30	5.54	11.79	11.99	11.48
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	46.67	154.00	179.48	182.20	6.12	13.75	13.94	13.56
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	45.77	149.10	173.37	177.03	6.02	13.07	13.40	12.93
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	42.84	138.60	162.51	165.87	5.91	12.32	12.70	12.42
S.Em±	0.91	3.03	4.13	4.67	0.28	0.36	0.38	0.35
CD (0.05)	2.73	9.09	13.39	14.01	NS	1.09	1.14	1.06

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM, NS: Non significant

+100 per cent FYM recorded 171.97 cm compare control treatment (T<sub>1</sub>) received 100 per cent RDF + 100 per cent FYM (164.54 cm). Significantly lower plant height was recorded in treatment T<sub>2</sub> (133.10 cm) and T<sub>4</sub> (137.84 cm) which supplied with biochar @ 2 and 4 t ha<sup>-1</sup>, respectively.

Similarly, at harvest stage among the treatments, the treatment (T<sub>7</sub>) which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM recorded significantly higher plant height of 182.20 cm, but found to on par with treatment T<sub>8</sub> and T<sub>4</sub> which received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and 2 t ha<sup>-1</sup> + 100 per cent FYM and registered 177.03 cm and 176.53 cm, respectively. Application biochar alone at 2 and 4 t ha<sup>-1</sup> recorded significantly lower plant height of 135.20 and 140.07 cm respectively compare to control T<sub>1</sub> (167.67 cm).

#### 4.9.2 Number of leaves

Application of biochar with FYM significantly influenced the number of leaves per plant at different growth stages of maize and data is presented in Table 11.

At 30 days after sowing number of leaves was not significantly influenced by the application of levels of biochar and FYM. However, higher number of leaves (6.12 plant<sup>-1</sup>) was recorded in the treatment T<sub>7</sub> which supplied with biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM compare to other levels of biochar and FYM, control (T<sub>1</sub>) and biochar alone application.

At 60 days after sowing the number of leaves per plant varied significantly due to application of biochar and FYM compare to control (T<sub>1</sub>). Among the treatments significantly higher number of leaves (13.75 plant<sup>-1</sup>) was recorded due to application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) compare to T<sub>2</sub> (10.26), T<sub>3</sub> (10.48) and control treatment T<sub>1</sub> (12.58) but it found on par with the treatment (T<sub>4</sub>) received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM recorded 13.10 and treatment (T<sub>8</sub>) recorded 13.07 number of leaves per plant which supplied with biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM. Significantly lower number of leaves (10.26 per plant) was recorded in T<sub>2</sub> which received biochar 2 t ha<sup>-1</sup>.

Similarly at 90 days after sowing application of biochar with FYM showed significant increase in number of leaves and higher number of leaves especially in the treatment (T<sub>7</sub>) received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (13.94 plant<sup>-1</sup>) but it found on par with treatment (T<sub>8</sub>) received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM which recorded 13.40 and treatment (T<sub>4</sub>) received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM which recorded 13.26 number of leaves per plant, compare to control treatment (T<sub>1</sub>) received 100 per cent RDF + 100 per cent FYM and recorded 12.74 number of leaves per plant. Significantly lower number of leaves (10.54 plant<sup>-1</sup>) was recorded in the treatment (T<sub>2</sub>) received biochar alone @ 2 t ha<sup>-1</sup>.

At harvest highest number of leaves was recorded in the treatment (T<sub>7</sub>) received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM which recorded 13.56 number of leaves per plant, and which found to be on par with the treatment (T<sub>8</sub>) received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM with 12.93 number of leaves per plant and treatment (T<sub>4</sub>) which recorded 12.77 number of leaves per plant due to application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM compare to control treatment (T<sub>1</sub>) which received 100 per cent RDF + 100 per cent of FYM recorded 12.45 number of leaves per plant. Lowest number of leaves (10.17 per plant) was recorded in treatment which received biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

#### **4.10 Effect of biochar levels on yield and yield attributes of maize**

The data pertaining to yield and yield parameters viz., cob length, cob girth, number of grain per cob, test weight, grain and stover yield of maize as influenced by the levels of biochar and FYM are presented in the Table 12.

The data revealed that at a given level of biochar (2 and 4 t ha<sup>-1</sup>) with reduced dose of FYM decrease maize yield and yield parameters were noticed. Further, combined and higher dose of biochar and FYM application registered significantly higher cob length, cob girth, number of grain per cob, test weight, grain and stover yield of maize compare to control treatment and application of biochar alone.

##### **4.10.1 Cob length**

The data pertaining to effect of different levels biochar and FYM on cob length (Table 12) revealed that, application of cob rind biochar in combination with FYM influenced the cob length. Significantly higher cob length (19.33 cm) was recorded due to application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) which found on par with treatment T<sub>8</sub> (biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM) recorded 18.97 cm and treatment T<sub>4</sub> (biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM) which recorded 18.30 cm, compare T<sub>2</sub> (15.30 cm) and T<sub>4</sub> (15.70 cm) which applied with biochar alone @ 2 and 4 t ha<sup>-1</sup> and control treatment (17.72 cm) which received 100 per cent RDF + 100 per cent FYM (T<sub>1</sub>).

##### **4.10.2 Cob girth**

Application of levels of biochar and FYM significantly influenced the cob girth over application of biochar alone and combined application of biochar with lower dose of FYM. Further, among the treatments highest cob girth (14.20 cm) was noticed in the treatment (T<sub>7</sub>) with application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM and it was on par with treatment T<sub>8</sub> which recorded 13.70 cm supplied with biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and treatment T<sub>4</sub> which received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM and recorded 13.50 cm, compare to control treatment T<sub>1</sub> (100 per cent RDF + 100 per cent FYM) which recorded 13.03 cm. The treatment which received biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>) recorded lower cob girth (11.12 cm).

**Table 12: Effect of biochar levels on yield and yield attributes of maize**

Treatments	Cob length (cm)		Cob girth	No of seeds cob <sup>-1</sup>	Test weight (g)	Grain yield (q ha <sup>-1</sup> )	Stover yield
T <sub>1</sub> : Control (RDF)+ RD-FYM	17.72	13.03		458.74	37.60	79.61	97.47
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	15.30	11.12		394.71	35.79	64.20	79.15
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	15.70	11.25		406.38	36.67	66.63	83.97
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	18.30	13.50		470.05	38.00	83.10	99.87
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	17.71	12.91		454.95	37.70	79.06	95.81
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	17.47	12.40		443.80	37.30	73.50	90.83
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	19.33	14.20		494.38	39.09	86.40	104.20
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	18.97	13.70		482.79	38.50	84.08	101.36
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	17.75	13.02		457.44	38.00	79.40	96.90
S.Em±	0.52	0.37		11.70	1.14	2.23	2.14
CD (0.05)	1.56	1.11		35.09	NS	6.69	6.42

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM, NS: Non significant

#### 4.10.3 Number of seeds per cob

Significantly high number of seeds (494.38 per cob) was recorded due to application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>), and which was on par with treatment which received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM (T<sub>8</sub>) and recorded 482.79 seeds per cob and treatment (T<sub>4</sub>) with application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM which recorded 470.05 seeds per cob compare to T<sub>2</sub> (394.71), T<sub>3</sub> (406.38) and control (458.74). Significantly lower number of seeds per cob (394.71) was recorded due to application of biochar alone @ 2 t ha<sup>-1</sup>.

#### 4.10.4 Test weight (weight of 100 seeds)

Test weight of seeds was not significantly influenced by the application of levels of biochar and FYM. However, highest weight (39.09 g) was recorded in the treatment T<sub>7</sub> supplied with biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM compared to other treatments.

#### 4.10.5 Grain yield

The data on grain yield of maize as influenced by the use of different levels of biochar and FYM (Table 12) showed that application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded significantly higher grain yield (86.40 q ha<sup>-1</sup>), which was found to be on par with the treatment T<sub>8</sub> (biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM), which recorded 84.08 q ha<sup>-1</sup> and treatment T<sub>4</sub> (biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM) which recorded 83.10 q ha<sup>-1</sup> compared to biochar alone application @ 2 and 4 t ha<sup>-1</sup> (T<sub>2</sub> and T<sub>3</sub>, respectively) which recorded 64.20 and 66.63 q ha<sup>-1</sup> and control T<sub>1</sub> with 100 per cent RDF + 100 per cent FYM which recorded 79.61 q ha<sup>-1</sup>. Significantly lower grain yield (64.20 q ha<sup>-1</sup>) was recorded in T<sub>2</sub> which received biochar alone @ 2 t ha<sup>-1</sup>.

