

**INFLUENCE OF LEVELS OF ARECAHUSK BIOCHAR ON
CARBON FRACTIONS AND GROWTH AND YIELD OF FIELD
BEAN (*Dolichus lablab* L.)**

**MADHUPRIYA, K.
MA1TAG0247**

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

**UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL
SCIENCES, SHIVAMOGGA**

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COLLEGE OF AGRICULTURE, SHIVAMOGGA
UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL SCIENCES,
SHIVAMOGGA

CERTIFICATE

This is to certify that the thesis entitled “**INFLUENCE OF LEVELS OF ARECA HUSK BIOCHAR ON CARBON FRACTIONS AND GROWTH AND YIELD OF FIELD BEAN (*Dolichus lablab* 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 **MADHUPRIYA, K., ID. NO. MA1TAG0247** (madhu.malyadri1995@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.

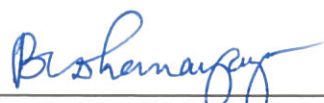
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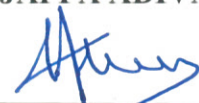
1.


(R. JAYAPRAKASH)

2.

(NAGARAJAPPA ADIVAPPAR)

3.


(A. Y. HUGAR)

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With ever regardful memories.....

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UAHS, Shivamogga

August, 2019



(MADHUPRIYA, K.)

Influence of Levels of Areca Husk Biochar on Carbon Fractions and Growth and Yield of Field Bean (*Dolichus lablab* L.)

(MADHUPRIYA, K.)

ABSTRACT

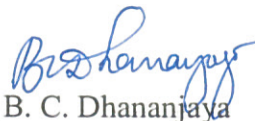
A field experiment was conducted at Agricultural and Horticultural Research Station, Bhavikere, Karnataka, during *Rabi* 2018 to study the response of field bean (Hebbal avaré -4) to different levels of areca husk biochar and FYM. Levels of biochar @ 5, 7.5 and 10 t ha⁻¹ in combination with 100 per cent (15 t ha⁻¹) and 75 per cent (11.25 t ha⁻¹) recommended FYM were tried in a randomized complete block design with three replications and nine treatments. Results of the experiment revealed that application of high level of biochar @ 10 t ha⁻¹ with 15 t ha⁻¹ FYM significantly increased the growth, yield and yield attributes of field bean. Higher values of nutrient content and uptake by field bean were recorded in the same treatment. The bulk density decreased and maximum water holding capacity, primary nutrients, secondary nutrients and DTPA extractable micronutrients status of the soil were increased due to application of biochar at 10 t ha⁻¹ with 100 per cent recommended FYM. Similar trend was also observed for total carbon, total organic carbon and total inorganic carbon fractions of soil during different growth stages of field bean. Positive response for soil enzyme activities such as dehydrogenase, acid phosphatase and urease activity at different growth stages of field bean were noticed with high rate of biochar application and highest values were recorded with treatment receiving biochar @ 10 t ha⁻¹ in combination with FYM @ 15 t ha⁻¹.

Department of Soil Science and
Agricultural Chemistry
UAHS, Shivamogga
August, 2019



Madhupriya, K

(madhu.malyadri1995@gmail.com)



B. C. Dhananjaya

(bcdssac@gmail.com)

ವಿವಿಧ ಪ್ರಮಾಣದ ಅಡಿಕೆ ಸಿಪ್ಪೆಯ ಜೈವಿಕ ಇದ್ದಿಲಿನ ಬಳಕೆಯಿಂದ ಮಣ್ಣಿನ ಇಂಗಾಲದ ಕಣಗಳು
ಮತ್ತು ಅವರೆಕಾಯಿಯ ಬೆಳವಣಿಗೆ ಹಾಗೂ ಇಳುವರಿಯ ಮೇಲಾಗುವ ಪರಿಣಾಮಗಳು

(ಮಧುಪ್ರಿಯ, ಕೆ.)

ಸಾರಾಂಶ

ಅವರೆಕಾಯಿಯ ಬೆಳೆಯಲ್ಲಿ ಅಡಿಕೆ ಸಿಪ್ಪೆಯಿಂದ ತಯಾರಿಸಲ್ಪಟ್ಟ ಜೈವಿಕ ಇದ್ದಿಲು ಹಾಗೂ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರದ ವಿವಿಧ ಪ್ರಮಾಣಗಳ ಪ್ರತಿಕ್ರಿಯೆಯನ್ನು ತಿಳಿಯಲು ೨೦೧೮ ನೇ ಹಿಂಗಾರಿನ ಹಂಗಾಮಿನಲ್ಲಿ ಕೃಷಿ ಮತ್ತು ತೋಟಗಾರಿಕಾ ಸಂಶೋಧನಾ ಕೇಂದ್ರ, ಬಾವಿಕೆರೆಯಲ್ಲಿ ಕ್ಷೇತ್ರ ಪ್ರಯೋಗ ನಡೆಸಲಾಯಿತು. ವಿವಿಧ ಮಟ್ಟದ ಜೈವಿಕ ಇದ್ದಿಲು @ ೫, ೭.೫, ೧೦ ಟನ್ ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ಹಾಗೂ ಶೇ. ೧೦೦ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ (೧೫ ಟನ್ ಪ್ರತಿ ಹೆಕ್ಟೇರ್) ಮತ್ತು ಶೇ. ೭೫ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರವನ್ನು (೧೧.೨೫ ಟನ್ ಪ್ರತಿ ಹೆಕ್ಟೇರ್) ೯ ಉಪಚಾರಗಳೊಂದಿಗೆ ಮೂರು ಬಾರಿ ಯಾದೃಚ್ಛಿಕ ಸಂಪೂರ್ಣ ಬ್ಲಾಕ್ ವಿನ್ಯಾಸದಲ್ಲಿ ಪ್ರತಿರೂಪಿಸಲಾಯಿತು. ಈ ಪ್ರಯೋಗದಿಂದ ತಿಳಿದು ಬಂದಿರುವುದೇನೆಂದರೆ ಶೇ. ೧೦೦ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ (೧೫ ಟನ್ ಪ್ರತಿ ಹೆಕ್ಟೇರ್) ದೊಂದಿಗೆ ಜೈವಿಕ ಇದ್ದಿಲು (೧೦ ಟನ್ ಪ್ರತಿ ಹೆಕ್ಟೇರ್) ಹಾಕುವುದರಿಂದ ಅವರೆಕಾಯಿಯ ಬೆಳವಣಿಗೆ ಮತ್ತು ಇಳುವರಿ ಗಮನಾರ್ಹವಾಗಿ ಹೆಚ್ಚಾಗಿ ಕಂಡುಬಂದಿದೆ. ಜೈವಿಕ ಇದ್ದಿಲನ್ನು ಶಿಫಾರಸ್ಸು ಮಾಡಲಾಗ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರದೊಂದಿಗೆ ಹಾಕುವುದರಿಂದ ಮಣ್ಣಿನ ಸಾಂದ್ರತೆಯ ಮಟ್ಟ ಇಳಿಮುಖವಾಗಿದ್ದು ಮತ್ತು ನೀರನ್ನು ಹಿಡಿದಿಟ್ಟುಕೊಳ್ಳುವ ಸಾಮರ್ಥ್ಯ ಉತ್ತಮವಾಗಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಮಣ್ಣಿನ ಗುಣಲಕ್ಷಣಗಳಾದ ರಸಸಾರ, ವಿದ್ಯುತ್ ವಾಹಕತ್ವ, ಲಭ್ಯವಿರುವ ಸಾರಜನಕ, ರಂಜಕ, ಪೋಷ್ಯಾಷಿಯಂ, ವಿನಿಮಯ ಮಾಡಬಹುದಾದ ಕ್ಯಾಲ್ಸಿಯಂ, ಮೆಗ್ನೀಷಿಯಂ, ಲಭ್ಯವಿರುವ ಗಂಧಕ ಮತ್ತು ಲಘು ಪೋಷಕಾಂಶಗಳ ಸ್ಥಿತಿ ಮತ್ತು ಪೋಷಕಾಂಶಗಳ ಹೀರಲ್ಪಡುವಿಕೆ ಉತ್ತಮವಾಗಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಅದೇ ರೀತಿಯಲ್ಲಿ ಬೆಳೆಯ ಬೆಳವಣಿಗೆಯ ವಿಭಿನ್ನ ಹಂತಗಳಲ್ಲಿ ಒಟ್ಟು ಇಂಗಾಲ, ಒಟ್ಟು ಸಾವಯವ ಇಂಗಾಲ ಮತ್ತು ಒಟ್ಟು ನಿರವಯವ ಇಂಗಾಲದ ಪ್ರಮಾಣವು ಕೂಡ ಉತ್ತಮವಾಗಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಹಾಗೆಯೇ, ಡಿಹೈಡ್ರೋಜೆನೀಸ್, ಯುರಿಯೇಸ್, ಆಮ್ಲೀಯ ಫಾಸ್ಫೇಟೇಸ್ ಕಿಣ್ವಗಳ ಚಟುವಟಿಕೆ ಸಕಾರಾತ್ಮಕವಾದ ಪ್ರತಿಕ್ರಿಯೆ ದಾಖಲಾಗಿದೆ.

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(ಮಧುಪ್ರಿಯ, ಕೆ)

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ಕೃತೋ.ವಿ.ವಿ. ಶಿವಮೊಗ್ಗ

ಆಗಸ್ಟ್, ೨೦೧೯

(madhu.malyadri1995@gmail.com)

ಬಿ.ಸಿ. ಧನಂಜಯ

(ಬಿ.ಸಿ. ಧನಂಜಯ)

(bcdssac@gmail.com)

CONTENTS

CHAPTER	PARTICULARS		PAGE No.
I	INTRODUCTION		1-2
II	REVIEW OF LITERATURE		3-21
	2.1	Characterization of biochar	3
	2.2	Influence of biochar on soil physical properties	6
	2.3	Influence of biochar on soil chemical properties	8
	2.4	Effect of biochar on soil biological properties	12
	2.5	Effect of biochar on performance of crops	15
	2.6	Influence of biochar on carbon fractions in soil	19
III	MATERIAL AND METHODS		22-35
	3.1	Location of the experimental site	22
	3.2	Soil characteristics	22
	3.3	Preparation of areca husk biochar	22
	3.4	Characteristics of areca husk and areca husk biochar	24
	3.5	Experimental details	24
	3.6	Biometric observations	27
	3.7	Yield and yield attributing parameters	27
	3.8	Plant analysis	28
	3.9	Methods of soil analysis	30
	3.10	Carbon pools in soil	31
	3.11	Estimation of soil enzymatic activities	34
	3.12	Statistical analysis	35
IV	EXPERIMENTAL RESULTS		36-70
	4.1	Effect of different levels of biochar on physical properties in soil at harvest	36
	4.2	Effect of different levels of biochar on physico-chemical properties of soil at harvest.	38
	4.3	Effect of different levels of biochar on chemical properties of soil at harvest	38
	4.4	Effect of different levels of biochar on distribution of carbon fractions in soil at different growth stages of Field bean	44

	4.5	Effect of different levels of biochar on dehydrogenase activity in soil at different intervals under Field bean	48
	4.6	Effect of different levels of biochar on phosphatase enzyme activity in soil at different intervals under Field bean	48
	4.7	Effect of different levels of biochar on urease enzyme activity in soil at different intervals under Field bean	51
	4.8	Effect of different levels of biochar on growth parameters of Field bean	53
	4.9	Effect of different levels of biochar on yield parameters of Field bean	55
	4.10	Effect of different levels of biochar on nutrient content and uptake by Field bean	58
V	DISCUSSION		71-85
	5.1	Effect of different levels of biochar on bulk density and water holding capacity of soil under Field bean	71
	5.2	Effect of different levels of biochar on soil pH and EC in soils	71
	5.3	Effect of different levels of biochar application on nutrient status in soil	73
	5.4	Effect of different levels of biochar application on carbon fractions in soil	76
	5.5	Effect of different levels of biochar on enzyme activities in soil at different growth stages in field bean	77
	5.6	Effect of different levels of biochar on growth and yield parameters of Field bean	79
	5.7	Effect of different levels of biochar application on primary nutrient content and uptake by Field bean	81
	5.8	Effect of different levels of biochar application on secondary nutrient content and uptake by Field bean	82
	5.9	Effect of different levels of biochar application on micronutrient content and uptake by Field bean	83
VI	SUMMARY		86-87
VII	REFERENCE		88-104
	APPENDIX		105

LIST OF TABLES

TABLE No.	TITLE	PAGE NO.
1	Initial soil properties of experimental site	23
.2	Characteristics of areca husk, areca husk biochar and FYM	25
3	Methods followed for the analysis of areca husk and areca husk biochar	33
4	Effect of different levels of biochar on bulk density and maximum water holding capacity of soil under Field bean	37
5	Effect of different levels of biochar on pH and EC of soil under Field bean	39
6	Effect of different levels of biochar on available status of primary and secondary nutrients in soil under Field bean	40
7	Effect of different levels of biochar on DTPA extractable micronutrients in soil under Field bean	43
8	Effect of different levels of biochar on total carbon content in soil at different growth stages of Field bean	45
9	Effect of different levels of biochar on total organic carbon content in soil at different growth stages of Field bean	46
10	Effect of different levels of biochar on total inorganic carbon content in soil at different growth stages of Field bean	47
11	Effect of different levels of biochar on dehydrogenase activity in soil at different growth stages of Field bean	49
12	Effect of different levels of biochar on acid phosphatase activity in soil at different growth stages of Field bean	50
13	Effect of different levels of biochar on urease activity in soil at different growth stages of Field bean	52
14	Effect of different levels of biochar on plant height, number of leaves and dry matter accumulation at different growth stages of Field bean	54
15	Effect of different levels of biochar on yield and yield parameters of Field bean	56
16	Effect of different levels of biochar on N, P and K content in Field bean	60
17	Effect of different levels of biochar on Ca, Mg and S content of Field bean	62
18	Effect of different levels of biochar on micronutrients content in Field bean	64
19	Effect of different levels of biochar on N, P and K uptake by Field bean	65
20	Effect of different levels of biochar on Ca, Mg and S uptake by Field bean	67
21	Effect of different levels of biochar on uptake of micronutrients by Field bean	69

LIST OF FIGURES

TABLE No.	TITLE	BETWEEN PAGES
1	Plan and layout of the experiment	23-24

LIST OF PLATES

PLATES	TITLE	BETWEEN PAGES
1	Preparation of biochar	23-24
2	Application of biochar to the experimental plot	27-28
3	General view of experimental plot during flowering	29-30
4	Overview of experimental plot	29-30

LIST OF APPENDIX

APPENDIX	TITLE	PAGE NO.
I	Monthly meteorological data for the experimental year 2018 recorded at AHRS, Bhavikere, Tarikere, Karnataka	105

INTRODUCTION

I INTRODUCTION

In the recent years, the environmentalists and agricultural scientists have realized that continuous and unbalanced use of chemical fertilizers deteriorate the soil fertility, causing environmental pollution and also affect the soil microbial activity. Progressive decline in soil quality and poor nutrient use efficiency continue to hamper agricultural productivity and food security in many developing countries. One potential source includes the recycling of organic sources back to land which help to sustain soil organic matter levels. The application of pyrolysed organic matter (biochar) to soils is currently gaining considerable interest worldwide due to its potential to improve soil nutrient retention, water holding capacity and reduced compaction. Biochar can also be used as an alternative source to FYM as it can supply different nutrients such as nitrogen, phosphorus, micronutrients, as a soil amendment and also there is a scarce availability of FYM in recent years.

Biochar is produced through pyrolysis or gasification processes that burn biomass in the absence (or under reduction) of oxygen. This 2,000 age-old practice converts agricultural waste into a soil enhancer that can hold carbon, boost food security, and increase soil biodiversity and discourage deforestation. The process creates a fine-grained, highly porous material that helps soil to retain nutrients and water. Biochar is high-carbon, fine-grained residue that produced today is through modern pyrolysis processes; it is the direct thermal decomposition of biomass in the absence of oxygen (preventing combustion), which produces a mixture of solids, liquid (bio-oil), and gas (syngas) products. The yield from the pyrolysis process is mainly affected by temperature, residence time and heating rate. These parameters are optimized for the production of either energy or biochar. Temperatures at 400 to 500 °C produce more char.