#### 4.10.6 Stover yield

Application of different levels of biochar in combination with FYM significantly influenced stover yield of maize (Table 12) over application of biochar @ 2 and 4 t ha<sup>-1</sup> (T<sub>2</sub> and T<sub>4</sub>) recorded 79.15 and 83.97 q ha<sup>-1</sup>, respectively. Further, among the treatments, the treatment received higher dose of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded significantly higher stover yield (104.20 q ha<sup>-1</sup>) and found on par with treatment T<sub>8</sub> (biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM) recorded 101.36 q ha<sup>-1</sup> and treatment T<sub>4</sub> received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM which recorded 99.87 q ha<sup>-1</sup>, compare to control (T<sub>1</sub>) which recorded 97.47 q ha<sup>-1</sup> supplied with 100 per cent RDF + 100 per cent FYM. The treatment which received biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>) recorded lower stover yield (79.15 q ha<sup>-1</sup>) of maize.

#### **4.11 Effect of biochar levels on dry matter production at different growth stages of maize**

The data on dry matter production at 30, 60 days after sowing and at the harvest of maize as influenced by biochar and FYM is presented in the Table 13. The data revealed that combined application of biochar and FYM significantly influenced the dry matter production of maize crop over control and alone application of biochar.

The results (Table 13) showed that application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded significantly higher dry matter yield (11.15, 80.09 and 295.00 g plant<sup>-1</sup>) at 30, 60 days after sowing and at the harvest of crop, respectively, but found on par with the treatment T<sub>8</sub> (biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM) which recorded 10.55, 78.18 and 283.67 g plant<sup>-1</sup> at 30, 60 days after sowing and at the harvest of maize, respectively and the treatment T<sub>4</sub> ( biochar @ 2 t ha<sup>-1</sup> + 100 % FYM) which recorded 10.48, 77.76 and 280.00 g plant<sup>-1</sup> at 30, 60 days after sowing and at harvest of the crop, respectively, compare to control which recorded 10.30, 73.40 and 272.00 g plant<sup>-1</sup> which supplied with 100 per cent RDF + 100 per cent FYM (T<sub>1</sub>) at 30, 60 days after sowing and at the harvest of crop, respectively. Lower dry matter production was recorded due to application of biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>) which recorded 9.52, 57.62 and 221.94 g plant<sup>-1</sup> at 30, 60 days after sowing and at harvest of crop, respectively.

#### **4.12 Effect of biochar levels on concentration and uptake of primary nutrients by maize at 60 days after sowing**

Results presented in Table 14 showed the effect of different levels of biochar and FYM on concentration and uptake of primary nutrients by maize plant.

It is realized from the data (Table 14) that increasing trend of nutrient concentration was observed with increasing levels of biochar and FYM. Among the treatments, significantly higher nutrient concentration (1.59, 0.26 and 1.57 % N, P and K, respectively) was recorded due to treatment T<sub>7</sub> supplied with biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, and it was on par with the treatment T<sub>4</sub> (biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM) which recorded 1.57, 0.24 and 1.55 per cent N, P and K respectively and treatment T<sub>8</sub> (biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM) which recorded 1.56, 0.24 and 1.52 per cent of N, P and K content in plant, respectively, compare to control treatment which recorded 1.52, 0.22 and 1.46 per cent N, P and K, respectively, with application of 100 per cent RDF + 100 per cent FYM (T<sub>1</sub>). Significantly lower nutrient concentration (1.37, 0.16 and 1.30 % of N, P and K, respectively) was recorded due to application of biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

**Table 13: Effect of biochar levels on dry matter production at different growth stages of maize**

Treatments	Dry matter (g plant <sup>-1</sup> )		
	30 DAYS	60 DAYS	At harvest
T <sub>1</sub> : Control (RDF)+ RD-FYM	10.30	73.40	272.00
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	9.52	57.62	221.94
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	9.70	60.10	232.00
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	10.48	77.76	280.00
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	10.16	72.43	265.00
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	10.12	67.76	257.67
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	11.15	80.09	295.00
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	10.55	78.18	283.67
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 5 0 % RD-FYM	10.28	72.64	269.33
SE.m±	0.23	2.06	5.71
CD(0.05)	0.69	6.18	17.13

Note: RDF-Recommended dose of fertilizer  
RD-FYM: Recommended dose of FYM

**Table 14: Effect of biochar levels on concentration and uptake of primary nutrients by maize at 60 days after sowing**

Treatments	Concentration (%)			Uptake (kg ha <sup>-1</sup> )		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
T <sub>1</sub> : Control (RDF)+ RD-FYM	1.52	0.22	1.46	82.84	12.21	79.21
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	1.37	0.16	1.30	58.26	6.64	55.65
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	1.40	0.17	1.32	62.30	7.67	58.74
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	1.57	0.24	1.55	90.62	13.54	89.46
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	1.51	0.21	1.47	80.84	11.21	78.87
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	1.48	0.21	1.42	74.46	10.32	71.12
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	1.59	0.26	1.57	94.13	15.37	93.03
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	1.56	0.24	1.52	90.35	13.61	88.27
T <sub>9</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 50 % RD-FYM	1.50	0.21	1.46	80.89	11.50	77.55
S.Em±	0.02	0.01	0.03	2.64	0.74	3.50
CD (0.05)	0.06	0.04	0.09	7.93	2.22	10.50

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM

Similarly, nutrient uptake by maize was also influenced by the application of levels of biochar and FYM which showed significantly higher N, P and K uptake compare to the treatments received their corresponding levels of biochar alone and control treatment. Among the treatments maximum uptake of N, P and K (94.13, 15.37 and 93.03 kg ha<sup>-1</sup>) was noticed in the treatment (T<sub>7</sub>) which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM and was on par with the treatment (T<sub>8</sub>) received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM which recorded 90.35, 13.61 and 88.27 kg ha<sup>-1</sup> N, P and K, respectively and treatment (T<sub>4</sub>) recorded 90.62, 13.54 and 89.46 kg ha<sup>-1</sup> N, P and K, respectively, compare to control treatment (T<sub>1</sub>) recorded 82.84, 12.21 and 79.21 kg ha<sup>-1</sup> N, P and K, respectively. Lower uptake of nutrients was recorded due to application of biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>) recorded 58.26 kg ha<sup>-1</sup> of N, 6.64 kg ha<sup>-1</sup> of P and 55.65 kg ha<sup>-1</sup> of K, respectively.

#### **4.13 Effect of biochar levels on primary nutrients concentration of stover and grain of maize at harvest**

The data pertaining to the effect of biochar on nitrogen, phosphorus and potassium concentration in maize stover and grain as influenced by combined application of biochar and FYM is presented in the Table 15.

##### 4.13.1 Nitrogen concentration in stover and grain

The data (Table 15) revealed that with increasing levels of biochar with FYM increased the nutrient concentration significantly compare to control. Higher nitrogen concentration in stover and grain was registered with the application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded 1.00 and 1.65 per cent of N respectively, which was on par with the treatment (T<sub>4</sub>) received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM which recorded 0.97 and 1.62 per cent of N in stover and grain, respectively, treatment (T<sub>4</sub>) which received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM and recorded 0.97 per cent in stover and 1.63 per cent in grain and treatment (T<sub>5</sub>) received biochar @ 2 t ha<sup>-1</sup> + 75 per cent FYM which recorded 0.95 and 1.59 per cent of N in stover and grain, respectively, compare to control treatment (T<sub>1</sub>) received 100 per cent RDF + 100 per cent FYM which recorded 0.92 and 1.58 per cent of N in stover and grain, respectively. Lower nitrogen concentration was noticed due to application of biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>) recorded 0.78 and 1.45 per cent N in stover and grain, respectively.

##### 4.13.2 Phosphorus concentration in stover and grain

Results presented in the Table 15 indicated application of different levels of biochar in combination with FYM showed significant effect on phosphorus concentration of maize stover and grain.

**Table 15: Effect of biochar levels on primary nutrients concentration of stover and grain of maize at harvest**

Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Stover	Grain	Stover	Grain	Stover	Grain
T <sub>1</sub> : Control (RDF)+ RD-FYM	0.92	1.58	0.18	0.24	1.00	0.44
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	0.78	1.45	0.12	0.14	0.84	0.29
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	0.84	1.50	0.13	0.16	0.89	0.34
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	0.97	1.63	0.21	0.28	1.06	0.47
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	0.95	1.59	0.19	0.25	1.02	0.43
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	0.91	1.57	0.17	0.22	0.96	0.40
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	1.00	1.65	0.22	0.29	1.07	0.49
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	0.97	1.62	0.20	0.27	1.05	0.47
T <sub>9</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 50 % RD-FYM	0.93	1.58	0.19	0.24	0.98	0.44
S.Em±	0.02	0.02	0.01	0.01	0.02	0.01
CD (0.05)	0.06	0.06	0.03	0.04	0.06	0.04

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM

Among the treatments, the treatment T<sub>7</sub> (biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM) registered significantly higher phosphorus concentration (0.22 and 0.29 %) in stover and grain, respectively, but found on par with the treatment T<sub>8</sub> (biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM) which recorded 0.20 and 0.27 per cent of P in stover and grain, respectively and the treatment (T<sub>4</sub>) which recorded 0.21 and 0.28 per cent in stover and grain with the application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM, compared to control treatment T<sub>1</sub> (100 per cent RDF + 100 per cent FYM) recorded 0.18 and 0.24 per cent of P in stover and grain, respectively. Lower P concentration (0.12 and 0.14 %) in stover and grain was recorded in the treatment T<sub>1</sub> which received 100 per cent RDF + 100 per cent FYM.

#### 4.13.3 Potassium concentration in stover and grain

Application of levels of biochar and FYM significantly influenced (Table 15) the potassium content in grain and stover over control treatment. Among the treatments, numerically high K concentration was recorded in the treatment (T<sub>7</sub>) which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM recorded 1.07 and 0.49 per cent of K in stover and grain respectively and was on par with the treatment (T<sub>8</sub>) recorded 1.05 and 0.47 per cent of K concentration in stover and grain, respectively and the treatment with the application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>4</sub>) which recorded 1.06 and 0.47 per cent of K in stover and grain, respectively, compared to control treatment (T<sub>1</sub>) received 100 per cent RDF + 100 per cent FYM and recorded 1.00 and 0.44 per cent of K concentration in stover and grain respectively. Lower K concentration was recorded with the application of biochar @ 2 t ha<sup>-1</sup> which recorded 0.84 and 0.29 per cent in stover and grain, respectively.

### **4.14 Effect of biochar levels on primary nutrients uptake by stover and grain of maize at harvest**

The data pertaining to effect of different levels of biochar and FYM on nitrogen, phosphorus and potassium uptake by maize stover and grain is presented in the Table 16 and the data revealed that combined application of biochar and FYM significantly influenced the nutrient uptake by stover and grain of maize over control treatment.

#### 4.14.1 Nitrogen uptake by stover and grain

The nitrogen uptake by maize stover and grain found to be varied among the treatments (Table 16) due to application of different levels of biochar and FYM.

The nitrogen uptake was recorded significantly higher in stover and grain to the tune of 103.89 and 142.93 kg ha<sup>-1</sup> in the treatment received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>), which was found to be on par with the treatment

**Table 16: Effect of biochar levels on primary nutrients uptake by stover and grain of maize at harvest**

Treatments	Nitrogen (kg ha <sup>-1</sup> )			Phosphorus (kg ha <sup>-1</sup> )			Potassium (kg ha <sup>-1</sup> )		
	Stover	Grain	Total	Stover	Grain	Total	Stover	Grain	Total
	T <sub>1</sub> : Control (RDF)+ RD-FYM	89.95	126.06	216.01	17.73	19.36	37.10	97.85	34.63
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	62.12	92.98	155.10	9.57	9.29	18.86	66.87	18.83	85.71
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	70.69	100.07	170.76	10.97	10.79	21.76	75.08	22.88	97.95
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	97.37	135.58	232.95	20.58	22.91	43.49	105.49	38.71	144.20
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	90.56	125.69	216.25	17.80	19.37	37.16	97.32	34.29	131.60
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	82.96	115.24	198.19	15.47	16.53	32.00	87.23	29.75	116.98
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	103.89	142.93	246.82	22.43	24.62	47.05	111.49	41.91	153.40
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	98.48	136.20	234.67	20.78	22.90	43.68	106.38	39.75	146.13
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	89.76	125.43	215.18	18.09	18.74	36.83	95.35	35.13	130.18
S.Em±	3.61	3.43	6.33	1.14	1.71	2.33	3.73	1.85	5.92
CD (0.05)	10.83	10.29	18.99	3.42	5.13	7.00	11.19	5.55	17.76

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM

T<sub>8</sub> (biochar @ 4 t ha<sup>-1</sup> + 75 % FYM) recorded 98.48 and 136.20 kg of N ha<sup>-1</sup> in stover and grain, respectively and treatment (T<sub>4</sub>) with application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM recorded 97.37 and 135.58 kg of N ha<sup>-1</sup> with respect to stover and grain. The lowest nitrogen uptake was recorded due to application of biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>) which recorded 62.12 and 92.78 kg ha<sup>-1</sup> in stover and grain, respectively.

The total nitrogen uptake by maize crop varied significantly due to different levels of biochar and FYM (Table 16). Higher nitrogen uptake was noticed in T<sub>7</sub> (246.82 kg of N ha<sup>-1</sup>) and lowest uptake was noticed in T<sub>2</sub> (155.10 kg ha<sup>-1</sup>) which received biochar @ 2 t ha<sup>-1</sup>.

#### 4.14.2 Phosphorus uptake in stover and grain

The perusal of the data in Table 16 showed that phosphorus uptake by maize stover and grain differ significantly due to different levels of biochar and FYM application. With increase in levels of biochar and increase in levels of FYM, the phosphorus uptake also increased in maize stover and grain. Significantly higher phosphorus uptake (22.43 and 24.62 kg ha<sup>-1</sup>) by stover and grain was recorded in T<sub>7</sub> where biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM was applied. However, it was found to be on par with treatment (T<sub>8</sub>) which received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM and recorded uptake of 20.78 and 22.90 kg of P ha<sup>-1</sup> in stover and grain, respectively and T<sub>4</sub> recorded (20.58 and 22.91 kg of P ha<sup>-1</sup>) with the application of biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM, compare to control treatment (T<sub>1</sub>) which received 100 per cent RDF + 100 per cent FYM and recorded 17.73 and 19.36 kg of P ha<sup>-1</sup> in stover and grain, respectively. Lower uptake in stover and grain was recorded in T<sub>2</sub> (9.57 and 9.29 kg of P ha<sup>-1</sup>, respectively) which received biochar @ 2 t ha<sup>-1</sup>.

The total uptake of phosphorus in stover and grain significantly differed among treatments with application of levels of biochar and FYM. Among the treatments, the treatment (T<sub>7</sub>) which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM recorded highest (47.05 kg ha<sup>-1</sup>) total P uptake and treatment (T<sub>2</sub>) which received biochar @ 2 t ha<sup>-1</sup> recorded low (18.86 kg ha<sup>-1</sup>) total P uptake by maize.

#### 4.14.3 Potassium uptake in stover and grain

The results showed (Table 16) that significantly higher potassium uptake was noticed in T<sub>7</sub> (111.49 and 41.91 kg ha<sup>-1</sup> in stover and grain, respectively) which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, which was found to be on par with the treatments (T<sub>8</sub>) received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM, which recorded 106.38 and 39.75 kg ha<sup>-1</sup> with respect to stover and grain and the treatment (T<sub>4</sub>) which received biochar @ 2 t ha<sup>-1</sup> + 100 per cent FYM, which recorded 105.49 and 38.71 kg ha<sup>-1</sup> in stover and grain, respectively, compared to control (T<sub>1</sub>) which

recorded and 97.85 and 34.63 kg ha<sup>-1</sup> of K in stover and grain, respectively, which supplied with 100 per cent RDF + 100 per cent FYM. The lowest K uptake was noticed with the application of biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>) and recorded 66.87 and 18.83 kg ha<sup>-1</sup> in stover and grain, respectively.