There is a large imbalance between carbon releases to the atmosphere and carbon uptake by other compartments that leads to continuous increase in atmospheric CO₂ equivalent to a rate of 4.11 tons of carbon per year. Addition of organic matter to soil (e.g. manures, composts, sewage sludge) is common practice in farming systems to overcome carbon loss in agricultural soils. Unfortunately the half-lives of such soil carbon amendments are relatively short. Hence, due to their low stability in the environment, these organic matter amendments require continued repeated application (this of course being time consuming and at an economic cost). In addition to creating as soil enhancer, sustainable biochar practices can produce oil and gas byproducts that can be used as fuel, providing clean, renewable energy. Biochar can be an important tool to increase food security and crop diversity in areas with severely depleted soils, scarce organic resources and inadequate water and chemical fertilizer supplies.

The biochar is found to have positive impact on soil fertility, resulting in an increase in crop yield without causing hazard to soil and water environment. The carbon in biochar resists degradation and can hold carbon in soils for hundreds to thousands of years. The half life of biochar ranges from 100 to 10,000 years (Zimmerman, 2010). Biochar also improves water quality and quantity by increasing retention of nutrients and agrochemicals in soils for crop utilization. Oxidized charcoal residue contribute to increase cation exchange capacity (CEC) in soil (Mao *et al.*, 2012) and can promote organic carbon (OC) stabilization through organo-mineral associations. More nutrients stay in the soil instead of leaching into groundwater and cause pollution. It may also reduce emission of nitrous oxide. Burning biomass through a pyrolysis process prevents not only the oxidation of nutrients (e.g. phosphorus, magnesium, manganese), but also of carbon as CO₂. Thus, it should be important to develop new strategies in order to retain carbon and other nutrients in soil in a stable form that can be stored for long period.

Studies on Amazon soils have revealed that charcoal was used from ancient civilizations as soil amendment for agricultural purposes (Marris, 2006). Due to such a significant impact on vegetation, biochar has become of great scientific interest and as a soil amendment as a means to improve soil fertility and crop yields.

Field bean (*Dolichus lablab* L.) belongs to the family Leguminosae / Fabaceae, and it is an annual herbaceous vegetable cum pulse in the tropics commonly called as Dolichos bean, Avare, Butter bean, Hyacinth bean, Indian bean, Kidney bean, Lubia bean, *etc.* It is one of the oldest vegetable crops grown as pod vegetable in the world and India in particular. In India, it is grown mainly in southern states like Karnataka, Andhra Pradesh, Tamil Nadu and Kerala as well as Assam. In Karnataka, field bean is cultivated on 0.59 lakh hectares (ha) with an annual production of 0.58 lakh tonnes with a productivity of 1039 kg ha⁻¹ (Anon., 2010). Field bean is largely grown as a mixed crop with finger millet and sorghum in different parts of Karnataka, although in some areas, it is also cultivated as pure crop under rainfed as well as irrigated conditions.

Hence in the present research work, an effort is made to know effect of different levels of biochar application on growth and yield of field bean, carbon fractions and soil properties. Realizing the potential of biochar in agriculture the present study is conducted with the following objectives,

1. Influence of levels of areca husk biochar on soil properties
2. Influence of levels of areca husk biochar on carbon fractions in soil under field bean
3. Influence of levels of areca husk biochar on growth, yield, nutrient content and uptake by field bean

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

The present study was undertaken to study “Influence of levels of areca husk biochar on carbon fractions and growth and yield of field bean”. The available review of literature related to the present investigation is given under the following headings.

- 2.1 Characterization of biochar
- 2.2 Influence of biochar on soil physical properties
- 2.3 Influence of biochar on soil chemical properties
- 2.4 Influence of biochar on soil biological properties
- 2.5 Influence of biochar on performance of crops
- 2.6 Influence of biochar on carbon fractions in soil

2.1 Characterization of biochar

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

Schmidt and Noack (2000) reported that biochar is a carbonaceous material which contains polycyclic aromatic hydrocarbons with an array of other functional groups. Even the low pyrolysis temperatures can create torrefied-like biochars that contain semi-degraded cellulose and hemi-cellulose compounds because 300 to 400 °C is the critical temperature range for their structural breakdown. Compared with 500 °C, biochars created at 250 °C probably contain more COOH functional group (Antal and Gronli, 2003)

Hamer *et al.* (2004) reported that different biochar products will decompose to varying extents, depending on the physical and chemical properties of a specific biochar. They also found that 0.3 and 0.8 per cent of initial C is emitted as CO₂ for two biochars produced at different temperatures.

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

Yuan *et al.* (2004) studied the composition and sorptive properties of wheat residue derived char. The char samples produced at high pyrolytic temperature (500-700 °C) were well carbonized and exhibited a relatively higher surface area (>300 m² g⁻¹) little organic matter (< 3 %) and low oxygen content (≤ 10 %). By

contrast, the chars formed at low temperatures (300-400 °C) were only partially carbonized, showing significantly different properties (< 200 m² / g surface area, 40-50% organic carbon, and >20 % oxygen).

Trompowsky *et al.* (2005) showed that the final pyrolysis temperature influenced the yield of humic and fulvic acids in biochar produced from two Eucalyptus species. Biochar is a carbon-rich material obtained from heating organic biomass under limited oxygen conditions appears to be a more stable source of carbon and it remains in the soil for hundreds or even thousands of years (Lehmann *et al.*, 2006).

Chan *et al.* (2008) reported that small differences in pyrolysis temperature when using the same feedstock (chicken manure), produced biochars with very different properties including, pH, EC and N and P concentrations.

DeLuca and Aplet (2008) reported that biochar and charcoal have a low bulk density of approximately 300 kg m⁻³ against a typical soil bulk density of 1300 kg m⁻³. Particles may be very fine in size and in addition surfaces may be hydrophobic.

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

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 biochar has lower bulk density than mineral soil with values on par with organic soils.

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

Charles *et al.* (2010) studied about the bio-char production from corn cobs and stover by fast pyrolysis. They have revealed that the biochar yield obtained was 18.9 per cent and 17.0 per cent from corn cobs and corn stover and also biochar consists of significant amount of carbon, sequester carbon and alleviate environmental problems associated with removal of crop residues from fields.

Didem and Ersoy (2010) investigated the characteristics of biochar samples obtained from the carbonization of apricot stone, hazelnut stone, grape seed stone and chestnut shell. It was found that the biochar products are carbon rich within a range of 21.47 per cent to 28.67 per cent of fixed carbon in it.

Keiluweit *et al.* (2010) reported 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.

The results of study conducted by Singh *et al.* (2010) suggested that, wood biochars had higher total C, lower ash content, lower total N, P, K, S, Ca, Mg, Al, Na and Cu contents, and lower potential cation exchange capacity (CEC) and exchangeable cations than the manure-based biochars and the leaf biochars were generally in-between. Increase in pyrolysis temperature increased the ash content, pH and surface basicity and decreased surface acidity.

Hossain *et al.* (2011) investigated the influence of pyrolysis temperature on production of waste water sludge biochar and evaluated the properties. They reported that by increasing the pyrolysis temperatures (over the range from 300 °C-700 °C) the yield of biochar decreased. Biochar produced at low temperature was acidic whereas at high temperature it was alkaline in nature. The concentration of nitrogen was found to decrease, while micronutrients increased with increasing temperature.

Gonzalez *et al.* (2013) reported the characterization of biochar derived from pyrolyzed oat hull and pine bark at 300 °C and 500 °C. The results obtained showed that the structural and chemical properties of biochar depend on the raw materials used and pyrolysis temperature. The specific surface area presented a similar trend, increasing with an increase in pyrolysis temperature. High enrichment of trace elements such as Ba, Cr, Cu, V and Zn was detected in biochar from pine bark.

Mendez *et al.* (2013) studied the physico-chemical properties of biochar obtained from sewage sludge pyrolysed at 400 °C and 600 °C in which pH, BET surface area, porosity and total concentration of Cu, Ni, Zn, Cd and Pb increased with pyrolysis whereas electrical conductivity and cation exchange capacity decreased. These biochar properties have a significant influence on their effects on soil properties.

Stella *et al.* (2016) conducted a laboratory study to characterize three biomass wastes *viz.*, cauliflower leaf (CL), orange peels (OP) and pea pod (PP), and they were carbonized at different temperatures. The PP and CL biochar had higher values of organic carbon, total surface anions, water holding capacity and mineral content for use as a best soil amendment than OP biochar.

Zaho *et al.* (2018) conducted experiment by pyrolysing corn straw and poplar leaf slowly in a furnace at 300 °C, 500 °C and 700 °C under oxygen deficient condition. They concluded that the yield of biochar decreases as the pyrolysis

temperature increases but the carbon content increases with the increase in pyrolysis temperature. The biochars are neutral to alkaline in nature.

2.2 Influence of biochar on soil physical properties

Tryon (1948) studied the effect of charcoal on the percentage of available moisture in soils of different textures. Only in sandy soil, addition of charcoal increased the available moisture. In loamy soil, no changes were observed, and in clayey soil the available soil moisture decreased with increasing biochar additions and attributed to hydrophobicity of the biochar. Therefore, improvements of soil water retention by charcoal additions may only be expected in coarse-textured soils or soils with large amounts of macro pores.

Briggs *et al.* (2005) measured changes in dry soil color from charcoal additions and found the Munsell value to decrease from 5.5 to 4.8 at charcoal concentrations of 10 g kg⁻¹ and down to 3.6 at 50 g kg⁻¹.

Gundale and DeLuca (2006) showed that biochar has a bulk density much lower than that of mineral soils. Therefore, the application of biochar can reduce the overall bulk density of the soil.

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

Amonette and Joseph (2009) showed that incorporation of biochar can influence soil structure, texture, porosity, particle size distribution and density, thereby potentially altering air oxygen content, water storage capacity and microbial and nutritional status of the soil within the plant rooting zone.

Downie *et al.* (2009) reported that the incorporation of biochar into soil can alter soil physical properties such as structure, pore size distribution and density with logical implications on soil aeration, water holding capacity, plant growth and soil workability.

Major *et al.* (2009) suggested that due to the physical characteristics of biochar there will be changes in soil pore-size distribution and this could alter percolation patterns, residence time and flow paths of the soil solution.

Emmanuel *et al.* (2010) reported increased water holding capacity (WHC) when bio-char was applied at various rates compared to zero application. However, there wasn't much difference in effect on WHC between the rates. Improving WHC by bio-char application was more effective in sandy textured soils.

Solaiman *et al.* (2010) reported beneficial effects of biochar to root colonization by mycorrhiza and crop water and P supply for dry land wheat production in Western Australia.

Yan *et al.* (2010) reported that bagasse charcoal increased available soil moisture in Shimajirimaji soil. Therefore, maintaining an appropriate level of water content in the soil increases not only yield but also sugar content in sugarcane. In addition, N absorption by sugarcane as well as decreased N eluviations and accumulation in the soil can be achieved with bagasse charcoal use.

Artiola *et al.* (2012) conducted a greenhouse experiment with the biochar amendment at two percent and four per cent and reported that the water holding capacities ranged from 185 to 200 per cent, proving that the biochar is capable of holding water twice its weight.

Sean *et al.* (2012) revealed that 5 per cent and 10 per cent biochar amendment increased soil WHC. Also, 10 per cent biochar amendment decreased bulk density of the soil.

Sukartono *et al.* (2012) revealed that water use efficiency (WUE) of maize under biochars were 9.44 kg / mm under coconut shell biochar and 9.24 kg mm⁻¹ under cattle dung biochar biochar and cattle manure are both valuable amendments for improving water use efficiency and to sustain maize production in the sandy loam soils of semiarid North Lombok, eastern Indonesia.

Sun *et al.* (2012) conducted a field experiment and observed that the soil water content was slightly higher *i.e.*, three percent with biochar application @ 20 t ha⁻¹ as compared to control, but the increase was not statistically significant.

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

The physical properties of biochar such as large surface area and presence of micro pores contribute to the adsorptive properties of biochars and potentially alter soil's surface area, pore size distribution, bulk density, water holding capacity and penetration resistance (Mukherjee and Lal, 2013).

Aslam *et al.* (2014) conducted a greenhouse experiment in loamy sand soils in which he reported that the bulk density steadily decreased with increase in the rates of

biochar application and reached the minimum of 0.38 g cm^{-3} at 100 per cent biochar application.

Ulyett *et al.* (2014) reported significant increase in the water holding capacity (1.3 %) on application of biochar @ 60 t ha^{-1} over conventionally managed soils where increase was only 0.3 percent.

Hansen *et al.* (2016) conducted an experiment to know the effect of straw and wood gasification biochar on selected soil fertility indicators. The results revealed that the addition of straw biochar increased aggregate stability and decreased clay dispersibility compared to the control and thus clearly had a positive effect on the structural stability of the soil.

2.3 Influence of biochar on soil chemical properties

Skjemstad *et al.* (2001) showed that the proportion of biochar carbon relative to the total amount of soil carbon increased from 33 and 7 per cent in two native savanna soils up to 53 and 27 per cent in the same soils during 50 years of cropping with mainly wheat and sorghum.

Glaser *et al.* (2002) have conducted an experiment to know the effects of charcoal application in agricultural fields on nutrient retention and crop production. Higher nutrient retention and nutrient availability were found after charcoal additions to soil, related to higher exchange capacity, surface area and direct nutrient additions. Charcoal may contribute to an increase in ion retention of soil and decrease in leaching of dissolved organic nutrients.

Lehmann *et al.* (2003) studied the soil fertility and leaching losses of nutrients were compared between a *Fimic Anthrosol* and a *Xanthic Ferralsol* from Central Amazonia. In the first experiment, cowpea (*Vigna unguiculata* L.) was planted in pots, while in the second experiment lysimeters were used to quantify water and nutrient leaching from soil cropped to rice (*Oryza sativa* L.). The *Anthrosol* showed significantly higher P, Ca, Mn and Zn availability than the *Ferralsol* increasing biomass production of both cowpea and rice by 38 to 45 per cent without fertilization. The soil N contents were also higher in the *Anthrosol* but the wide C-to-N ratios due to high soil C contents led to immobilization of N.

Steiner (2004) attributed decreased leaching rates of applied mineral fertilizer N in soils amended with charcoal to increased nutrient use efficiency. Biochar is a high surface area, highly porous and variable charge organic material that has the potential to increase soil water-holding capacity, cation exchange capacity, surface sorption capacity and base saturation when added to soil (Keech *et al.*, 2005).

Lehmann *et al.* (2006) reported that the ability of biochar to enhance soil productivity is partially attributed to its effect on increasing cation and anion exchange capacity of soils as well as its positive influence on soil structure and microbial dynamics.

Liang *et al.* (2006) corroborated that a high specific surface area was attributable to the presence of black carbon, which may contribute to the high CEC found in soils that are rich in black carbon-14. Soils with high CEC hold greater amount of nutrients on their exchange sites and will have higher buffering capacity. In such cases leaching loss of nutrients is minimized and availability of nutrients to the plants is enhanced.

Chan *et al.* (2007) reported that biochar application increased P, K and Ca concentration of radish significantly at the higher application rates (50 and 100 t ha⁻¹). The increase in P and K contents of radish grown in biochar-amended soil was related to the high concentrations of available P and exchangeable K present in the green waste biochar.

Cowie and Singh (2008) observed the biochar decomposition, across different biochar types, as between 0.15 to 7.7 per cent of the biochar carbon they applied to soil within the first 66 weeks of incubation. They observed the highest increase in decomposition with low temperature biochar amended with poultry litter. In conclusion, about 0.2 to 8 per cent of fresh biochar decomposes within months after soil application.

Oguntunde *et al.* (2008) showed a significant increase in soil pH, electrical conductivity and exchangeable Ca, Mg, K, Na and P in the soil and grain and biomass yield of maize increased by 91 per cent and 44 per cent, respectively at the charcoal site soils, compared to the adjacent soils.

Liang *et al.* (2009) reported that after soil application, biochar is predominately found in fractions of soil organic matter (SOM) that reside in small clusters of soil particles or soil aggregates, rather than as free organic matter.

Novak *et al.* (2009) conducted an incubation study to know the impact of biochar application on fertility of Norfolk loamy sand soil. After 67 days and two leaching events, biochar additions increased the soil organic carbon, Ca, K, Mn and P and decreased S, Zn and exchangeable acidity. Biochar additions did not significantly increase soil cation exchange capacity. Leachates contained higher concentration of K and Na concentrations but decreasing levels of Ca, P, Mn and Zn. These effects reflect the addition of elements and the higher sorption capacity of biochar for selective nutrients (especially Ca, P, Zn and Mn).

Singh *et al.* (2010) suggested that, wood biochars had higher total C, lower ash content, lower total N, P, K, S, Ca, Mg, Al, Na and Cu contents, and lower potential cation exchange capacity (CEC) and exchangeable cations than the manure-based biochars, and the leaf biochars were generally in-between. Increase in pyrolysis temperature increased the ash content, pH and surface basicity and decreased surface acidity.

Beesley and Marmiroli (2011) showed a significant increase in soil pH, EC and exchangeable Ca, Mg, K, Na and P in the soil as compared to the adjacent soils.

Taghizadeh-Toosi *et al.* (2012) reported that application of biochar has resulted in capture of anthropogenic ammonia emissions and made bioavailable in soils, thus leading to nitrogen capture by crops, while simultaneously sequestering carbon in soils.

Cayuela *et al.* (2013) investigated the effect of biochar as a means to reduce N₂O emission. They reported that there was a significant impact of biochar on denitrification, with consistent decrease in N₂O emissions by 10 to 90 per cent in 14 different agricultural soils.

Masto *et al.* (2013) conducted a field experiment and concluded that application of biochar 4 t ha⁻¹ has increased the pH value from 6.09 to 6.64. The pH of the soil amended with biochar @ 7.5 t ha⁻¹ was significantly increased by 0.4 units over control (Mukherjee *et al.*, 2014).

Mu and Matsunka (2013) conducted pot experiments to evaluate biochar derived from dead dairy cattle as a mineral fertilizer, especially phosphorus (P) fertilizer. Soil analysis after harvest indicated that the biochar application increased soil pH, available P and exchangeable calcium (Ca) and magnesium (Mg) compared with the soil before seeding, while soil available N and exchangeable potassium (K) were considerably decreased.

Xu *et al.* (2013) evaluated the effects of four biochar application rates (0, 1, 5 and 10 %) on available NO₃⁻-N, NH₄⁺-N, K, Na, Ca, Mg and of Fe, Al oxides in a sandy soil. The results suggested that cations such as K, Ca, Na, Mg were mainly originated from biochar while inorganic N showed little effects from biochar regardless of direct or indirect mechanisms. P solubility with biochar application was more complex because they also affected by altering soil pH, changes of Fe and Al oxides, and direct P contributions from biochar.

A study was conducted by Chintala *et al.* (2014) to know the effect of biochar incorporation on soil chemical properties of acidic soil. The study demonstrated the effectiveness of biochar in ameliorating acidity which increased the soil pH, EC and

CEC and decreased the exchangeable acidity. The liming potential of biochar can be attributed to their alkalinity, proton consumption capacity and base cation concentration.

Rajesh *et al.* (2014) conducted an experiment by incubating acidic soil of $\text{pH} < 4.80$ with biochars for 165 days to study effect of biochar on chemical properties. Corn stover biochar, switch grass biochar and lime (calcium carbonate) were applied at four rates (0, 52, 104, and 156 Mg ha^{-1}) to acidic soil. Amendment type, application rate and their interaction had significant effects on soil pH, EC, and CEC of acidic soil. Application of corn stover biochar had shown a relatively larger increase in soil pH than switch grass biochar at all application rates.

The incorporation of biochar produced from crop straws increased the soil pH, exchangeable base cation, CEC and base saturation and decreased exchangeable acidity, exchangeable Al and reactive Al. The resultant effects were dependent upon feedstock characteristics and pyrolysis temperature (Wan *et al.*, 2014).

Widowati *et al.* (2014) studied the effect of biochar on leaching and uptake of nitrogen and potassium from degraded soils. Results of the study showed that the lowest nitrate leaching was observed with the application of wood biochar @ 45 t / ha whereas application of 45 t / ha coconut shell biochar resulted in highest K leaching.

Yang *et al.* (2016) conducted an incubation experiment to investigate the effect of biochar produced from bamboo and rice straw (at temperatures $\geq 500^\circ\text{C}$) on physico-chemical properties in a contaminated sandy loam paddy soil. Three rates (0, 1, and 5 %) and two mesh sizes (< 0.25 and $< 1 \text{ mm}$) of biochar applications were investigated. The results demonstrated that rice straw biochar significantly increased the pH, electrical conductivity and cation exchange capacity of the soil, especially at the 5 per cent application rate.

Xu *et al.* (2017) studied the influence of rice husk biochar (RHB) on nitrogen and phosphorus leaching in yellow brown soil. Different rates of RHB, viz., 0, 1, 8 and 12 per cent were applied to soil. Compared with the control, biochar application at 12 per cent had the best inhibitory effect by reducing the leaching of total nitrogen, nitrate nitrogen, and ammonium nitrogen by 85.41, 85.16 and 92.61 per cent, respectively and reducing the leaching of dissolved organic carbon by 32.02 per cent. With the increase of the biochar application rate, the leaching of total phosphorus and phosphate increased. Soil total nitrogen, nitrate nitrogen, phosphorus and microbial biomass carbon and microbial biomass nitrogen content increased.

Boersma *et al.* (2018) investigated the effect of macadamia nut shell biochar on nitrogen, potassium, phosphorus, magnesium, calcium and sodium concentrations

in potting mix used to grow *Eucalyptus nitens* seedlings in a glasshouse experiment. Biochar significantly increased nitrate-N, Colwell- P, Colwell-K and exchangeable Na and reduced ammonium-N, Mg and Ca concentrations in the potting mix. Seedling leaf concentrations of P, K and Na were increased by biochar application, while N remained dependent on fertilizer rate only. Mg and Ca leaf concentrations decreased in response to increasing biochar rates.

Dali *et al.* (2018) revealed that all maize straw biochar-amended treatments significantly increased soil pH values by 0.03 to 0.12 units compared with that of the NPK treatment ($P < 0.05$).

Zhang *et al.* (2018) studied the persistent effects of biochar application on soil organic carbon (SOC) mineralization. Biochar was applied at the rate of 0, 2.5, 5, 10, 20, 30 and 40 t ha⁻¹ in the field experiment and designated as treatments B₀, B₁, B₂, B₃, B₄, B₅ and B₆. Biochar application at rates of 30 and 40 t ha⁻¹ (B₅ and B₆ treatment) distinctly increased soil pH value, SOC, total N and available P relative to B₀.

2.4 Effect of biochar on soil biological properties

Bolton *et al.* (1985) studied the impact of biochar on extracellular enzymatic activities of soil in maize crop. Compared to the control application of biochar significantly increased the α -1, 4-glucosidase, β -D-cellobiohydrolase and β -1, 4 N acetylglucosaminidase.

Van Gestel *et al.* (1993) reported that less direct alterations in soil water content induced by biochar include changes in soil oxygen tensions which influence soil micro-organisms and their capacity to oxidize soil organic matter.

Pietikainen *et al.* (2000) reported that biochar additions to soil have the potential to alter soil microbial populations and shift functional groups in soil organic compounds.

Activities of certain enzymes like, alkaline phosphatase, aminopeptidase and N- acetyl glucosaminidase have been reported to increase due to biochar application (Bailey *et al.*, 2010).

Ameloot *et al.* (2013) studied the effect of biochar on the microbial properties of soil in which swine manure and willow wood was pyrolyzed at 350 °C and 700 °C. The results revealed that the microbial biomass carbon and dehydrogenase activity consistently increased due to the biochar additions. They also observed that the net N mineralization was higher in the digestate biochar treatment than in the willow biochar treatments.

Masto *et al.* (2013) revealed that the maximum increase in soil enzymes like acid phosphatase activity (+ 32%), alkaline phosphatase activity (+ 22.8 %), and fluorescein hydrolases activity (50%) occurred at the *Eichhornia* biochar (EBC) dose of 20 g kg⁻¹ EBC significantly enhanced the soil biological activity particularly the active microbial biomass which has increased by three times and soil respiration by 1.9 times

Sandeep *et al.* (2013) investigated on effect of *Parthenium* biochar (PBC) at different doses: 0, 1, 3, 5, 10 and 20 g kg⁻¹ on soil microbial activity in a laboratory. Soil dehydrogenase activity (DHA) increased from 5 g kg⁻¹ PBC onwards; catalase activity increased at lower doses (1 and 3 g kg⁻¹ PBC). Hydrolytic enzyme activities decreased with PBC application.

Du *et al.* (2014) conducted a field experiment with two different rates of biochar application *i.e.*, 4.5 and 9.4 t ha⁻¹ and revealed that the soil urease and soil phosphatase activities were significantly increased at both the levels of biochar application.

Ouyang *et al.* (2013) conducted an incubation study with different types of biochar @ 5 per cent and revealed that the significant increase in the soil urease, soil phosphatase and dehydrogenase activity were observed in most of biochar treatments.

Rutiliano *et al.* (2014) conducted a field experiment to know the effect of biochar on soil microbial properties in wheat for a period of two seasons. The study revealed that biochar addition stimulated soil microbial activity without causing any apparent disturbance to soil.

Akca and Namli (2015) conducted a greenhouse experiment with different levels of biochar (20, 40 and 60 kg ha⁻¹) in combination with 15:15:15 fertilizer. The results revealed that the β -glucosidase, alkaline phosphatase, urease and arylsulphatase enzyme activities in soils were increased by biochar applications significantly as compared to control and chemical fertilizer alone.

Purakayasta *et al.* (2015) studied the microbial effects of four biochars produced from crop residues (maize stover, pearl millet stalk, rice straw and wheat straw). The soil microbial activities measured in terms of dehydrogenase activity (DHA), microbial biomass carbon (MBC) and alkaline phosphomonoesterase activity were enhanced due to biochar application thus could be useful for the restoration of biological fertility of soil.

Sivadevika (2015) showed that there was a significant effect on addition of biochar on soil enzyme activity. Urease, alkaline phosphatase and dehydrogenase activities were higher in biochar treatments than that of control.

Mierzwa *et al.* (2016) conducted an experiment to know the effect of poultry litter biochar on soil enzymatic activity. Biochar had more adverse effect on soil enzymatic activity and grass crop yield than non-converted poultry litter.

Yang *et al.* (2016) conducted an incubation experiment to investigate the effect of biochar produced from bamboo and rice straw (at temperatures ≥ 500 °C) on enzyme activity in a contaminated sandy loam paddy soil. Three rates (0, 1, and 5 %) and two mesh sizes (< 0.25 and < 1 mm) of biochar applications were investigated. Urease activity increased by 143 and 107 per cent after the addition of 5 percent coarse and fine rice straw biochars, respectively. Both bamboo and rice straw biochars significantly increased catalase activity.

Jiang *et al.* (2017) conducted a pot experiment in which different rates of biochar was applied. They reported that addition of biochar influenced soil microbial community in terms of their abundance and diversity. The addition of biochar stimulated the growth of actinomycetes and bacteria, especially ammonifying bacteria and azotobacteria due to the porous structure and nutrient availability of biochar.

Xu *et al.* (2017) conducted an experiment to know the influence of rice husk biochar (RHB) on nitrogen and phosphorus leaching in yellow brown soil. Different rates of RHB viz., 0, 1, 8 and 12 per cent was applied to soil. The results revealed that the application of 12 per cent biochar increased the soil total nitrogen, microbial biomass carbon and microbial biomass nitrogen content.

Meththika *et al.* (2018) studied the effect of woody biochars (BC) derived by pyrolyzing *Gliricidia sepium* at 300 °C and 500 °C on soil enzymatic activity with tomato (*Lycopersicon esculentum* L.) at biochar application rates, viz., 1, 2.5, and 5 per cent. The maximum activity of dehydrogenase and catalase was observed in 1 per cent BC 500 and 2.5 per cent BC 300.

Dali *et al.* (2018) revealed that the application of NPK + maize straw biochar (MC) 450 °C treatment promoted the increases in soil C- and N-cycling enzyme activities. All the NPK plus MC soils significantly reduced the relative abundance of soil fungi and enhanced soil nutrient contents (excluding soil inorganic nitrogen) and total phospholipid fatty acid concentrations. A redundancy analysis revealed that the changes in soil microbial community depended mainly on the contents of microbial biomass carbon (MBC), microbial biomass nitrogen and available K as well as the C/N ratio. The activities of β -glucosidase, β -cellobiosidase, β -xylosidase and N-acetyl-glucosaminidase in the MC300°C + NPK and MC 450 °C + NPK treatments were significantly higher than those of the CK and NPK-only treatment.

2.5 Effect of biochar on performance of crops

Pietikainen *et al.* (2000) reported increasing rates of biochar and positive plant responses until 30 t ha⁻¹ of biochar wherein a maximum was reached, above which growth response was negative for beans with application of 0 to 93 t ha⁻¹.

Lehmann *et al.* (2002) reported that biochar addition resulted in higher C, P, K and Zn availability and to a lesser extent Ca and Cu along with greater stabilization of organic matter and better retention of cations due to greater cation exchange capacity which results in immediate beneficial effects of biochar additions for soil nutrient availability resulting in plant uptake, increased crop growth and yield attributes.

Lehmann *et al.* (2003a) reported that biochar amendments at rates varying from 0.5 to 135 t ha⁻¹ are indeed capable of improving nutrient availability and microbial activity in soil, resulting in a significant increase (up to 34%) in yield when applied to crops like rice, sorghum, corn, various beans (soybean, common bean, cow pea), banana and vegetables such as carrots.

Lehmann *et al.* (2003b) reported that biochar application does little to contribute directly to the soil nutrient status (a source of available mineral elements); again it is combinations of biochar and applied fertilizer which cause yield enhancements *via* reduced fertilizer (nutrient) leaching.

Lehmann and Rondon (2005) report that depending on the amount of biochar added, significant improvements in plant productivity were achieved ranging from 20 to 220 per cent.

Yamato *et al.* (2006) reported that biochar has been shown to increase the yields of maize and peanut by changes in P availability and also stated that increases in the root amount and colonization rate of arbuscular mycorrhizal fungi were observed on maize after bark charcoal application.

Rondon *et al.* (2007) reported that the positive effects of biochar, including N fixation led to 30 to 40 per cent increase in bean yield with biochar additions up to 50 g kg⁻¹.

Steiner *et al.* (2007) reported a cumulative yield increase of rice and sorghum on a Brazilian Oxisol of approximately 75 per cent after three repeated biochar applications of 7 t ha⁻¹ over two years. They also reported a progressive increase in beneficial effects of biochar over time like increased NPK availability in soil.

Chan *et al.* (2008) reported that the enhancement of P content in biochar is apparent when poultry litter is subjected to pyrolysis at 450 °C compared to 550 °C and this may be the cause for observed increases in radish yields.

Kimetu *et al.* (2008) found a doubling of cumulative maize yield after three repeated biochar applications of 7 t ha⁻¹ over 2 years.

Asai *et al.* (2009) reported that rice yields have been shown to increase with biochar application when soils are known to be low in available P. Bagasse charcoal decreased soil density and increased available moisture, which resulted in increased yields and decreased nitrate nitrogen concentration (Chen *et al.*, 2010).

Krull *et al.* (2010) reported the positive effects of biochar including N fixation led to 30 to 40 per cent increase in bean yield with biochar additions up to 50 g / kg.

Graber *et al.* (2010) conducted an experiment to know the impact of addition of wood-derived biochar on pepper (*Capsicum annuum* L.) and tomato (*Lycopersicon esculentum* Mill.) Pepper plant development in the biochar-treated pots was significantly enhanced as compared with the unamended controls. They noticed the increase in most measured plant parameters: leaf area, canopy dry weight, number of nodes, and yields of buds, flowers and fruit. In addition to the observed increases in plant growth and productivity, the rhizosphere of biochar-amended pepper plants had significantly greater abundances of culturable microbes belonging to prominent soil-associated groups. In tomato, biochar treatments positively enhanced plant height and leaf size, but had no effect on flower and fruit yield.