Application of biochar and FYM influenced the total uptake of K by maize stover and grain. Significantly higher (153.40 kg ha<sup>-1</sup>) total uptake of K was noticed in the treatment T<sub>7</sub> (biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM) and lowest total uptake of K (85.71 kg ha<sup>-1</sup>) was noticed in the treatment which received biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

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## **DISCUSSION**

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## V DISCUSSION

The potentiality of organic sources like biochar is exploited limited extent for improving soil fertility status and getting higher crop production as it is nature of slow rate of decomposition and slow release of plant nutrients. The application of biochar as a source of nutrients will have positive effect when applied with FYM on soil physical and chemical properties which ultimately increases the productivity of crops and soils.

The results of the present investigation entitled “Effect of biochar on soil physical properties, carbon pools and productivity of maize (*Zea mays* L.)” presented in the previous chapter have been discussed here with suitable scientific reasoning under following heads.

5.1 Characterization of biochar and FYM

5.2 Effect of biochar levels on physical properties of soil at different growth stages of maize

5.3 Effect of biochar levels on carbon pools of soil after harvest of maize

5.4 Effect of biochar levels on chemical properties of soil at different growth stages of maize

5.5 Effect of biochar levels on available primary nutrient status of soil at different growth stages of maize

5.6 Effect of biochar levels on growth and yield parameters of maize

5.7 Effect of biochar levels on primary nutrients concentration and uptake by maize

### 5.1 Characterization of biochar and FYM

Biochar used in the present study was derived from maize cob rind which was pyrolysed at 350 to 500 °C temperature using kiln apparatus. The powdered biochar and FYM was characterized for different physical (BD and WHC) and chemical properties. The data showed (Table 3) that, the cob rind biochar showed lower bulk density of 0.57 Mg m<sup>-3</sup>. Similar results were reported by Brewer *et al.* (2014) who estimated the BD of biochars produced from different feedstock ranged from 0.25 to 0.6 g cm<sup>-3</sup>. Biochar derived from cob rind showed high (70.5%) water holding capacity. Lower BD and higher porosity contributed to higher water holding capacity. The chemical analysis of suggested that biochar found to be alkaline in nature with pH 8.03, medium in salt content with an electrical conductivity of 1.22 dS m<sup>-1</sup>. It might be due to presence of ash residue that is dominated by carbonates of alkali and alkaline earth metals Rumi, (2015) reported that maize stover biochar was found to have higher EC, followed by coir waste biochar. Similar results were reported by

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Wan *et al.* (2014) and Rondon *et al.* (2007). The total carbon, nitrogen, phosphorus and potassium were found to be higher with 74.08, 0.56, 0.05 and 1.02 per cent, respectively. The higher N content (0.56 %) observed in the biochar might be attributed to the optimum heat maintained during pyrolysis. It also recorded good amount of calcium, magnesium and sulphur and the values were 0.60, 0.41 and 0.12 per cent, respectively (Lehman, 2009). The composition of iron, manganese, zinc and copper (121.50, 32.30, 16.40 and 2.90 mg kg<sup>-1</sup>, respectively) found to be in appreciable amounts in biochar. Similar results also reported by Wang *et al.* (2013). Lua and Yang, (2004) reported that the variability in physical and chemical properties of biochar depends on the material used to produce biochar, the oxygen supply and the temperature achieved during pyrolysis.

The initial composition of FYM also showed that, it has recorded lower BD value and low WHC compared to biochar. The pH of FYM found to be neutral (7.2), lower EC value and low in N, P and K content. The total carbon, total inorganic and total organic carbon recorded lower than biochar (Sharif *et al.*, 2015)

## **5.2 Effect of biochar levels on physical properties of soil at different growth stages of maize**

Application of biochar reduced the bulk density of soil but not significantly but it has significantly influenced in increase in porosity and water holding capacity of soil (Table 4) at 60 days after sowing and at the harvest of maize. Among the treatments, the T<sub>7</sub> which receiving biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM has recorded lower BD value (1.29 and 1.28 Mg m<sup>-3</sup>), significantly higher porosity (32.61 and 32.93 %) and water holding capacity (36.86 and 37.41 %) at 60 days after sowing and at harvest of crop over rest of the treatments. This may be attributed to increased organic carbon content of soil which might have contributed from biochar and FYM. The FYM and biochar act as cementing materials in forming soil aggregates and moreover the porous structure of biochar might have influenced on increase in soil porosity, water holding capacity and adsorption capacity of soil. Prasanna (2012) reported decreased bulk density and increased water holding capacity with the application of biochar and FYM. Hesu *et al.* (2014) also reported that application of biochar increased porosity of soil by 16 to 22 per cent (Njoku *et al.*, 2015). Lowest porosity and water holding capacity in soil was recorded in the treatment T<sub>2</sub> which received biochar alone @ 2 t ha<sup>-1</sup>.

## **5.3 Effect of biochar levels on carbon pools of soil after harvest of maize**

A perusal of the data presented in the Table 5 and 6 revealed that application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded higher labile organic carbon pools such as, potassium dichromate oxidizable carbon, potassium permanganate

oxidizable carbon, microbial biomass carbon and total carbon status such as total carbon, total organic carbon except cold water extractable carbon and total inorganic carbon compared to other treatments.

Combined application of biochar and FYM influenced per cent increase in soil organic carbon (Fig 2) compare to alone application of biochar and FYM. Highest percent increase (33.45 %) was noticed in the treatment which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>). This may be due to the increased levels of biochar and FYM increased the carbon status in the soil. The highest values in biochar and FYM treated soils indicated the recalcitrance of organic carbon in biochar and easily mineralizable carbon compound present in the FYM and native soil organic matter content that were preferentially mineralized by microbes in tern contributed to labile organic carbon pools of soil. Increased C/N ratio of biochar showed slow mineralization of biochar which contributed to sequestration of carbon in soil. The use of biochar could allow the total soil organic carbon (SOC) sequestered in soils to be several magnitudes larger than is naturally possible. The lowest value was recorded in treatment T<sub>2</sub> which received biochar alone @ 2 t ha<sup>-1</sup> alone.

High organic carbon in soils with the application of biochar has been reported by Lehmann (2007a). Demise *et al.* (2014) showed that biochar had less lability but more accumulation of organic carbon which could contributed to sequestration of carbon in soil. In addition it is a store house of carbon of its own. Biochar would enhance the intrinsic soil organic carbon storage of soil, by affecting the turnover of indigenous carbon (Wardle *et al.*, 2008; Jerry and Leenheer, 2009). Application of cattle manure or biochar and combined manure-biochar levels has increased carbon mineralization by 45 to 125 per cent reported by Daniel *et al.* (2018).

#### **5.4 Effect of biochar levels on chemical properties of soil at different growth stages of maize**

##### **5.4.1 Soil pH**

There was no significant change was observed in soil reaction at 30, 60 days after sowing and at harvest of maize among the treatments due to application of biochar (Table 7). However remarkable increase in soil pH was observed due to combined application of biochar and FYM. Higher soil pH at 30, 60 DAS and at harvest of crop was recorded in T<sub>9</sub> (biochar @ 4 t ha<sup>-1</sup> + 50 % FYM). The increase in soil pH might be due to high content of calcium carbonates present in ashes and release of basic cations of biochar and more over it is alkali nature (Chintala *et al.*, 2014). Many researchers had reported a rise in pH by the application of biochar (Rajesh *et al.*, 2014; Hass *et al.*, 2012; Rodriguez *et al.*, 2009). Low soil pH was

recorded in control treatment with the application of 100 per cent RDF + 100 per cent FYM.

#### 5.4.2 Electrical conductivity

Application of different levels of biochar had significantly influenced the electrical conductivity (Table 7) of soil. The biochar in combination with FYM showed significant differences among treatments at different days after sowing. However the treatment (T<sub>9</sub>) received biochar @ 4 t ha<sup>-1</sup> + 50 per cent FYM recorded the maximum electrical conductivity at 30, 60 days after sowing and at harvest of maize and minimum values was observed in the control treatment. Increase in EC in biochar amended treatments were recorded with increasing crop period in present investigation may be attributed to the salt concentration and exchangeable cations in biochar which can increase the EC in treated plot compared to untreated plot. Significant Increase in EC with biochar application was often reported in literature (Glaser *et al.*, 2002; Gundale and DeLuca, 2007; Chan *et al.*, 2008 and Chintala *et al.*, 2014).