Namgay *et al.* (2010) conducted a pot culture experiment on maize and revealed that the concentration of Cu in shoots was significantly decreased and concentration of Zn in shoots significantly increased with biochar application at the rates of 5 g kg⁻¹ and 15 g kg⁻¹ as compared to control.

Paul *et al.* (2010) reported that banded application of wood derived biochar has shown that combined biochar and fertilizer application can increase wheat yield or increase fertilizer efficiency for dry land wheat production in low available-P soils of south-western Australia in some dry seasons.

Solaiman *et al.* (2010) reported that biochar application at 6 t ha⁻¹ combined with half of the recommended rate of soluble fertilizer produced significant increases in wheat yield and significant yield increases were also observed when biochar treatments (1.5, 3.0 and 6.0 t ha⁻¹) were applied with inoculated mineral fertilizer.

Van *et al.* (2010) revealed that plant biomass increased significantly with increasing biochar addition when applied in combination with lower N application rates. Application of biochar at the highest rate resulted in significantly more NO₃-N in the soil. Application of biochar also increased microbial activity and available P in the soil.

Haefele *et al.* (2011) observed clear positive effect of biochar application on yield and fertilizer use efficiency only in the site where the natural soil fertility was very low. Biochar application improved the CEC and soil water holding capacity and 16 to 35 per cent improvement in grain yield over control.

Jeffery *et al.* (2011) evaluated the evidences regarding the relationship between biochar and crop productivity by conducting a meta-analysis. The greatest positive effects were seen with biochar application rates of 100 t ha⁻¹ (39 %). Other positive effects were seen in acidic (14 %) and neutral pH soils (13 %) and soils with coarse (10 %) or medium (13 %). These results suggest main two mechanisms for yield improvement viz., liming effect and improved water holding capacity.

Sukartono *et al.* (2012) conducted a field experiment and reported that application of biochar @ 15 t ha⁻¹ significantly increased the yield of maize and uptake of N, P and K.

Junxiang *et al.* (2012) performed a pot experiment was performed to estimate the effect of maize (*Zea mays* L.) straw biochar application on vegetable yield through cultivation of choy sum (*Brassica rapa* L.) and amaranth (*Amaranthus mangostanus* L.) in China. On average, urea + manure + biochar combined treatment significantly enhanced vegetable production by 32, 48 and 28 per cent as compared to urea, urea + manure and urea + biochar.

Widowati *et al.* (2012) conducted a field experiment and revealed that the total nitrogen absorption by maize at the end of the vegetative stage was significantly higher (63.46 kg ha⁻¹) with the integral application of N fertilizer @ 145 kg ha⁻¹ and city waste biochar @ 30 t ha⁻¹ as compared to the sole use of N fertilizer @ 145 kg ha⁻¹ (62.45 kg ha⁻¹).

Karer *et al.* (2013) conducted a field experiment in two seasons with the application of biochar @ 0, 24, 72 t ha⁻¹ and revealed that the nitrogen uptake was significantly higher (131 t ha⁻¹) with the application of biochar @ 24 t ha⁻¹ 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 was significantly higher (4 t ha⁻¹) on application of biochar @ 4 t ha⁻¹ as compared to the control (3.59 t ha⁻¹).

Ma and Matsunka (2013) studied the effect of biochar on plant growth (*Zea mays* L.) and P uptake. The biochar was of high pH and rich in major plant nutrients, especially P. Application of fine biochar increased P uptake by the corn plants grown in soil with low available P status. As a result, plant growth was improved following biochar application and dry matter production was also increased.

The effect of the biochar application on the P uptake and plant growth was promoted by the application of mineral nitrogen (N) fertilizer.

Evangelou *et al.* (2014) studied the soil application of biochar produced from biomass on trace element contaminated land on ryegrass (*Lolium perenne*, var. *Calibra*). They reported that the root biomass of the biochar treated plants was lower than that of the non-amended plants, while that of the shoot was higher. Plant shoot K and Zn concentrations were increased significantly by up to 7 and 3.3 folds, respectively.

Imran *et al.* (2014) reported that in maize 1000 seed weight was significantly increased with increase in the biochar levels. Maximum 1000 seed weight (285.6 g) was reported at the application of 25 t ha⁻¹ biochar while minimum was recorded in control (250.5 g). They also reported that the maximum grain yield (4013 kg ha⁻¹) on application of biochar @ 24 t ha⁻¹ and minimum in control (3660 kg ha⁻¹).

Liu *et al.* (2014) conducted a meta-analysis to investigate soil constraints, and reported that there was 25 per cent average crop yield increase in tropical soils upon biochar addition, mostly through liming and nutrient effects (N and K retention, P availability and direct K addition).

Mau and Utami (2014) conducted a glass house experiment to study the interaction effects of biochar amendment and arbuscular mycorrhizal fungi (AMF) inoculation in which biochar was made from cow dung. They reported that the highest available P phosphorus uptake was in the soils inoculated with 7.5 g biochar kg⁻¹ and 10 AMF spores kg⁻¹ after 8 weeks incubation. Application of biochar alone did not significantly improve maize growth and phosphorus uptake by maize.

Dong *et al.* (2015) conducted a 2-year field study to investigate the effects of bamboo biochar and rice straw biochar amendment at a rate of 22.5 t ha⁻¹ (with or without urea) on N retention and rice growth. Amendment with rice straw biochar resulted in higher rice yields than in paddy soils that had bamboo biochar amendments. Incorporating rice straw biochar into a paddy field increased the rice yield by 19.8 per cent in 2009 and 21.6 per cent in 2010 without urea and by 11.3 per cent in 2009 and 14.4 per cent in 2010 with urea, compared with their corresponding control treatments.

Baiga and Rajashekhar (2017) conducted to study the effect of soil applications of kunai grass (*Imperata cylindrica*) biochar (0 and 10 t ha⁻¹) and laboratory grade urea (0, 200 and 500 kg N ha⁻¹) and their co-application on nitrogen (N) mineralization in an acid soil. Chinese cabbage (*Brassica rapa* L. ssp. *chinensis* L.) showed significantly greater marketable fresh weight, dry matter

production and N uptake in soil receiving urea N at 500 kg ha⁻¹ or co-application of biochar with urea N compared to the control.

Bandara *et al.* (2017) conducted a pot experiment with tomato (*Lycopersicon esculentum* L.) at different rate of biochar application (0, 22, 55, and 110 t / ha). Improvement in plant growth in biochar-amended soil was observed due to decrease in metal toxicity as a consequence of metal immobilization.

Dali *et al.* (2018) conducted an experiment to investigate the effects of control (CK), chemical fertilizer (NPK) and NPK with maize straw biochar (MC) produced at 300 °C, 450 °C and 600 °C (NPK + MC 300 °C, NPK + MC 450 °C and NPK + MC 600 °C) on wheat crop yield. The results showed that the NPK + MC 450 °C treatment obtained the highest wheat yield and N, P and K uptakes.

2.6 Influence of biochar on carbon fractions in soil

Chan *et al.* (2007) conducted a field experiment on different rates of biochar application and reported that the organic carbon values (64.6 g kg⁻¹) were significantly increased with biochar application @ 100 t ha⁻¹ as compared to no biochar application (21.2 g kg⁻¹).

Van *et al.* (2010) conducted a glass house experiment with five different biochar rates (0, 1.1, 2.2, 4.4 and 11.0 %), reported that the total carbon content was increased significantly from 2.1 to 8.6 per cent with increase in the biochar content, but only minor increase in the organic carbon was detected.

Lehmann and Joseph (2009) investigated the influence of pre-existing soil organic matter on biochar stabilization in soil in comparison to labile organic additions. Biochar application reduced the rate of CO₂-C loss by 27 per cent. With biochar application, a greater proportion of C (6.8 times) was found in the intra aggregate fraction per unit C.

Andrew *et al.* (2011) studied the interactive effects of biochar addition to soil on CO₂ evolution were evaluated. They reported that over the long term, biochar–soil interaction will enhance soil C storage *via* the processes of OM sorption to biochar and physical protection. More C was released from biochar-amended than from non-amended soils.

Jones *et al.* (2011) reported that the initial C loss during a short-term CO₂ emission is comparatively negligible compared to the amount of C stored within the biochar itself and thus should not overshadow the C sequestration potential of biochar on a long-term basis.

An incubation experiment was conducted for 120 days by Keith *et al.* (2011) to quantify the interactive priming effects of biochar-C and labile organic matter (LOM) in a smectite clayey soil with sugarcane residue biochar (source of LOM) and wood biochar. They showed that biochar application possesses considerable merit for long-term soil carbon sequestration and it has stabilizing effect on LOM in soil.

Zavalloni and Alessandro (2011) investigated the effect of biochar addition to soil on CO₂ emissions, microbial biomass, soil soluble carbon (C), nitrogen (N) and nitrate–nitrogen (NO₃–N) with four soil treatments soil only (control); soil + 5 per cent biochar; soil + 0.5 per cent wheat straw; soil + 5 per cent biochar + 0.5 per cent wheat straw. They concluded that the biochar is a very stable C source and could be an efficient and long-term strategy to sequester C in soils.

Widowati *et al.* (2012) reported that the use of city waste as biochar increased the organic carbon content in the soils with the integral application of N fertilizer @ 145 kg ha⁻¹ and city waste biochar @ 30 t ha⁻¹ was significantly higher (3.21 %) than the sole use of N fertilizer @ 145 kg ha⁻¹ (1.41 %) and control (1.39 %).

Hua *et al.* (2013) studied the effect of biochar on carbon dioxide release and organic carbon accumulation. The results indicated the amendment of biochar to soil could reduce the CO₂ emission and increase the organic matter of soil effectively. The influence extent enhanced as the increase of biochar and the influence extent on soil with lower organic matter content is much obvious than soil with higher organic matter content.

Sandeep *et al.* (2013) reported that active microbial biomass carbon was 1.4, 1.7 and 2.1 times higher than control at 1, 3 and 5 g kg⁻¹ *Parthenium* biochar applied treatments, respectively.

Demise *et al.* (2014) conducted incubation study to study the effect of biochar on carbon fractions in which oak wood biochar (OB) and bamboo biochar (BB) at different rate (0.5, 1.0 and 2 %) were applied. The higher potassium permanganate oxidizable carbon, light fraction organic carbon, hot- water extractable carbon and microbial biomass carbon was recorded highest at 0.5 per cent rate of biochar (OB and BB) application. The changes in total carbon in the soil and its lability increased by 50 to 286 per cent in the biochar applied treatments.

Hansen *et al.* (2016) studied the effect of straw and wood gasification biochar on carbon sequestration. Soil application of wood and straw gasified biochar resulted in very low CO₂ emissions, confirming the stability of the material against microbial degradation. Both gasified biochar and straw biochar application increased the TOC in the beginning of the incubation. Also, the TOC content in the straw treatments

decreased again during the incubation, whereas in gasified biochar treatments the increased TOC remained stable throughout the incubation period.

Gurwindersingh (2016) conducted a research to know the impact of different rates of rice-residue biochar (0 %, 0.5 %, 1 %, 2 % and 4 %, respectively). The rate of C mineralization ($\text{mg CO}_2\text{-C g}^{-1} \text{ SOC day}^{-1}$) was higher in treatments receiving more quantity of biochar dissolved organic carbon and microbial biomass carbon concentration increased with increasing rate of biochar addition and followed the order B4 per cent > B2 per cent > B0.5 per cent > B zero per cent in the soil.

Hartely and Waterson (2016) reported that the addition of several feed stocks increased the total organic carbon in micro aggregate fraction and also rise in the concentration of dissolved organic carbon in the soil pore water from the biochar treated soil.

Riaz *et al.* (2017) conducted an incubation study by using biochar produced from corn cobs. The results revealed that addition of corn cob biochar significantly increased microbial C (MBC) but decreased water extractable organic matter (WEOM). The biochar could decrease carbon mineralization and enhanced microbial carbon use efficiency.

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

MATERIAL AND METHODS

III MATERIAL AND METHODS

A field experiment on “Influence of levels of areca husk biochar (AHB) on carbon fractions and growth and yield of field bean” was conducted at the Agricultural and Horticultural Research Station (AHRS), Bhavikere during *Rabi* season of 2018-19. Details of the materials used and techniques adopted during the investigation are described in this chapter.

3.1 Location of the experimental site

The experiment was conducted at AHRS, Bhavikere which is located in the north western side of Tarikere. The research station comes under Southern Transition Agro-climatic Zone (STZ-VII) of Karnataka. It is situated at 13°42' N latitude and 75°51' E longitude and at an altitude of 695 meters above mean sea level. The average rainfall of the zone is 1193.8 mm.

3.2 Soil characteristics

Prior to the initiation of experiment, composite soil samples from experimental area were collected from 0 to 15 cm depth and analyzed for physical and chemical properties. The result of the analysis is given in Table 1. Initial characterization of soil for the experimental site indicates that the soil pH was acidic in reaction (6.06). Further, the soil was low in nitrogen (250.88 kg ha⁻¹), high in phosphorus (60.90 kg ha⁻¹) and medium in available potassium (215.70 kg ha⁻¹). The exchangeable Ca and Mg were 4.40 and 2.40 cmol (p⁺) kg⁻¹, respectively, whereas available sulphur was 17.2 mg kg⁻¹. The micronutrient status of soil was high with respect to Fe (20.50 mg kg⁻¹), Mn (17.89 mg kg⁻¹), Zn (1.71 mg kg⁻¹) and Cu (6.55 mg kg⁻¹). Carbon pools of the initial soil *i.e.*, total organic carbon, total inorganic carbon and total carbon was 10.20, 0.24 and 10.44 g kg⁻¹, respectively (Table 1).

3.3 Preparation of areca husk biochar

The biochar was prepared from areca husk at 400 - 600°C in a kiln by the process of pyrolysis. After drying the residue in the sun, areca husk is weighed and placed in the inner kiln and closed. Later it is burnt by using wood feedstock as burning material which is put in outer kiln. After reaching the specified temperature, it was left for cooling under natural environmental condition. Next day, the biochar was removed and weighed to record the conversion factor.