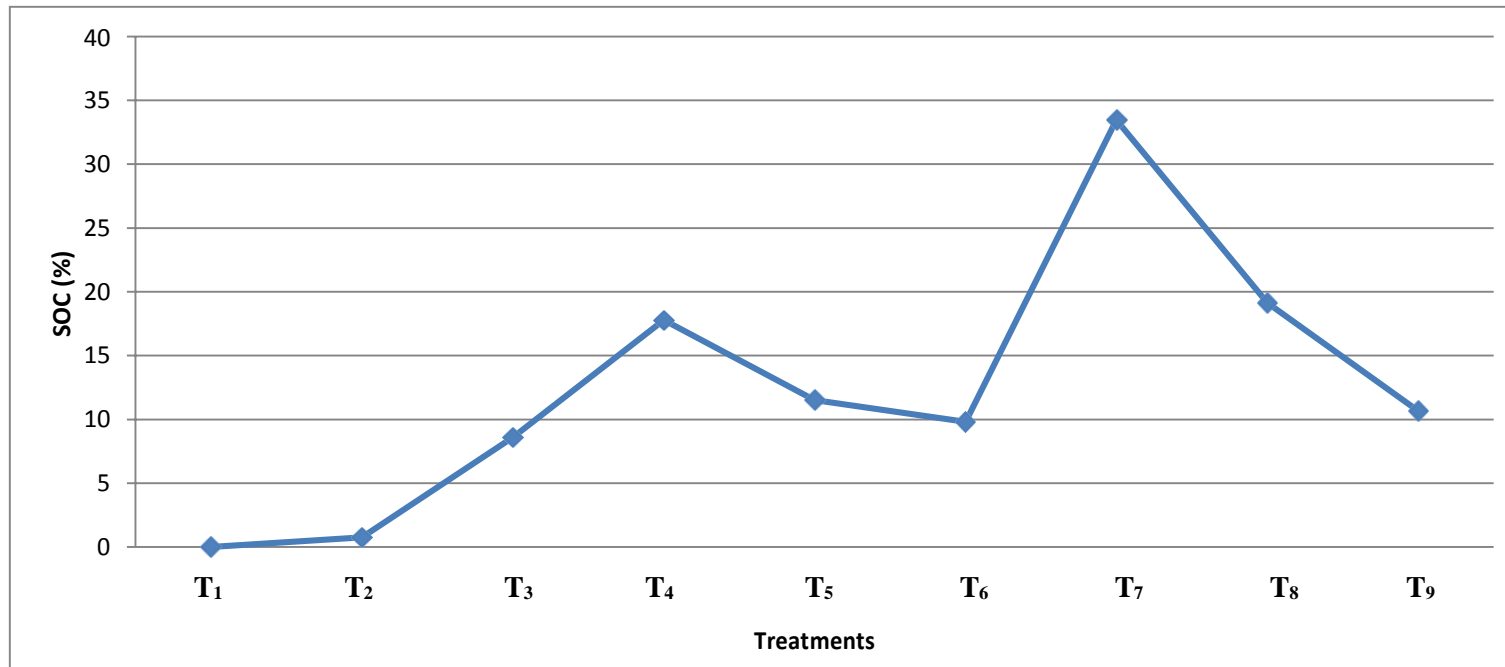
### **5.5 Effect of biochar levels on available primary nutrient status of soil at different growth stages of maize**

#### 5.5.1 Available nitrogen

In the present investigation application of various levels of biochar and FYM varied soil available nitrogen content at different growth stages of maize (Table 8). Higher soil available nitrogen (395.00, 346.97 and 316.10 kg ha<sup>-1</sup> at 30, 60 days after sowing and at harvest of crop, respectively) was recorded due to the application of higher dose biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>). The increase in available nitrogen status of soil may be due to addition of biochar alters the N dynamics in soil (Lehmann, 2007). Decreased loss of N<sub>2</sub>O-N through emissions had little influence on nitrogen retention which improved total nitrogen in soil (Feng *et al.*, 2017). The slow release of N from biochar resulted in increased availability of N and less loss of nitrogen (Chan and Xu, 2009; Steiner *et al.*, 2008). It might also due to N immobilization and decreased loss of N by leaching in the presence of recalcitrant biochar materials (Rondon *et al.*, 2007). Lower available nitrogen was recorded in the treatment which received biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>).

#### 5.5.2 Available phosphorus

Perusal of the data presented in the Table 9 revealed that biochar and their interaction in soil showed significant effect on soil available P<sub>2</sub>O<sub>5</sub> status at different crop growth stages. Among the treatments T<sub>7</sub> (biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM) showed high available P<sub>2</sub>O<sub>5</sub> (64.60, 60.97 and 55.18 kg ha<sup>-1</sup> at 30, 60 days after



**Fig 2. Percent increase of soil organic carbon as influenced by different levels of biochar and FYM**

T<sub>1</sub>: Control (RDF) + RD-FYM

T<sub>2</sub>: Cob rind biochar @ 2t ha<sup>-1</sup>

T<sub>3</sub>: Cob rind biochar @ 4t ha<sup>-1</sup>

T<sub>4</sub>: Cob rind biochar @ 2t ha<sup>-1</sup> + 100% RD-FYM

T<sub>5</sub>: Cob rind biochar @ 2t ha<sup>-1</sup> + 75% RD-FYM

Note: SOC- Soil organic carbon

T<sub>6</sub>: Cob rind biochar @ 2t ha<sup>-1</sup> + 50% RD-FYM

T<sub>7</sub>: Cob rind biochar @ 4t ha<sup>-1</sup> + 100% RD-FYM

T<sub>8</sub>: Cob rind biochar @ 4t ha<sup>-1</sup> + 75% RD-FYM

T<sub>9</sub>: Cob rind biochar @4t ha<sup>-1</sup> + 50% RD-FYM

sowing and at harvest of crop, respectively) in soil, followed by application of biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM (T<sub>8</sub>). Application of higher dose of biochar along with FYM increased the available P<sub>2</sub>O<sub>5</sub> in soil. The possible mechanisms for increased P<sub>2</sub>O<sub>5</sub> availability with the application of biochar in soil due to, biochar acts as a modifier of soil pH and ameliorator of P complexing metals (Al<sup>3+</sup>, Fe<sup>3+</sup>) and promoter of microbial activity. Uzoma *et al.* (2011) conducted an experiment on maize by application of cow manure biochar and reported that increase in P availability as a result of increase in soil pH. Also due to high porous nature of biochar which provides favorable environment for mycorrhizal fungi, which make unavailable P to available P to plant by secretion of P-solubilizing organic acid (Gul and Whalen, 2016). Arif *et al.* (2018) reported that application of biochar with FYM and nitrogen fertilizer increased the phosphorus status of soil.

### 5.5.3 Available potassium

Effect of biochar and FYM application on available K content of soil at different stages of maize is presented in the Table 10. High available potassium (294.92, 266.78 and 253.33 kg ha<sup>-1</sup> at 30, 60 days after sowing and at harvest of crop, respectively) in soil was recorded in T<sub>7</sub> with the application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, followed by T<sub>8</sub> (biochar 4 t ha<sup>-1</sup> + 75 % FYM) and the lowest value was recorded in T<sub>2</sub> (biochar @ 2 t ha<sup>-1</sup>). This increase was due to the high concentration of potassium found in the biochar (Chan *et al.*, 2007). The immediate beneficial effects of biochar additions on nutrient availability are largely due to higher potassium (Lehmann *et al.*, 2003a). The ash content of biochar itself has more amount of potassium content compared to other major nutrients, so addition of ash rich biochar to soil increased the K content of soil. Application of biochar increased the pH of soil which intern react on strongly attached K on soil clay particles and released into the soil solution (Smider and Singh, 2014; Manolikaki and Diamadopoulos, 2016).

## **5.6 Effect of biochar levels on growth and yield parameters of maize**

### 5.6.1 Growth parameters of maize

Application of biochar increased plant height with increase in crop period. The soil application of biochar in combination with FYM showed increase in plant height at different days after sowing. The data pertaining to plant height presented in the Table 11 revealed that significantly higher plant height was recorded in the treatment (T<sub>7</sub>) received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, whereas the lowest values were recorded in the treatment receiving 2 t ha<sup>-1</sup> of biochar (T<sub>2</sub>).

Similarly application of biochar increased the number of leaves at different days after sowing except at 30 days after sowing. The highest number of leaves were

recorded in T<sub>7</sub> (biochar 4 t ha<sup>-1</sup> + 100 % FYM) and lowest number of leaves were recorded in treatment (T<sub>2</sub>) received biochar @ 2 t ha<sup>-1</sup>.

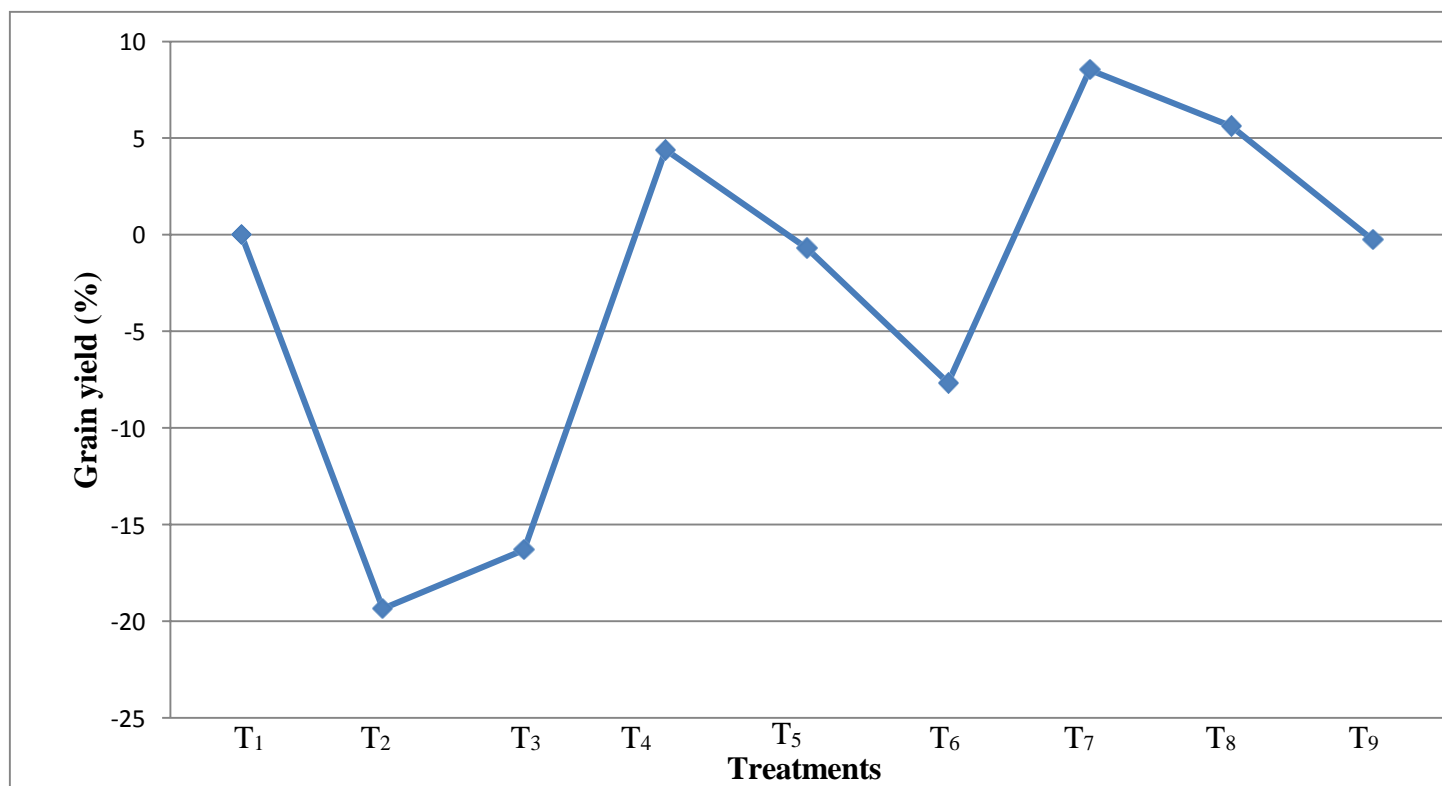
Similarly increase in dry matter production (Table 13) was observed with the application of biochar and FYM compared to alone application of biochar. The high dry matter production was recorded in T<sub>7</sub> with the application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, but T<sub>2</sub> received only biochar @ 2 t ha<sup>-1</sup> recorded low dry matter production at different stages of crop. This may be due to the fact that biochar had a higher chemical composition to supply almost all the nutrients to crops. Kalyani *et al.* (2016) also reported increased plant height and number of leaves of bean, fenugreek, and mint with biochar in the combination of organic manure than biochar alone or compost alone. Also fact that decrease in soluble Al and Fe, rise in pH, balanced and slow release of nutrients, increased plant available water content and improved microbial activity would have contributed for improvement of growth parameters of plant in biochar and FYM treated plots over alone application of biochar. Similar results were also observed by Chan *et al.* (2008) in radish and Blackwell *et al.* (2010) in wheat in an initially nutrient poor and acidic Australian ferrosol.

#### 5.6.2 Yield parameters and dry matter production of maize

Yield is largely depends upon the production and mobilization of carbohydrates, uptake of water and nutrient from soil. It is a complex character which involves several environmental factor during growth period and several interaction between internal and external factor.

Application of levels of biochar with levels of FYM showed increase (Table 12) in grain yield, stover yield and yield parameters like cob length, cob girth, number of seeds per cob except test weight of maize. Among the treatments, the application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded higher cob length (19.33 cm), cob girth (14.20 cm), number of seeds per cob (494.38), grain yield (86.40 q ha<sup>-1</sup>), and stover yield (104.20 q ha<sup>-1</sup>), whereas T<sub>2</sub> with biochar alone recorded lower cob length, cob girth, number of seeds per cob, grain yield and stover yield. Also percent increase in grain yield to an extent of 8.52 per cent (Figure 3) was recorded with application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) compare to control.

Similarly increase in dry matter production (Table 13) was observed with the application of biochar and FYM compared to alone application of biochar. The high dry matter production was recorded in T<sub>7</sub> with the application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, but T<sub>2</sub> received only biochar @ 2 t ha<sup>-1</sup> recorded low dry matter production at different stages of crop. This might be due to addition of



**Fig 3. Percent increase in grain yield as influenced by different levels of biochar and FYM**

T<sub>1</sub>: Control (RDF) + RD-FYM

T<sub>2</sub>: Cob rind biochar @ 2t ha<sup>-1</sup>

T<sub>3</sub>: Cob rind biochar @ 4t ha<sup>-1</sup>

T<sub>4</sub>: Cob rind biochar @ 2t ha<sup>-1</sup> + 100% RD-FYM

T<sub>5</sub>: Cob rind biochar @ 2t ha<sup>-1</sup> + 75% RD-FYM

T<sub>6</sub>: Cob rind biochar @ 2t ha<sup>-1</sup> + 50% RD-FYM

T<sub>7</sub>: Cob rind biochar @ 4t ha<sup>-1</sup> + 100% RD-FYM

T<sub>8</sub>: Cob rind biochar @ 4t ha<sup>-1</sup> + 75% RD-FYM

T<sub>9</sub>: Cob rind biochar @ 4t ha<sup>-1</sup> + 50% RD-FYM

nutrients through combination of biochar, FYM and inorganic fertilizers resulted in higher grain and stover yield. It may also attributed to better uptake of essential nutrients because of improvement in physical and chemical properties of soil which favored the more availability of nutrients thereby increased the nutrients uptake and its translocation to economic parts which resulted in improvement in yield attributing characters like cob length, cob girth, number of seeds per cob and dry matter of plant. Masto *et al.* (2013) reported significant increase in maize grain yield with the application of biochar 4 t ha<sup>-1</sup>. Alie *et al.* (2014) also reported that increase in plant height, stem girth, fresh and dry shoot weight of maize and rice plants with the addition of biochar. Party *et al.* (2014) reported that increase in maize yield with combined application of green manure and biochar. Kalyani *et al.* (2016) reported increased yield of the bean, fenugreek and mint with biochar in the combination of organic manure than biochar alone or compost alone, the results were also agreement with Naeem *et al.* (2017) who reported that maize yield significantly increased by the application of biochar + compost + RDF compared with control and other treatments. Similar results were also observed by Gokila and Basker (2017), Coumaravel *et al.* (2015), Imran *et al.* (2014), Cornelissen *et al.* (2013) in maize crop.