Table 1: Initial soil properties of experimental site

Physical properties	Value
Sand (%)	65.16
Silt (%)	14.29
Clay (%)	20.55
Textural class	Sandy loam
Bulk density (g cm^{-3})	1.36
MWHC (%)	33.25
Chemical properties	
pH	6.07
Electrical conductivity (dS m^{-1})	0.21
Cation exchange capacity [$\text{cmol (p}^+) \text{ kg}^{-1}$]	8.12
Available macro nutrient status	
Available N (kg ha^{-1})	250.88
Available P_2O_5 (kg ha^{-1})	60.90
Available K_2O (kg ha^{-1})	215.70
Secondary nutrient status	
Exchangeable Ca [$\text{cmol (p}^+) \text{ kg}^{-1}$]	4.40
Exchangeable Mg [$\text{cmol (p}^+) \text{ kg}^{-1}$]	2.40
Available S (ppm)	17.2
Micronutrient status (mg kg^{-1})	
Available Fe	20.5
Available Zn	1.71
Available Cu	6.55
Available Mn	17.89
Carbon pools	
Total carbon (g kg^{-1})	10.44
Total inorganic carbon (g kg^{-1})	0.24
Total organic carbon (g kg^{-1})	10.20



Plate 1: Preparation of biochar from areca husk

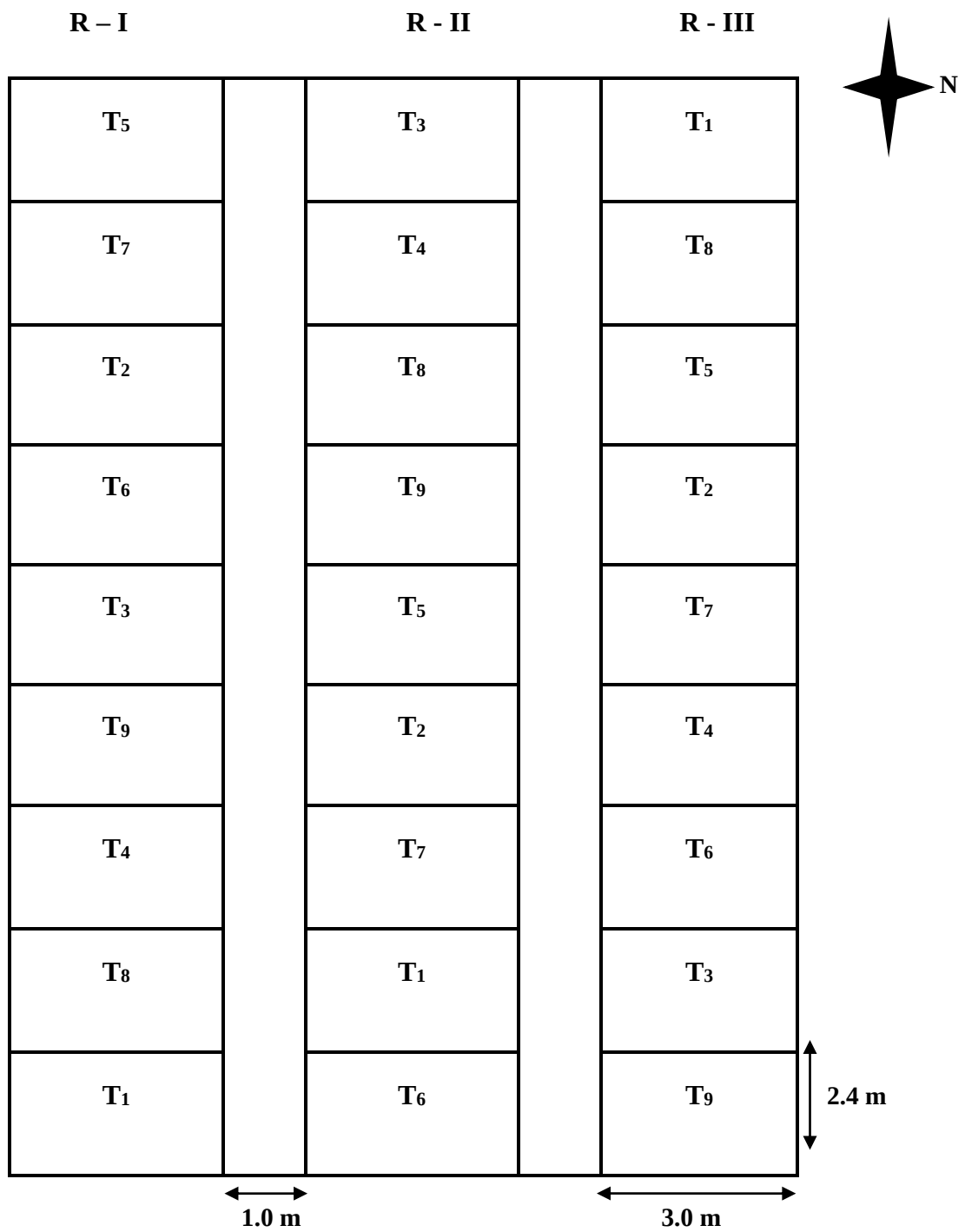


Fig. 1 Plan of layout of the experiment

The charring yield (% char) provided by a kiln is given by $\% \text{ char} = 100 \times (\text{m biochar} / \text{m areca husk})$, where biochar is the dry mass of charred areca husk taken from the kiln and areca husk is the dry mass of the feedstock loaded into the kiln (Antal and Gronli, 2003). The recovery percentage of the biochar obtained from areca husk is found to be 42 per cent.

Biochar was ground manually and made into fine powder, passed through 2 mm sieve, stored in plastic bags and applied to the experimental plot prior to sowing.

3.4 Characteristics of areca husk and areca husk biochar

Total elemental composition of areca husk and areca husk biochar is presented in Table 2. The pH of areca husk was 6.3 with electrical conductivity of 1.69 dS m^{-1} , bulk density of 0.24 Mg m^{-3} and the total C content was 1.9 g kg^{-1} . The concentration of total nitrogen, phosphorus and potassium were 0.64, 0.32 and 0.96 per cent, respectively. Areca husk contains total calcium, magnesium and sulphur to an extent of 1.82, 1.07, and 0.31 per cent, respectively. The concentration of iron, manganese, zinc and copper were 26.4, 18.4, 25.2 and 0.94 mg kg^{-1} , respectively.

The pH of areca husk biochar was 7.3 with electrical conductivity of 0.36 dS m^{-1} , maximum water holding capacity (MWHC) of 59.44 per cent, bulk density of 0.74 Mg m^{-3} and total C content of 93.3 g kg^{-1} . The values of total nitrogen, phosphorus and potassium were 0.53, 0.71 and 3.04 per cent, respectively. Areca husk biochar contained total calcium, magnesium and sulphur to an extent of 2.16, 1.24, and 0.12 per cent, respectively. The concentration of iron, manganese, zinc and copper were 26.4, 43, 21.3 and 1.78 mg kg^{-1} , respectively.

3.5 Experimental details

Crop	Field bean
Design	RCBD
Replications	3
Treatments	9
Location	PG Center, AHRS, Bhavikere
Net plot size	3.0 m × 2.4m
Spacing	45 cm × 15 cm
Variety	HA-4
Season	Rabi, 2018-19
Date of sowing	25 th September, 2018
Date of harvesting	25 th December, 2018

Table 2: Characteristics of areca husk, areca husk biochar and FYM

Parameters	Areca husk	Areca husk biochar	FYM
pH (1:5)	6.3	7.3	7.19
Electrical conductivity (dSm ⁻¹) (1.5)	1.69	0.36	0.46
Bulk density (Mg m ⁻³)	0.24	0.74	-
Water holding capacity (%)	-	59.44	-
Total carbon (g kg ⁻¹)	50.75	93.31	88.61
Inorganic carbon (g kg ⁻¹)	0.01	0.18	0.15
Total organic carbon (g kg ⁻¹)	50.62	93.12	88.46
CEC [cmol (p ⁺) kg ⁻¹]	12.9	20.5	-
Nitrogen (%)	0.64	0.53	1.29
Phosphorus (%)	0.32	0.71	0.32
Potassium (%)	0.96	3.04	0.54
Calcium (%)	1.82	2.16	1.47
Magnesium (%)	1.07	1.24	0.73
Sulphur (%)	0.31	0.10	0.65
Fe (mg kg ⁻¹)	74.9	26.4	894.25
Zn (mg kg ⁻¹)	25.2	21.3	158.37
Cu (mg kg ⁻¹)	0.94	1.78	84.69
Mn (mg kg ⁻¹)	18.4	43.0	236.40

3.5.1 Treatment details

The plan and layout of the experiment is given in fig 1. The experiment comprised of nine treatments and details of the treatments are as follows:

T₁: Control (only NPK)

T₂: 100 % Rec. FYM + Rec. NPK

T₃: 100 % Rec. NPK and biochar equivalent to FYM

T₄: 100 % Rec. FYM + NPK + areca husk biochar @ 5 t ha⁻¹

T₅: 100 % Rec. FYM + NPK + areca husk biochar @ 7.5 t ha⁻¹

T₆: 100 % Rec. FYM + NPK + areca husk biochar @ 10 t ha⁻¹

T₇: 75 % Rec. FYM + NPK + areca husk biochar @ 5 t ha⁻¹

T₈: 75 % Rec. FYM + NPK + areca husk biochar @ 7.5 t ha⁻¹

T₉: 75 % Rec. FYM + NPK + areca husk biochar @ 10 t ha⁻¹

Recommended fertilizer dose to field bean is 25:50:25 kg N, P₂O₅ and K₂O ha⁻¹ applied as urea, di-ammonium phosphate and muriate of potash applied as per package of practice. Recommended dosage of FYM to field bean is 15 t ha⁻¹.

3.5.2 Variety and their salient feature

HebbalAvare-4 (HA-4) is a short duration variety released from UAS, GKVK, Bangalore during 2007. The seeds of HA-4 were procured from ZARS, GKVK, Bangalore. The plant emits characteristic odour and it matures in 70 to 90 days. It is semi-erect, leaflets innately trifoliate, inflorescence is a raceme with many flowers on elongated peduncles. Flowers borne on a straight upright stalk, often a foot high on which they open in succession, white in colour. Pods grow up to 4 to 5 cm long, oblong, flat and broad, firm-walled and contain three to four seeds with their long axis at right angles to the suture. Seeds are buff or pale brown-coloured, round in shape and produces seed yield of 10 to 12.5 q ha⁻¹.

3.5.3 Imposition of treatments, sowing and raising of field bean crop

The FYM @ 15 tons ha⁻¹ was applied to T₂, T₄, T₅, T₆ treatments and 11.25 tons ha⁻¹ was applied to T₇, T₈, T₉ treatments along with areca husk bio-char. Areca husk biochar along with FYM was spread uniformly and mixed along with soil across all the treatments two weeks prior to sowing. The next day irrigation was given to maintain the optimum moisture for decomposition of FYM and biochar. The N, P and K were applied through urea, DAP (di-ammonium phosphate) and MOP (muriate of potash) for all the treatments during sowing. Field bean seeds were sown in each

plot with a spacing of 45 cm in between the rows and 15 cm in between the plants. Weeds are removed as and when they appeared and also other inter-cultivation operation and plant protection measures were taken up as per package of practices.

3.6 Biometric observations

Five plants from each plot were randomly selected and labelled for recording growth parameters at different growth stages viz. 30 and 60 days after sowing (DAS) and at harvest of crop.

3.6.1 Plant height

Plant height of randomly selected labelled five plants was measured from the base of the plant to the tip of growing point and the average of five plants was expressed in centimeter at 30 and 60 DAS.

3.6.2 Number of leaves

Five plants were selected from each treatment and the average was counted at 30 and 60 DAS and expressed as number of leaves plant⁻¹.

3.6.3 Total dry matter production

Three plants were sampled randomly for dry matter studies at 30, 60 DAS and at harvest. The plant samples from each treatment were uprooted, washed with water, dried under shade for 2 days and then oven dried at 65 to 70 °C to get a constant weight. The mean dry weight of plants was recorded by pooling the observations of three selected plants and expressed in g plant⁻¹.

3.7 Yield and yield attributing parameters

The plants selected for growth studies were utilized for recording the observations on the following yield components.

3.7.1 Number of pods

Fully developed green pods were harvested from five plants and were counted and the average was taken as the number of pods plant⁻¹.

3.7.2 Pod length

Pods were harvested from five plants and the length of five pods is measured by standard scale and its average is expressed in cm.



Plate 2: Application of biochar to the experimental plot

3.7.3 Pod weight (g)

Pods were harvested from each five plants and an average weight of 10 pods was recorded and pod weight is expressed in grams.

3.7.4 Pod yield

Green pods were harvested from each net plot with three pickings and pod weight of the net plot was recorded and pod yield in quintal per hectare was calculated.

3.7.5 Hundred seed weight

Seed samples from produce of each plot were taken randomly and 100 healthy seeds were weighed separately and expressed in grams.

3.7.6 Number of seeds per pod

The seeds from ten representative pods were separated from each treatment, counted and the mean number of seeds per pod was calculated by dividing the number of seeds by the number of pods.

3.7.7 Haulm yield

Plants excluding pods from the net plot after harvest were sun dried for 10 days and their weight was recorded per plot through which haulm yield in quintal per hectare was calculated.

3.8 Plant analysis

3.8.1 Collection of plant samples

The plant samples were collected plot wise at the time of harvest and were dried at 60 °C in hot air oven after thorough cleaning with water, then powdered using a grinder fitted with stainless steel blades and preserved in polythene covers for further analysis (Jackson, 1973).

3.8.2 Total Nitrogen

Total nitrogen in plant samples was determined by Kjeldhal's method of nitrogen determination as described by Jackson (1973). In this method, powdered sample of 1.0 g was digested with concentrated H₂SO₄ in presence of digestion mixture (K₂SO₄: CuSO₄. 5H₂O : Se in the proportion of 100:20:1) and distilled under alkaline medium. The liberated NH₃ was trapped in 4 percent boric acid containing mixed indicator and titrated against standard H₂SO₄.

3.8.3 Digestion of plant sample with di-acid mixture

One gram of powdered plant sample was pre-digested with HNO₃ and then digested with di-acid mixture containing HNO₃ and HClO₄ in the proportion of 9:4 as described by Jackson (1973). The volume of the digest was made up to 100 ml with distilled water and used it for total elemental analysis.

3.8.4 Total phosphorus

A known volume of the di-acid digest was taken for total phosphorus determination using by vanadomolybdo phosphoric yellow colour method in nitric acid system as described by Jackson (1973).

3.8.5 Total potassium

Five ml of the di-acid digested extract was diluted to 25 ml with distilled water and fed to a calibrated flame photometer. By comparing the flame photometer reading of the sample with the calibration curve of potassium, per cent potassium in the plant sample was calculated (Piper, 1966).

3.8.6 Total calcium and magnesium

Calcium and magnesium in di-acid digested plant sample was estimated by complexometric titration method (Jackson, 1973).

3.8.7 Total sulphur

Sulphur in the di-acid digested sample was quantified by using BaCl₂ to develop turbidity following estimation of the sample at 420 nm (Piper, 1966).

3.8.8 Total plant micronutrients

Micronutrient cations in di-acid digested plant samples were determined by using Atomic Absorption Spectrophotometer using appropriate hollow cathode lamps as outlined by Lindsay and Norvell (1978).

3.8.9 Uptake of nutrients by field bean plant

The uptake of nutrients by different parts of field bean plants was worked out by multiplying the nutrient content and dry matter yield of the plant part as given in the following formulae;

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \% \text{ nutrient content} \times \text{dry matter yield (kg ha}^{-1}\text{)}$$



Plate 3: General view of experimental plot during flowering



Plate 4: Overview of experimental plot

3.9 Methods of soil analysis

3.9.1 Collection and preparation of soil sample

During the field experiment, a composite soil sample was drawn from each plot at 30, 60 DAS and at harvest of the field bean crop. The collected soil samples were dried under shade, powdered using wooden pestle and mortar and passed through 2 mm sieved samples were subjected for further grinding and passed through 0.2 mm sieve.

3.9.2 Particle size distribution

The relative proportion of sand, silt and clay particles present in soil sample was determined by international pipette method using sodium hexa-metaphosphate as a dispersing agent (Piper, 1966). The soil texture was identified based on the relative proportion of sand, silt and clay present in these soils using the textural diagram given by IUSS and USDA.

3.9.3 Water holding capacity

The maximum water holding capacity of soil was determined using Keen's cup as described by Piper (1966).

3.9.4 Bulk density

Bulk density of the disturbed soil samples was determined using glass vial method (Black, 1965).

3.9.5 Soil reaction (pH)

Soil pH was determined in 1:2.5 soil: water extract by potentiometric method using pH meter (Jackson, 1973).

3.9.6 Electrical conductivity

The electrical conductivity of soil was determined in the supernatant solution of 1:2.5 soil: water extract using conductivity meter (Jackson, 1973).

3.9.7 Cation exchange capacity

Ten grams of soil was leached several times with 100 ml of neutral normal ammonium acetate solution followed by washing with alcohol to remove excess of the electrolyte. The adsorbed NH_4^+ ions were displaced by K^+ ion by leaching the soil with 100 ml of 10 per cent KCl solution. Finally, the concentration of NH_4^+ ions in the leachate was determined by distillation method as described by Page *et al.* (1982).

3.9.8 Available nitrogen

Available nitrogen in the soil was determined by alkaline potassium permanganate method as described by Subbaiah and Asija (1956).

3.9.9 Available phosphorus

Available phosphorus was extracted from the soils using Bray's No.1 extractant ($0.03 \text{ N NH}_4\text{F} + 0.025 \text{ N HCl}$) and the concentration of phosphorus in the extract was determined by chlorostannous reduced molybdo phosphoric acid blue color in HCl system using spectrophotometer (Jackson, 1973).

3.9.10 Available potassium

Available potassium was extracted from the soils using neutral normal ammonium acetate in 1:5 soil to extractant ratio and the concentration of potassium present in the extract was determined by digital flame photometer (Jackson, 1973).

3.9.11 Exchangeable calcium and magnesium

The exchangeable calcium and magnesium were determined by leaching the soil with neutral normal ammonium acetate solution and calcium and magnesium in the leachate were determined by versenate titration method (Jackson, 1973).