## **5.7 Effect of biochar levels on primary nutrient concentration and uptake by maize**

### **5.7.1 Nitrogen concentration and uptake**

Application of biochar and FYM influenced the nitrogen concentration and uptake at 60 days after sowing in plant (Table 14), in stover and grain (Table 15-16) of maize. The highest N concentration in stover and grain at 60 days after sowing, was recorded in the treatment receiving biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM. The same trend was also observed in the case of N uptake (kg ha<sup>-1</sup>) of plant sample collected at 60 days after sowing, in stover and grain. The lowest N concentration and uptake was recorded in the treatment received biochar alone @ 2 t ha<sup>-1</sup> (T<sub>2</sub>). The increase in N concentration and uptake in biochar and FYM treated plots might be due to decrease in N loss and slow release pattern of N synchrony with the demand of maize crop thereby increased the tissue content of N. Lehmann *et al.* (2003) reported that, increase in N uptake in plants with the application of biochar. The increase in nitrogen concentration by the addition of biochar was also suggested by Glaser *et al.* (2002) and Lehmann *et al.* (2003a). The increase in N uptake in plants with the addition of biochar was also observed by Zwieten *et al.* (2010) similar findings were noticed by Chan *et al.* (2007) who reported high N uptake by radish plants grown in soil amended by biochar.

### 5.7.2 Phosphorus concentration and uptake

Increased levels of biochar and FYM application increased P concentration and uptake in plant sample collected at 60 days after sowing (Table 14), in stover and grain (Table 15-16). Treatment (T<sub>7</sub>) with application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM recorded higher P concentration and uptake and lower value was recorded in the treatment received biochar @ 2 t ha<sup>-1</sup> (T<sub>2</sub>). The higher P concentration and uptake may be due to more P availability to crop through addition of biochar and FYM also due to improved physical and chemical properties of soil resulted in high P uptake. Aziz *et al.* (2006) reported that the increased P availability may also be due to healthy root growth by decreased Al toxicity which cause damage to roots. Chng *et al.* (2016) also reported an increase in P concentration and uptake by the application of biochar and vermicompost. Similarly, Uzoma *et al.* (2011) and Yamato *et al.* (2006) reported an increase in plant available P in soil with the addition of biochar.

### 5.7.3 Potassium concentration and uptake

The data on K concentration and uptake showed that application of biochar with FYM increased the K concentration and uptake in plant sample collected at 60 days after sowing (Table 14), in stover and grain of maize (Table 15-16). The lowest and highest concentration and uptake was recorded in T<sub>2</sub> (biochar 2 t ha<sup>-1</sup>) and T<sub>7</sub> (biochar @ 4 t ha<sup>-1</sup> + 100 % FYM) treatments, respectively. The increase in concentration and uptake of K may be due to the ash content of biochar helps for immediate release of occluded mineral nutrients like K for crop use. Most of nutrient (N and K) uptake will increase due to increased water availability as influenced by biochar. Moreover, biochar has the capacity to increase the CEC of soil, thereby the ability of soil increased to hold K and make it available for plant uptake. The K availability increased as the soil pH increased by the application of biochar (Manolikaki and Diamadopoulos, 2016), Rondon *et al.* (2007) also reported increased K uptake by plant biomass in common bean. Similarly, the K concentration in maize grains increased by the application of cow manure biochar (Uzoma *et al.*, 2011).

Higher nutrient concentration of maize in biochar and FYM treated soil might be due to improvement in physical and chemical properties of soil, increased availability of nutrients thereby increased the nutrients uptake. Also due to fact that added FYM and biochar acts as store house of several macro and micronutrients and were released during slow mineralization process (Appendix-II). In addition to release of plant nutrients from organic matter, the organic acids released in the decomposition process also release the native nutrients in soil and increased the availability to plants. Similar results were reported by Lehmann *et al.* (2003).

## **Conclusion**

Present investigation clearly suggested that, compared to biochar alone application and RDF of crop only, the combined use biochar and FYM at higher dose has shown significant effect on improvement of physical and chemical properties of acid soil there by soil fertility and productivity has increased. The biochar also proved its potentiality in achieving higher performance of maize crop in terms of growth and yield without any adverse effect. The soil carbon and its pools is an index of soil fertility that could be increased by the addition of carbon rich biochar to soil.

## **Future line of work**

- Need to conduct long term investigations to study the effect of biochar on improvement of soil properties as degradability of biochar is less.
- Need to conduct field experiment on biochar use along with microbial consortia for best mineralization and utilization.
- Need to assess the performance of biochar in mitigating soil chemical stress like Fe, Mn and Al toxicity in acidic soil.

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**SUMMERY**

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## VI SUMMARY

The present investigation on “Effect of biochar on soil physical properties, carbon pools and productivity of maize (*Zea mays* L.)” was carried out during *kharif* season of 2018 at Agricultural and Horticultural Research Station, Bavikere, UAHS, Shivamogga. The results of the investigation are summarized and presented in this chapter.

Representative biochar sample prepared from maize cob rind through pyrolysis process was ground to pass through 2 mm sieve and analysed for different physical and chemical properties.

The biochar has high water holding capacity of 70.5 per cent and low bulk density value of 0.57 Mg m<sup>-3</sup>. The chemical composition indicated that biochar was alkaline in nature (pH 8.03) with lower electrical conductivity of 1.22 dS m<sup>-1</sup> and the total carbon content was 74.08 g kg<sup>-1</sup>. The nitrogen, phosphorus and potassium were found to be 0.56, 0.05 and 1.02 per cent, respectively. It also had good amount of calcium, magnesium and sulphur (0.60, 0.41 and 0.12 per cent, respectively). Biochar also had appreciable quantities of iron, manganese, zinc and copper (121.50, 32.30, 16.40, and 2.90 mg kg<sup>-1</sup>, respectively).

The physical properties of soil *viz.*, water holding capacity and porosity were significantly influenced by application of biochar except bulk density of soil, which showed remarkable decrease with addition of biochar at 60 days after sowing and at the harvest stage of maize. The treatment which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded higher water holding capacity and porosity over rest of the treatments. The treatment received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded lower bulk density.

Combined application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded higher potassium permanganate oxidizable carbon, potassium dichromate oxidizable carbon, microbial biomass carbon, cold water extractable carbon and carbon stocks like total organic carbon, total inorganic carbon and total carbon followed by treatment (T<sub>8</sub>) received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM. The lowest value was recorded in treatment T<sub>2</sub> which received biochar @ 2 t ha<sup>-1</sup>.

Chemical properties of soil differed among the treatments due to application of levels of biochar and FYM. There was no significant change in soil reaction and significant change in electrical conductivity was observed in biochar and FYM treated plots at 30, 60 days after sowing and at harvest stage of maize. In this present investigation higher soil pH and EC was recorded in treatment T<sub>9</sub> which received

biochar @ 4 t ha<sup>-1</sup> + 50 per cent FYM. The lowest pH and EC was recorded in treatment T<sub>1</sub> which received 100 per cent RDF + 100 per cent FYM.

Available nitrogen, phosphorus and potassium content of soil varied due to application of various levels of biochar and FYM at different days after sowing. Application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) resulted significantly high available nitrogen, phosphorus and potassium, followed by T<sub>8</sub> received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM. The lowest was recorded in treatment T<sub>2</sub> which received biochar @ 2 t ha<sup>-1</sup>.

Application of biochar and FYM in combination significantly influenced plant height, number of leaves at different days after sowing and recorded significantly higher in the treatment received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) followed by T<sub>8</sub> received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM. The treatment received biochar @ 2 t ha<sup>-1</sup> recorded lower value.

Cob length, cob girth, number of seeds per cob, grain yield, stover yield and dry matter production was recorded significantly higher value in (T<sub>7</sub>) where biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM. The lowest value was recorded in treatment where biochar @ 2 t ha<sup>-1</sup> applied alone (T<sub>2</sub>). This data clearly shows that application of biochar combination with FYM significantly increase the grain and stover yield of maize compared to application of biochar.

Significantly higher nitrogen, phosphorus and potassium concentration and uptake in maize plant at 60 days after sowing in plant sample was recorded in T<sub>7</sub> treatment which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, followed by treatment which received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM. The lowest value was recorded in T<sub>2</sub> received biochar 2 t ha<sup>-1</sup>.