3.9.12 Available sulphur

Available sulphate was determined by turbidometric method. The light transmittance was read on spectro-photometer at 420 nm (Black, 1965).

3.9.13 Available micronutrients

The available micronutrients in soil were extracted with DTPA- extractant ($0.005 \text{ M Diethylene Triamine Penta Acetic acid} + 0.01 \text{ M CaCl}_2 + 0.1 \text{ M Triethanol Amine}$) at 1:2 soil to extractant ratio as described by Lindsay and Norvell (1978). The concentration of zinc in the extract was determined by Atomic Absorption Spectrophotometer (AAS) under suitable measuring conditions (Page *et al.* 1982).

3.10 Carbon pools in soil

Estimation of total carbon (TC), total inorganic carbon (TIC) and total organic carbon (TOC) was carried out using Total Organic Carbon (TOC) analyzer following the catalytic combustion or oxidation method (Pradeepa, 2018).

The catalytic combustion method achieves total combustion of samples by heating them to 680°C 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 $4\mu\text{g L}^{-1}$ 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 $680\text{ }^{\circ}\text{C}$ 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 TC (Total Carbon) in the soil sample was obtained through comparison with a calibration curve

3.10.1 Total Carbon (TC)

About 50 to 80 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 $900\text{ }^{\circ}\text{C}$) within the sample combustion zone. At higher temperature, all the carbon within the soil sample got rapidly oxidized to CO_2 . 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.

3.10.2 Total Inorganic Carbon (TIC)

About 50 to 80 mg of soil sample was weighed into a silver boat then the soil sample was treated with the acid (HNO_3 80%) later the boat was placed into a quartz ladle which is introduced to the high temperature and oxygen atmosphere (typically 200°C) within the soil sample combustion zone. At higher temperature, all the carbon within the sample got rapidly oxidized to CO_2 and evolved CO_2 was carried to the detector by the carrier gas and the concentration of CO_2 was read through the infrared detector.

3.10.3 Total Organic Carbon (TOC)

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

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

Table 3: Methods followed for the analysis of areca husk and areca husk biochar

Sl. No.	Parameters	Methods	References
1	pH	pH was measured using pH meter in soil water suspension of 1: 5.	Jackson (1973)
2	EC (dS m ⁻¹)	Electrical conductivity was measured using conductivity bridge	Jackson (1973)
3	MWHC (%)	MWHC of biochar was measured by following Keen's cup method	Piper (1966)
4	Bulk density (Mg m ⁻³)	Glass vial method	Black (1965)
5	Nitrogen (%)	Biochar sample was digested using H ₂ SO ₄ + Selenium mixture followed by estimation in continues flow analyzer	Jackson (1973)
6	Phosphorus (%)	Phosphorus in di acid digested biochar sample was estimated by forming yellow colour phospho vanadomolybdate complex using spectrophotometer at 430nm.	Jackson (1973)
7	Potassium (%)	Potassium in diacid digested biochar sample was estimated with flame photometer	Jackson (1973)
8	Total calcium and magnesium	Calcium and magnesium in diacid digested biochar sample was estimated by complexometric titration method	Jackson (1973)
9	Sulphur (mg kg ⁻¹)	Sulphur in di acid digested biochar sample was quantified by using BaCl ₂ to develop turbidity following estimation	Black (1965)
10	Zinc (mg kg ⁻¹)	Micronutrient cations in di acid digested biochar samples were determined by using Atomic Absorption Spectrophotometer using appropriate hallow cathode lamps	Lindsay and Norwell (1978)
11	Iron (mg kg ⁻¹)		
12	Copper (mg kg ⁻¹)		
13	Manganese (mg kg ⁻¹)		

3.11 Estimation of soil enzymatic activities

3.11.1 Dehydrogenase activity

The dehydrogenase activity was determined by the procedure as given by Casida *et al.* (1964). Two grams of air-dried soil (< 2 mm) was thoroughly mixed with 0.2 g of CaCO₃ and one ml of 3% aqueous solution of 2, 3, 5-triphenyl tetrazolium chloride (TTC) and 2.5 ml of distilled water were added. The contents of each tube were mixed with a glass rod and the tubes were stoppered and incubated at 37 °C. After 24 hours, the stopper was removed and 20 ml of methanol was added to the tube and shaken for one minute and the suspension was filtered into a 50 ml volumetric flask through a glass funnel plugged with absorbent cotton. The soil in the tube was washed repeatedly till the filtrate coming from the tip of the funnel was colorless. Then, the volume was made to 50 ml with methanol. The intensity of reddish color was read using UV spectrophotometer at a wavelength of 485 nm with methanol as the blank. The amount of TPF (2, 3, 5-triphenyl formazan) produced was calculated using a standard graph prepared by using different concentrations of TPF standards. For this Ten ml of the TPF standard solution containing 1000 µg of TPF / ml was diluted to 50 ml with methanol to get TPF concentration of 50 µg TPF / ml, from this working TPF standards aliquots of 5, 10, 15, and 20 ml were pipetted into 100 ml volumetric flasks which had concentrations of 500, 1000, 1500 and 2000 µg of TPF/100 ml, respectively. The volume was made to 100 ml with methanol and mixed thoroughly and the intensity of red colour of TPF was measured as described earlier.

3.11.2 Acid phosphatase activity

The acid phosphatase activities were estimated as per the procedure given by Eivazi and Tabatabai (1977). For this, one-gram of each of the soil sample (< 2 mm) was placed in 50 ml Erlenmeyer flask and 0.2 ml of toluene, 4 ml of modified universal buffer (pH 6.5), 1ml of *p*-nitro phenyl phosphate solution made in the same buffer was added. The tubes were swirled for a few seconds to mix the contents. The tubes were then stoppered with rubber cork and placed in an incubator at 37 °C. After one hour the stoppers were removed and 1ml of 0.5 M CaCl₂ and 4 ml of 0.5 M NaOH were added. The soil suspension was filtered and the intensity of yellow colour of the supernatant was measured using UV spectrophotometer at 420 nm wave length.

The *p*-nitro phenol content of the filtrate was obtained by reference to a calibration graph plotted from the results obtained with standards containing 0, 10, 20, 30, 40, and 50 µg of *p*-nitro phenol. The control was performed with each soil analyzed to allow for colour not derived from *p*-nitro phenol released by phosphatase activity.

3.11.3 Urease activity

The assay of urease activity in soil involves estimation of urea hydrolysis in soils. It is achieved by determination of the urea remaining after incubation with soil at 37 °C for 5 hours. The rate of disappearance of urea from the system is taken as an estimation of urease activity. Urea is estimated colorimetrically, which involves the reaction of urea when heated with diacetylmonoxime (DAM) in the presence of thiosemicarbazide (TSC), H_3PO_4 and H_2SO_4 . The intensity of red colour formed as a result of this reaction is measured at 527 nm wavelength by spectrophotometer (McGarity and Myers, 1967).

3.12 Statistical analysis

The experimental data obtained was subjected to statistical analysis by adopting Fisher's method of analysis of variance (ANOVA) 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, was used wherever the 'F' test was found significant.

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

A field experiment was conducted during *Rabi* season 2018 at PG Center, AHRS, Bavikere, to study the influence of levels of areca husk biochar on carbon fractions and growth and yield of field bean.

Results of the investigation are presented in this chapter under the following sections.

- 4.1 Effect of different levels of biochar on physical properties in soil at harvest
- 4.2 Effect of different levels of biochar on physico-chemical properties of soil at harvest
- 4.3 Effect of different levels of biochar on chemical properties of soil at harvest
- 4.4 Effect of different levels of biochar on distribution of carbon fractions in soil at different growth stages of Field bean
- 4.5 Effect of different levels of biochar on dehydrogenase activity in soil at different intervals under Field bean
- 4.6 Effect of different levels of biochar on phosphatase enzyme activity in soil at different intervals under Field bean
- 4.7 Effect of different levels of biochar on urease enzyme activity in soil at different intervals under Field bean
- 4.8 Effect of different levels of biochar on growth parameters of Field bean
- 4.9 Effect of different levels of biochar on yield parameters of Field bean
- 4.10 Effect of different levels of biochar on nutrient content and uptake by Field bean

4.1 Effect of different levels of biochar on physical properties in soil at harvest

4.1.1 Bulk density

The data pertaining to effect of biochar application on bulk density of soil is presented in Table 4. There was no significant difference in bulk density due to the application of biochar, however decrease in bulk density is observed. Higher bulk density of soil was recorded in control (T_1) (1.36 Mg m^{-3}) which was followed by the treatment (T_2) receiving Rec. NPK and FYM. Whereas, lowest bulk density of soil was observed in the treatment receiving (T_6) 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (1.28 Mg m^{-3}) followed by T_9 (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}) (1.30 Mg m^{-3}).

Table 4: Effect of different levels of biochar on bulk density (BD) and maximum water holding capacity (MWHC) of soil under Field bean

Treatments	BD (Mg m⁻³)	MWHC (%)
T₁ : Control (only NPK)	1.36	33.34
T₂ : 100 % Rec. FYM + Rec. NPK	1.34	34.42
T₃ :100 % Rec. NPK and AHB equivalent to FYM	1.33	34.73
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	1.33	35.06
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	1.31	36.37
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	1.28	37.19
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	1.32	35.30
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	1.31	35.81
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	1.30	36.68
S. Em_±	0.01	0.66
C.D at 5%	NS	1.98

***AHB: Areca husk biochar**

4.1.2 Maximum water holding capacity (MWHC)

The data pertaining to effect of biochar application on MWHC of soil are presented Table 4. Biochar applied treatment (T₆) 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded significantly higher (37.19 %) MWHC in soil followed by the treatment (T₉) receiving 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (36.68 %). Lowest MWHC content in soil (33.34 %) was observed in the treatment receiving only recommended dose of NPK (T₁).

4.2 Effect of different levels of biochar on physico-chemical properties of soil at harvest

4.2.1 Soil pH

The data pertaining to effect of different levels of biochar in combination with FYM on soil pH is presented in Table 5. At harvest, significantly higher (6.78) pH of soil was recorded in treatment T₃ receiving a combination of RDF and biochar equivalent to FYM (6.78) followed by T₆ (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (6.73). Lowest pH in soil (6.05) was observed in the control (T₁) receiving only recommended dose of RDF followed by T₂ treatment (RDF along with FYM) (6.26).

4.2.2 Electrical conductivity

The data pertaining to effect of different levels of biochar application on soil electrical conductivity is presented in Table 5. At harvest, significantly lowest EC in the soil (0.20 dSm⁻¹) was observed in the control treatment whereas, the treatment receiving 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded higher EC in the soil (0.36 dS m⁻¹) followed by T₉ (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (0.31dS m⁻¹).

4.3 Effect of different levels of biochar on chemical properties of soil at harvest

4.3.1 Available nitrogen

Application of biochar at different quantities along with FYM had no significant difference on the available N status in the soil (Table 6). However there was marginal increase in available nitrogen as compared to control. Treatment T₆ (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) recorded higher available nitrogen status in the soil (271.79 kg ha⁻¹) followed by T₉ treatment (225.79 kg ha⁻¹) (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) and lowest available nitrogen status in the soil (234.16 kg ha⁻¹) was observed in the control treatment (T₁).

Table 5: Effect of different levels of biochar on pH and EC of soil under Field bean

Treatments	pH	EC (dS m⁻¹)
T₁ : Control (only NPK)	6.05	0.20
T₂ : 100 % Rec. FYM + Rec. NPK	6.26	0.23
T₃ :100 % Rec. NPK and AHB equivalent to FYM	6.78	0.27
T₄ :100 % Rec. FYM + NPK + AHB @ 5t ha⁻¹	6.40	0.30
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	6.51	0.32
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	6.73	0.36
T₇ :75 % Rec. FYM + NPK + AHB @ 5t ha⁻¹	6.39	0.29
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5t ha⁻¹	6.62	0.29
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	6.58	0.31
S. Em_±	0.14	0.02
C.D at 5%	0.42	0.08

***AHB: Areca husk biochar**

Table 6: Effect of different levels of biochar on available status of primary and secondary nutrients in soil under Field bean

Treatments	Avail. N	Avail. P ₂ O ₅	Avail. K ₂ O	Exch. Ca	Exch. Mg	Available S
	(kg ha ⁻¹)			[c mol (p ⁺) kg ⁻¹]		(mg kg ⁻¹)
T₁ : Control (only NPK)	225.79	64.80	214.01	4.90	1.80	18.45
T₂ : 100 % Rec. FYM + Rec. NPK	234.16	72.19	222.63	5.10	2.76	19.30
T₃ :100 % Rec. NPK and AHB equivalent to FYM	240.88	66.56	227.96	5.90	2.80	20.05
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	259.24	67.21	234.85	5.23	3.20	21.30
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	263.42	75.45	250.44	5.43	3.36	22.20
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	271.79	83.30	261.23	5.76	3.83	31.70
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	246.70	67.48	239.83	5.20	2.86	19.50
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	250.88	73.34	242.96	5.26	3.13	21.65
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	267.61	78.07	254.62	5.36	3.53	25.90
S. Em±	17.24	6.29	10.39	0.18	0.30	1.58
C.D at 5%	NS	18.86	31.17	0.55	0.91	4.74

*AHB: Areca husk biochar

4.3.2 Available phosphorus

The available P status increased in soil during harvest compared to initial soil and differed significantly due to the application of different levels of biochar and FYM (Table 6). Significantly higher (83.30 kg ha⁻¹) available P status was found in treatment T₆ (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) compared to control. However, it was on par with other treatments receiving biochar along with different levels of FYM, respectively. Lowest available P status in soil was observed in T₁ (control) (64.80 kg ha⁻¹).

4.3.3 Available potassium

Effect of biochar application at different quantities significantly influenced the available K status of the soil (Table 6).

At harvest, the treatment receiving biochar @ 10 t ha⁻¹ + RDF + FYM (T₆) recorded significantly highest available potassium status in the soil (261.23 kg ha⁻¹), which was on par with the treatments T₅ and T₉. Significantly lowest available potassium status in the soil (214.01 kg ha⁻¹) was observed in control treatment (T₁) followed by T₂ treatment with Rec. NPK and FYM (222.63 kg ha⁻¹).

4.3.4 Exchangeable calcium

Application of biochar at different quantities significantly influenced the exchangeable Ca status of soil (Table 6). During harvest, highest exchangeable calcium status in the soil [5.90 c mol (p⁺) kg⁻¹] was recorded in T₃ treatment in which Rec. NPK and biochar equivalent to FYM is applied followed by T₆ treatment receiving 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ [5.76 c mol (p⁺) kg⁻¹]. Lowest exchangeable calcium status of soil [4.90 c mol (p⁺) kg⁻¹] was recorded in control (T₁).

4.3.5 Exchangeable magnesium

Significant differences were found between treatments with respect to exchangeable magnesium status. Significantly higher [3.83 cmol (p⁺) kg⁻¹] exchangeable magnesium was recorded in 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) treatment, whereas significantly lower magnesium value of 1.80 cmol (p⁺) kg⁻¹ was found in T₁ treatment (control).

4.3.6 Available sulphur

Application of biochar at different quantities significantly influenced the Available sulphur status of soil (Table 6). The available sulphur status in soil showed significant difference among the treatments. However, the highest available sulphur

status (31.70 mg kg^{-1}) was found with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6). The lower sulphur status (18.45 mg kg^{-1}) was found in control (T_1) (18.45 mg kg^{-1}) followed by T_2 treatment (Rec. NPK with FYM) (19.30 mg kg^{-1}).

4.3.7 DTPA extractable micronutrients

A significant difference was found with respect to DTPA extractable Fe, Zn, Cu and Mn in soil after harvest of field bean crop due to imposition of different treatments.

Significant effect of various levels of biochar on DTPA extractable Fe content was recorded in soil at harvest (Table 7). Significantly higher Fe content in soil (23.97 kg ha^{-1}) was recorded with 100 per cent Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6) followed by treatment T_9 (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}) (22.47 mg kg^{-1}) and was on par with other treatments receiving biochar along with FYM. Significantly lower Fe content was observed in T_3 treatment receiving biochar equivalent to FYM and followed by control (T_1) (17.87 and 18.72 mg kg^{-1} , respectively) as compared to T_6 .

The zinc content in soil differed significantly due to different treatments imposed (Table 7). Significantly higher zinc content in soil was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6) (1.93 mg kg^{-1}) and followed by (T_5) 100 % Rec. FYM + NPK + biochar @ 7.5 t ha^{-1} treatments (1.88 mg kg^{-1}) and is on par with other treatments applied with biochar along with FYM. Significantly lower zinc content was observed in control (T_1) (1.57 mg kg^{-1}) and followed by T_3 treatment receiving RDF with biochar equivalent to FYM (1.67 mg kg^{-1}).

Significant effect of various levels of biochar application on DTPA extractable Cu status was recorded in soil at harvest (Table 7). Significantly higher Cu status in soil (3.83 mg kg^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6) and followed by T_9 (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}) (3.53 mg kg^{-1}) and was on par with other treatments receiving biochar along with FYM. Significantly lower Cu content was observed in control (T_1) (1.80 mg kg^{-1}) and followed by T_3 treatment receiving FYM along with Rec. NPK (2.76 mg kg^{-1}).

The Mn status differed non-significantly in soil (Table 7) with the application of different levels of biochar at harvest. Among different treatment combinations, application of biochar and 100% Rec. FYM (T_6) recorded higher Mn status (5.62 mg kg^{-1}) followed by T_9 treatment with biochar and 75 per cent Rec. FYM (5.54 mg kg^{-1}). Significantly lower manganese status was observed in receiving biochar equivalent to FYM (T_3) (4.29 mg kg^{-1}) followed by control treatment (4.37 mg kg^{-1}), respectively.

Table 7: Effect of different levels of biochar on DTPA extractable micronutrients in soil under Field bean

Treatments	Fe	Zn	Cu	Mn
	(mg kg ⁻¹)			
T₁ : Control (only NPK)	18.72	1.57	1.80	4.37
T₂ : 100 % Rec. FYM + Rec. NPK	21.05	1.69	2.76	4.70
T₃ :100 % Rec. NPK and AHB equivalent to FYM	17.87	1.67	2.80	4.29
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	21.88	1.76	3.20	5.20
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	22.17	1.88	3.36	5.41
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	23.97	1.93	3.83	5.62
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	21.29	1.76	2.86	5.29
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	21.32	1.80	3.13	5.38
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	22.47	1.87	3.53	5.54
S. Em±	1.08	0.06	0.30	0.35
C.D at 5%	3.25	0.20	0.91	NS

***AHB: Areca husk biochar**

4.4 Effect of different levels of biochar on distribution of carbon fractions in soil at different growth stages of field bean

4.4.1 Total carbon

The results pertaining to the effect of biochar application on total carbon (TC) in soil are presented in Table 8. Application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded significantly higher value (14.43, 15.43 and 15.70 g kg⁻¹ at 30, 60 DAS and at harvest, respectively) followed by the application of 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (14.38, 15.25 and 15.30 g kg⁻¹ at 30, 60 DAS and at harvest, respectively). Lower values were noticed with the application recommended dose of NPK (T₁) (9.47, 8.25 and 8.06 g kg⁻¹ 30, 60 DAS and at harvest, respectively).

4.4.2 Total organic carbon

Application of biochar and FYM with their combination increased the soil total organic carbon (TOC) which is presented in Table 9 at 30 DAS and was found to be non significant, whereas, at 60 and 90 DAS significant difference was observed as compared to control (T₁). The treatment T₆ receiving 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded higher amount of TOC at all the stages of crop growth, respectively over all other treatments. The highest TOC status (14.21, 15.16 and 15.30 g kg⁻¹ at 30, 60 DAS and at harvest, respectively) was recorded in treatment with 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆). Lowest TOC content (9.29, 8.04 and 7.72 g kg⁻¹ at 30, 60 DAS and at harvest, respectively) was recorded in control treatment (T₁).

4.4.3 Total inorganic carbon

The results pertaining to the effect of biochar application on total inorganic carbon (TIC) in soil are presented in Table 10. Application of 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded no significant difference but higher value on total inorganic carbon (0.23, 0.28 and 0.40 g kg⁻¹ at 30, 60 DAS and at harvest, respectively) followed by the application of 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (0.21, 0.26 and 0.38 g kg⁻¹) at 30, 60 DAS and at harvest, respectively). Lower values were noticed with the application recommended dose of NPK only (T₁) (0.19, 0.21 and 0.34 g kg⁻¹ at 30, 60 DAS and at harvest, respectively).

Table 8: Effect of different levels of biochar on total carbon content in soil at different growth stages of Field bean

Treatments	Total carbon (g kg ⁻¹)		
	30 DAS	60 DAS	Harvest
T₁ : Control (only NPK)	9.47	8.25	8.06
T₂ : 100 % Rec. FYM + Rec. NPK	11.65	12.56	13.78
T₃ :100 % Rec. NPK and AHB equivalent to FYM	11.57	12.29	13.61
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	13.19	14.29	15.17
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	14.11	15.20	15.50
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	14.43	15.43	15.70
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	12.98	13.76	14.16
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	13.97	14.72	14.89
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	14.38	15.25	15.30
S. Em±	1.13	1.21	1.01
C.D at 5%	NS	3.65	3.03

*AHB: Areca husk biochar, DAS: Days after sowing

Table 9: Effect of different levels of biochar on total organic carbon in soil at different growth stages of Field bean

Treatments	Total organic carbon(g kg ⁻¹)		
	30 DAS	60 DAS	Harvest
T₁ : Control (only NPK)	9.29	8.04	7.72
T₂ : 100 % Rec. FYM + Rec. NPK	11.44	12.32	13.41
T₃ :100 % Rec. NPK and AHB equivalent to FYM	11.34	12.06	13.29
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	12.98	14.03	14.79
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	13.89	14.93	15.10
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	14.21	15.16	15.30
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	12.78	13.50	13.79
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	13.77	14.47	14.51
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	14.17	14.99	14.92
S. Em±	1.14	1.21	1.02
C.D at 5%	NS	3.63	3.08

***AHB: Areca husk biochar, DAS: Days after sowing**

Table 10: Effect of different levels of biochar on total inorganic carbon content in soil at different growth stages of Field bean

Treatments	Total inorganic carbon (g kg ⁻¹)		
	30 DAS	60 DAS	Harvest
T₁ : Control (only NPK)	0.19	0.21	0.34
T₂ : 100 % Rec. FYM + Rec. NPK	0.21	0.24	0.37
T₃ :100 % Rec. NPK and AHB equivalent to FYM	0.23	0.23	0.32
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	0.21	0.27	0.38
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	0.22	0.27	0.39
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	0.23	0.28	0.40
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	0.20	0.27	0.37
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	0.21	0.25	0.38
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	0.21	0.26	0.38
S. Em±	0.07	0.06	0.03
C.D at 5%	NS	NS	NS

***AHB: Areca husk biochar, DAS: Days after sowing**

4.5 Effect of different levels of biochar on dehydrogenase activity in soil at different intervals in field bean

Result on the effect of biochar levels and FYM on dehydrogenase activity (TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) in soil at different intervals of field bean is presented in Table 11. At 30, 60 DAS and at harvest of crop, dehydrogenase activity varied due to various levels of biochar application and higher values were recorded in 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) and the enzyme activity increased and later decreased with crop growth at different intervals of field bean.

At 30 DAS, among the treatments, 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) treatment recorded highest dehydrogenase activity (16.06 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) followed by T₉ (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) treatment with 15.93 $\mu\text{g h}^{-1} \text{g}^{-1}$ soil and were significantly higher compared to rest of the treatments. Lowest dehydrogenase activity in field bean (10.25 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) was recorded in control (T₁) followed by T₃ treatment (Rec. NPK + biochar equivalent to FYM) (7.64 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil).

At 60 DAS, treatment T₆ receiving 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded highest dehydrogenase activity (22.36 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) followed by T₉ treatment (75% Rec. FYM + NPK + biochar @ 10 t ha⁻¹) with 21.24 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil and were significantly higher compared to rest of the treatments. Lowest dehydrogenase activity in field bean (14.01 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) was found in control (T₁) followed by T₃ treatment (Rec. NPK + biochar equivalent to FYM) (16.89 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil).

At harvest, T₆ treatment with 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded highest dehydrogenase activity (13.77 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) followed by T₉ treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) with 13.68 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil and were significantly higher compared to rest of the treatments. Lowest dehydrogenase activity in field bean was found in control (T₁) (8.36 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) followed by T₃ treatment (Rec. NPK + biochar equivalent to FYM) (9.33 TPF $\mu\text{g h}^{-1} \text{g}^{-1}$ soil) treatment.

4.6 Effect of different levels of biochar on acid phosphatase activity in soil at different intervals in field bean

Result on the effect of biochar levels in combination with FYM on phosphatase enzyme activity in soil at different intervals of field bean is presented in Table 12. Acid phosphatase enzyme activity ($\mu\text{g PNP h}^{-1} \text{g}^{-1}$ soil) in soil varied at all the stages due to various levels of biochar and FYM application.

Table 11: Effect of different levels of biochar on dehydrogenase activity in soil at different growth stages of Field bean

Treatments	Dehydrogenase activity ($\mu\text{g TPF h}^{-1} \text{g}^{-1}$)		
	30 DAS	60 DAS	Harvest
T ₁ : Control (only NPK)	10.25	14.01	8.36
T ₂ : 100 % Rec. FYM + Rec. NPK	12.42	18.40	11.32
T ₃ :100 % Rec. NPK and AHB equivalent to FYM	11.64	16.87	9.33
T ₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	14.27	20.56	11.73
T ₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	15.88	20.77	12.21
T ₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha ⁻¹	16.06	22.36	13.77
T ₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	14.10	20.30	11.56
T ₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	15.80	20.67	12.14
T ₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha ⁻¹	15.93	21.24	13.68
S. Em $\pm$	1.07	1.57	0.84
C.D at 5%	3.21	4.72	2.52

*AHB: Areca husk biochar

Table 12: Effect of different levels of biochar on acid phosphatase activity in soil at different growth stages of Field bean

Treatments	Acid phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ hr}^{-1}$)		
	30 DAS	60 DAS	Harvest
T ₁ : Control (only NPK)	23.52	28.34	32.80
T ₂ : 100 % Rec. FYM + Rec. NPK	28.64	31.92	35.40
T ₃ :100 % Rec. NPK and AHB equivalent to FYM	26.10	30.58	34.03
T ₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	30.16	33.54	36.38
T ₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	32.44	34.04	36.86
T ₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha ⁻¹	35.43	36.22	38.35
T ₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	30.01	33.11	35.81
T ₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	31.50	33.57	36.10
T ₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha ⁻¹	32.72	33.88	37.07
S. Em $\pm$	2.20	1.13	0.99
C.D at 5%	6.62	3.39	2.97

* AHB: Areca husk biochar

At 30 DAS, among the treatments, T₆ treatment receiving 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded highest acid phosphatase enzyme activity (35.43 µg PNP h⁻¹ g⁻¹ soil) followed by T₉ treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) with 32.72 µg PNP h⁻¹ g⁻¹ soil and were significantly higher compared to rest of the treatments. Lowest acid phosphatase enzyme activity in field bean was found in control (T₁) (23.52 µg PNP h⁻¹ g⁻¹ soil) followed by T₃ treatment (Rec. NPK and biochar only) 26.10 µg PNP h⁻¹ g⁻¹ soil).

Similar trend of variation in the acid phosphatase enzyme activity was observed at 60 DAS. At 60 DAS, treatment T₆ (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) recorded significantly higher acid phosphatase enzyme activity (36.22 µg PNP h⁻¹ g⁻¹ soil). Lowest values of acid phosphatase enzyme activity in soil were recorded in T₁ (control) treatment (28.34 µg PNP h⁻¹ g⁻¹ soil).

Even at harvest of crop, among the treatments, 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆ treatment) recorded highest acid phosphatase enzyme activity (38.35 µg PNP h⁻¹ g⁻¹ soil) followed by T₉ treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) with (37.07 µg PNP h⁻¹ g⁻¹ soil) and were on par with rest of the treatments in which FYM in combination with biochar was applied. Lowest acid phosphatase enzyme activity in field bean was found in control (T₁) (32.80 µg PNP h⁻¹ g⁻¹ soil) followed by T₃ treatment (Rec. NPK and biochar only) (34.03 µg PNP h⁻¹ g⁻¹ soil).

4.7 Effect of different levels of biochar on urease activity in soil at different intervals in field bean

Result on the effect of biochar levels and FYM on urease activity (µg NH₄⁺-N g⁻¹ hr⁻¹ soil) in soil at different intervals of field bean is presented in Table 13. At 30, 60 DAS and at harvest of crop, urease activity varied due to various levels of biochar application and higher values were recorded in T₆ treatment receiving 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ and the urease enzyme activity increased and later decreased with different intervals of field bean. Lower values of enzyme activity were recorded at harvest of the crop.

At 30 DAS, among the treatments, T₆ treatment receiving 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded highest urease activity (137.22 µg NH₄⁺-N g⁻¹ hr⁻¹ soil) followed by T₉ (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) treatment with 133.14 µg NH₄⁺-N g⁻¹ hr⁻¹ g⁻¹ soil and were significantly higher. Lowest urease activity in field bean was found in control (T₁) (98.26 µg NH₄⁺-N g⁻¹ hr⁻¹ g⁻¹ soil) followed by T₃ treatment (Rec. NPK + biochar equivalent to FYM) (111.86 µg NH₄⁺-N g⁻¹ hr⁻¹ g⁻¹ soil).

Table 13: Effect of different levels of biochar on urease activity in soil at different growth stages of Field bean

Treatments	Urease activity ($\mu\text{g NH}_4^+ - \text{N g}^{-1} \text{ hr}^{-1}$)		
	30 DAS	60 DAS	Harvest
T₁ : Control (only NPK)	98.26	80.65	50.37
T₂ : 100 % Rec. FYM + Rec. NPK	113.29	104.78	55.26
T₃ :100 % Rec. NPK and AHB equivalent to FYM	111.86	92.66	47.06
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	121.66	112.78	62.21
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	130.44	119.20	66.25
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	137.22	122.17	71.94
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	118.81	109.50	60.66
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	126.89	114.19	63.92
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	133.14	120.78	67.10
S. Em $\pm$	5.37	4.84	4.96
C.D at 5%	16.12	14.52	14.89

***AHB: Areca husk biochar**

At 60 DAS T₆ treatment 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded highest urease activity (122.17 µg NH₄⁺-N g⁻¹ hr⁻¹ soil) followed by T₉ treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) with 133.14 µg NH₄⁺-N g⁻¹ hr⁻¹ g⁻¹ soil and were significantly higher compared to rest of the treatments. Lowest urease activity in field bean was recorded in control (T₁) (80.65 µg NH₄⁺-N g⁻¹ hr⁻¹ soil) followed by T₃ treatment receiving Rec. NPK + biochar equivalent to FYM (92.66 µg NH₄⁺-N g⁻¹ hr⁻¹).

At harvest, T₆ treatment with 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded highest urease activity (71.94 µg NH₄⁺-N g⁻¹ hr⁻¹ soil) followed by T₉ treatment receiving 75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (67.10 µg NH₄⁺-N g⁻¹ hr⁻¹ g⁻¹ soil) and were significantly higher compared to rest of the treatments. Lowest urease activity in field bean was found in control (T₁) (50.37 µg NH₄⁺-N g⁻¹ hr⁻¹ soil) followed by T₃ treatment receiving Rec. NPK + biochar equivalent to FYM (47.06 µg NH₄⁺-N g⁻¹ hr⁻¹) treatment.

4.8 Effect of different levels of biochar on growth parameters of field bean

Data recorded on growth parameters like plant height, number of leaves plant⁻¹ and total dry matter accumulation of field bean is given in Table 14.