Application of biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM (T<sub>7</sub>) recorded significantly higher nitrogen, phosphorus and potassium concentration in stover and grain of maize, respectively followed by T<sub>8</sub> received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM. The low concentration of nitrogen, phosphorus and potassium in stover and grain was recorded in T<sub>2</sub> received biochar @ 2 t ha<sup>-1</sup>.

Higher uptake of nitrogen, phosphorus and potassium by maize stover and grain was observed in the treatment T<sub>7</sub> which received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM, followed by T<sub>8</sub> which received biochar @ 4 t ha<sup>-1</sup> + 75 per cent FYM. This increased uptake of N, P and K might be due to high stover and grain yield (T<sub>7</sub>).

Significantly higher total uptake of N, P and K by maize was recorded in the treatment (T<sub>7</sub>) received biochar @ 4 t ha<sup>-1</sup> + 100 per cent FYM and lower uptake of these nutrients was recorded in the treatment T<sub>2</sub> where biochar was applied @ 2 t ha<sup>-1</sup>.

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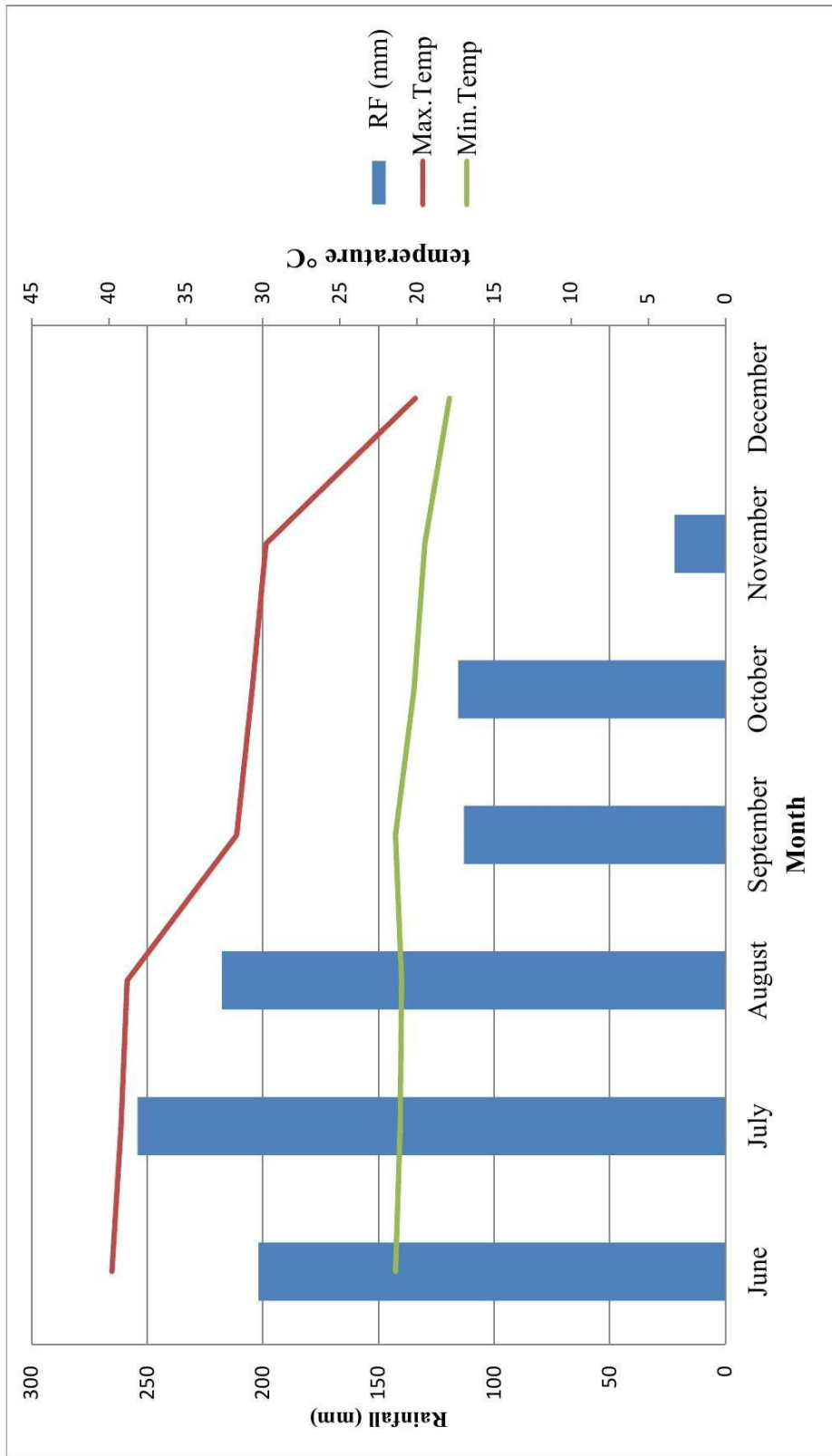
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# **APPENDICES**

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## VIII APPENDICES



Appendix I: Meteorological data during experimental period, *kharif* 2018

**Appendix II: Effect of biochar on CO<sub>2</sub> evolution at different periods of incubation (mg CO<sub>2</sub> /100g soil)**

Treatments	Days of incubation							
	15	30	45	60	75	90	105	120
T <sub>1</sub> : Control (RDF)+ RD-FYM	8.04	9.22	10.16	13.16	15.92	16.96	19.276	20.3
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	7.85	7.90	7.94	8.31	8.51	8.66	9.51	10.29
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	7.91	7.95	8.02	8.61	8.96	9.2	10.02	10.84
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	9.4	10.2	11.6	13.75	17.26	18.0.2	20.74	20.61
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	8.96	9.16	9.58	12.21	13.68	15.64	16.63	18.25
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	8.94	9.03	9.21	12.16	13.08	14.06	16.00	17.00
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	9.6	10.84	11.95	14.28	18.62	18.92	21.3	21.92
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	9.13	9.66	9.96	12.68	14.16	15.86	16.85	18.56
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	9.00	9.65	9.75	12.58	13.04	14.64	16.32	17.5

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM

**Appendix III: Effect of biochar application on soil textural composition of soil after harvest of maize crop**

Treatments	Sand	Silt (%)		Clay
T <sub>1</sub> : Control (RDF)+ RD-FYM	69.91	15.86	14.19	
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	70.11	15.11	14.70	
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	69.22	14.92	15.83	
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	70.68	15.45	13.82	
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	69.18	14.85	15.89	
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	70.73	15.83	13.36	
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	70.29	14.81	14.83	
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	69.36	14.98	15.57	
T <sub>9</sub> : Cob rind biochar @4t ha <sup>-1</sup> + 50 % RD-FYM	71.16	15.28	13.50	
S.Em±	2.18	0.70	0.88	
CD (0.05)	NS	NS	NS	

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM, NS: Non significant.

**Appendix IV: Effect of levels of biochar on secondary nutrients status of soil at harvest of maize**

Treatments	Ca	Mg	S
	( $\mu\text{mol (p}^+) \text{ kg}^{-1}$ )	( $\text{mg kg}^{-1}$ )	( $\text{mg kg}^{-1}$ )
T <sub>1</sub> : Control (RDF)+ RD-FYM	7.13	5.00	15.20
T <sub>2</sub> : Cob rind biochar @ 2t ha <sup>-1</sup>	5.84	4.21	13.00
T <sub>3</sub> : Cob rind biochar @ 4t ha <sup>-1</sup>	6.10	4.72	13.87
T <sub>4</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 100 % RD-FYM	7.30	5.11	15.35
T <sub>5</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 75 % RD-FYM	6.89	4.95	15.02
T <sub>6</sub> : Cob rind biochar @ 2t ha <sup>-1</sup> + 50 % RD-FYM	6.68	4.93	14.37
T <sub>7</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 100 % RD-FYM	7.59	5.52	15.65
T <sub>8</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 75 % RD-FYM	7.34	5.18	15.42
T <sub>9</sub> : Cob rind biochar @ 4t ha <sup>-1</sup> + 50 % RD-FYM	6.90	4.85	14.58
S.Em±	0.22	0.20	0.34
CD (0.05)	0.66	0.60	1.02

Note: RDF-Recommended dose of fertilizer, RD-FYM: Recommended dose of FYM,