4.8.1 Plant height

Plant height was influenced by the treatments at all the growth stages of field bean. Application of higher biochar levels along with FYM had no significant difference in the plant height but increase in plant height was observed at 30 days after sowing (DAS). Among the treatments, treatment T₆ (100 % Rec. FYM + RDF + biochar @ 10 t ha⁻¹) recorded higher plant height (26.85 cm) followed by application of 75 per cent Rec. FYM + RDF + biochar @ 10 t ha⁻¹ (T₉) (25.07 cm) and T₅ (100 % Rec. FYM + NPK + biochar @ 7.5 t ha⁻¹) (24.10 cm). Lowest value of plant height at 30 DAS (19.60 cm) was recorded in control followed by application of biochar with NPK (T₃) treatment (20.15 cm).

At 60 DAS, biochar levels along with FYM significantly influenced the plant height. Treatment T₆ (100 % Rec. FYM + RDF + biochar @ 10 t ha⁻¹) recorded significantly higher plant height (62.13 cm) followed by application of 75 % Rec. FYM + RDF + biochar @ 10 t ha⁻¹ (T₉) (58.80 cm) and were significantly superior over the treatment that were not applied with biochar and FYM. At 60 DAS, lowest plant height of 49.76 cm was recorded in control followed by 52.03 cm in application of biochar in combination with NPK.

Table 14: Effect of different levels of biochar on plant height, number of leaves and dry matter accumulation at different growth stages of field bean

Treatments	Plant height (cm)		No. of leaves plant ⁻¹		Dry matter accumulation (g)		
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	Harvest
T₁ : Control (only NPK)	19.60	49.76	6.86	8.70	6.99	16.95	19.24
T₂ : 100 % Rec. FYM + Rec. NPK	21.85	53.10	7.26	9.30	7.32	20.17	22.37
T₃ :100 % Rec. NPK and AHB equivalent to FYM	20.15	52.03	7.53	9.16	7.20	18.84	21.49
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	22.33	56.20	7.66	9.60	7.57	21.68	23.64
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	24.10	57.16	7.80	9.84	7.87	23.26	25.61
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	26.85	62.13	8.13	12.00	8.16	24.36	27.54
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	21.92	53.43	7.53	9.43	7.24	20.92	23.97
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	23.20	54.60	7.60	9.56	7.69	22.82	24.52
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	25.07	58.80	7.900	10.96	8.00	23.63	26.92
S. Em+	1.44	2.033	0.55	0.62	0.24	1.47	1.63
C.D at 5%	NS	6.09	NS	1.87	0.727	4.40	4.89

***AHB: Areca husk biochar, DAS: Days after sowing**

4.8.2 Number of leaves

The data pertaining to number of leaves plant⁻¹ as influenced by the FYM, RDF and different levels of biochar are presented in Table 14. Number of leaves plant⁻¹ differed non-significantly during 30 DAS and significant results were observed at 60 DAS. Application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded higher number of leaves plant⁻¹ at 30 and 60 DAS (8.13 and 12.00, respectively) as compared to other treatments. It was followed by the application of 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (7.90 & 10.96 at 30 & 60 DAS, respectively). Shorter plants were noticed in the control treatment (6.86 & 8.70 at 30 and 60 DAS, respectively).

4.8.3 Total dry matter accumulation

The data pertaining to total dry matter accumulation in plants as influenced by various treatments at 30, 60 DAS and at harvest are presented in Table 14.

The treatments receiving biochar along with FYM recorded higher total dry matter accumulation than biochar alone. The total dry matter plant⁻¹ increased progressively from 30 DAS till harvest in all the treatments.

The total dry matter accumulation plant⁻¹ differed significantly due to various treatments at all the stages of field bean. Among different treatments, application of higher dose of biochar (10 t ha⁻¹) with FYM (T₆) resulted in increased total dry matter accumulation (8.16 g, 24.36 g and 27.54 g at 30, 60 DAS and at harvest, respectively) and was on par with other treatments receiving different levels of biochar along with FYM at all the stages of growth as compared to all the other treatments. The lowest dry matter accumulation plant⁻¹ (6.99 g, 16.95 g and 19.24 g at 30, 60 DAS and at harvest, respectively) was recorded in treatment receiving only RDF (T₁).

4.9 Effect of different levels of biochar on yield parameters of field bean

The data pertaining to yield and yield parameters in Field bean as influenced by various treatments are presented in Table 15.

4.9.1 Number of pods

There was significant difference recorded with respect to number of pods plant⁻¹ of field bean due to application of different levels of biochar and FYM. Higher number of pods plant⁻¹ (37.00) was observed in T₆ treatment (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) followed by T₉ (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (34.67). Lowest number of pods plant⁻¹ (27.33) was recorded in control treatment followed by T₃ treatment (28.67) receiving RDF and biochar application equivalent to FYM.

Table 15: Effect of different levels of biochar on yield parameters of Field bean

Treatments	Number of pods (plant ⁻¹)	Pod length (cm)	Test weight (100 seed in g)	Pod yield (g plant ⁻¹)	Pod weight (g)	Total pod yield (q ha ⁻¹)	Haulm yield (q ha ⁻¹)
T₁ : Control (only NPK)	27.33	5.10	13.73	39.05	2.00	23.89	13.39
T₂ : 100 % Rec. FYM + Rec. NPK	30.67	5.20	15.10	42.81	2.15	30.18	16.31
T₃ :100 % Rec. NPK and AHB equivalent to FYM	28.67	5.13	14.90	40.96	2.12	25.10	14.63
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	32.00	5.30	15.46	45.13	2.18	32.52	19.01
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	34.00	5.33	16.13	48.58	2.22	33.67	20.92
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	37.00	5.33	16.56	51.72	2.29	35.77	21.56
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	31.33	5.20	15.16	42.77	2.12	31.70	18.02
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	32.67	5.26	15.96	46.56	2.15	32.49	19.91
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	34.67	5.30	16.36	50.97	2.18	34.54	20.67
S. Em ±	1.29	0.08	0.38	2.72	0.04	1.81	1.21
C.D at 5%	3.86	NS	1.14	8.17	0.13	5.44	3.64

***AHB: Areca husk biochar**

4.9.2 Pod length

There was a non-significant difference observed in pod length of field bean among different treatments after harvest. However, the highest pod length (5.33 cm) was found in T₅ (100 % Rec. FYM + NPK + biochar @ 7.5 t ha⁻¹) and T₆ treatment (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹). The lowest pod length was found with control (T₁) treatment (5.10 cm) followed by T₃ treatment receiving biochar equivalent to FYM (5.13).

4.9.3 100 seed weight

The 100 seed weight varied significantly among the different treatments imposed (Table 15). Treatment which received 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) showed significantly higher (16.56 g) seed weight followed by T₉ (16.36 g) with 7.5 t ha⁻¹ biochar application in combination with FYM, whereas other treatments were found to be on par with each other. Significantly lowest 100 seed weight (13.73 g) was found in control followed by T₃ treatment (14.90 g) with RDF and biochar equivalent to FYM.

4.9.4 Pod weight

Significant increase in pod weight of field bean due to application of different levels of biochar along with FYM is observed. Significantly higher pod weight (2.29 g) was observed in T₆ treatment (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) and was found on par with T₉ treatments (2.18 g) (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) and T₄ (100 % Rec. FYM + NPK + biochar @ 5 t ha⁻¹). Significantly lower pod weight (2.00 g) was recorded in control (T₁) followed by T₃ treatment receiving biochar equivalent to FYM (2.12 g) and T₇ treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (2.12 g).

4.9.5 Pod yield

Significant difference was recorded with respect to pod yield (g plant⁻¹) of field bean due to application of different levels of biochar along with FYM. Significantly higher pod yield per plant (51.72 g) was observed in T₆ treatment (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) and was found on par with T₉ treatments. Significantly lower pod yield (39.05 g) was recorded in control (T₁) followed by T₃ treatment receiving biochar equivalent to FYM (40.96 g).

4.9.6 Total yield

Significant increase in pod yield of field bean was recorded due to application of different levels of biochar and FYM (Table 15). Significantly higher pod yield (35.77 q ha⁻¹) was recorded with T₆ treatment (100 % Rec. FYM + NPK + biochar @

10 t ha⁻¹) followed by T₉ (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (34.54 q ha⁻¹) and T₅ (100 % Rec. FYM + NPK + biochar @ 7.5 t ha⁻¹) (33.67 q ha⁻¹). The lowest pod yield of 23.89 q ha⁻¹ was found in T₁ (control) followed by T₃ treatment receiving biochar equivalent to FYM (25.10 q ha⁻¹).

4.9.7 Haulm yield

There was a significant difference in haulm yield of field bean due to different levels of biochar and FYM. Significantly higher haulm yield of 21.56 q ha⁻¹ was recorded with application of 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) and was on par with T₅ (75 % Rec. FYM + NPK + biochar @ 7.5 t ha⁻¹) (20.92 q ha⁻¹) and T₉ (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (20.67 q ha⁻¹) treatment. The lowest haulm yield of 13.39 q ha⁻¹ was recorded in control (T₁) followed by 14.63 q ha⁻¹ in T₃ treatment receiving biochar equivalent to FYM.

4.10 Effect of different levels of biochar on nutrient content and uptake by field bean

4.10.1 Macronutrient content

The results pertaining to the effect of levels of different levels of biochar along with FYM on available N, P and K content in pod and haulm at harvest of field bean are presented in Table 16. The N, P and K content in pods and haulm of field bean differed significantly due to imposition of different treatments.

Significantly higher nitrogen content in pod (3.35 %) and haulm (1.57 %) was recorded in 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) and was on par with T₅ (100 % Rec. FYM + NPK + biochar @ 7.5 t ha⁻¹) and T₉ treatment receiving 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹. The significantly lower content in pod (2.63 %) and haulm (1.11 %) of nitrogen were found in control (T₁) and followed by T₃ treatment receiving biochar equivalent to FYM in both pod and haulm (2.83 and 1.33 %), respectively.

Significantly higher phosphorus content in pod (0.49 %) and haulm (0.30 %) was recorded in T₆ treatment receiving 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) and followed by T₉ treatment 75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (0.47 % and 0.28 %, respectively). The significantly lower content in pod (0.39 %) and haulm (0.21 %) of phosphorus were found in control (T₁) and followed by T₃ treatment receiving biochar equivalent to FYM, in both pod and haulm (0.42 and 0.23 %) respectively.

Table 15: Effect of different levels of biochar on yield parameters of Field bean

Treatments	Number of pods (plant ⁻¹)	Pod length (cm)	Test weight (100 seed in g)	Pod yield (g plant ⁻¹)	Pod weight (g)	Total pod yield (q ha ⁻¹)	Haulm yield (q ha ⁻¹)
T ₁ : Control (only NPK)	27.33	5.10	13.73	39.05	2.00	23.89	13.39
T ₂ : 100 % Rec. FYM + Rec. NPK	30.67	5.20	15.10	42.81	2.15	30.18	16.31
T ₃ :100 % Rec. NPK and AHB equivalent to FYM	28.67	5.13	14.90	40.96	2.12	25.10	14.63
T ₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	32.00	5.30	15.46	45.13	2.18	32.52	19.01
T ₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	34.00	5.33	16.13	48.58	2.22	33.67	20.92
T ₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha ⁻¹	37.00	5.33	16.56	51.72	2.29	35.77	21.56
T ₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	31.33	5.20	15.16	42.77	2.12	31.70	18.02
T ₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	32.67	5.26	15.96	46.56	2.15	32.49	19.91
T ₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha ⁻¹	34.67	5.30	16.36	50.97	2.18	34.54	20.67
S. Em ±	1.29	0.08	0.38	2.72	0.04	1.81	1.21
C.D at 5%	3.86	NS	1.14	8.17	0.13	5.44	3.64

*AHB: Areca husk biochar

Table 16: Effect of different levels of biochar on N, P and K content in Field bean

Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Pod	Haulm	Pod	Haulm	Pod	Haulm
T₁ : Control (only NPK)	2.63	1.11	0.39	0.21	1.11	1.50
T₂ : 100 % Rec. FYM + Rec. NPK	3.09	1.37	0.43	0.24	1.15	1.61
T₃ :100 % Rec. NPK and AHB equivalent to FYM	2.83	1.33	0.42	0.23	1.13	1.56
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	3.18	1.41	0.46	0.25	1.18	1.83
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	3.31	1.45	0.47	0.28	1.24	1.97
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	3.35	1.57	0.49	0.30	1.42	2.07
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	3.11	1.39	0.45	0.23	1.17	1.67
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	3.28	1.39	0.46	0.26	1.19	1.82
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	3.30	1.44	0.47	0.28	1.36	2.04
S. Em+	0.15	0.07	0.04	0.01	0.06	0.12
C.D at 5%	0.45	0.22	NS	0.05	0.19	0.37

***AHB: Areca husk biochar**

Significantly higher potassium content in pod (1.42 %) and haulm (2.07 %) was recorded in T₆ treatment 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ followed by T₉ treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹). Significantly lower content of K in pod (1.11 %) and haulm (1.50 %) were found in control (T₁) followed by T₃ treatment receiving FYM and NPK in both pod and haulm (1.13 and 1.56 %) respectively.

4.10.2 Secondary nutrients content

The results pertaining to the effect of levels of different levels of biochar along with FYM on available Ca, Mg and S content in pod and haulm at harvest of field bean are presented in Table 17.

The calcium content in pod and haulm of pod bean differed significantly due to imposition of different treatments. Calcium content decreased in pod and haulm due to combined application of biochar and FYM over treatments. However, higher calcium content in pod and haulm was recorded in T₂ (100 % Rec. NPK with FYM) (1.40 and 5.36 %) followed by control (T₁) (1.26 and 4.16 %) whereas lower calcium content was recorded in T₃ treatment (NPK + biochar equivalent to FYM) (1.09 and 3.06 %) in higher rate of biochar application without FYM.

The magnesium content in field bean pod and haulm differed due to different treatments imposed (Table 17). Higher magnesium content in pod (0.50 %) and haulm (0.50 %) was recorded in 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) treatment and followed by T₅ treatment (100 % Rec. FYM + NPK + biochar @ 7.5 t ha⁻¹) in pod and haulm and is on par with other treatments applied with biochar along with FYM. Significantly lower content of Mg in T₃ treatment receiving biochar equivalent to FYM, in both pod and haulm (0.49 and 0.37 %) followed by control (T₁) (0.52 and 0.41 %, respectively).

The sulphur content in field bean pod differed significantly but no significant difference was observed in haulm due to different treatments imposed (Table 17). Higher sulphur content in pod (0.23 %) and haulm (0.16 %) was recorded with 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) and followed by T₉ (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) and T₂ treatments. Lower content of S in pod (0.18 %) and haulm (0.13 %) were found in control (T₁) and followed by T₃ treatment receiving biochar equivalent to FYM in both pod and haulm (0.19 and 0.14 %) respectively.

Table 17: Effect of different levels of biochar on Ca, Mg and S content of Field bean

Treatments	Calcium (%)		Magnesium (%)		Sulphur (%)	
	Pod	Haulm	Pod	Haulm	Pod	Haulm
T₁ : Control (only NPK)	1.26	4.16	0.52	0.41	0.18	0.13
T₂ : 100 % Rec. FYM + Rec. NPK	1.40	5.36	0.56	0.43	0.20	0.16
T₃ :100 % Rec. NPK and AHB equivalent to FYM	1.09	3.06	0.49	0.37	0.19	0.14
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	1.16	4.03	0.53	0.48	0.21	0.15
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	1.16	4.10	0.52	0.49	0.21	0.15
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	1.12	3.60	0.50	0.50	0.23	0.16
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	1.18	5.00	0.54	0.48	0.20	0.15
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	1.17	3.26	0.52	0.32	0.20	0.15
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	1.13	3.43	0.51	0.39	0.22	0.16
S. Em ±	0.10	0.34	0.06	0.06	0.01	0.08
C.D at 5%	0.30	1.01	0.18	NS	0.03	NS

***AHB: Areca husk biochar**

4.10.3 Micronutrient content

The Fe content in field bean pod and haulm had differed significantly due to different treatments imposed (Table 18). Significantly, higher iron content in pod (67.03 mg kg^{-1}) and haulm (57.23 mg kg^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6). Lower iron content was observed in T_3 treatment receiving biochar equivalent to FYM in both pod and haulm (57.13 and 50.33 mg kg^{-1}), respectively.

The zinc content in field bean pod and haulm differed significantly due to different treatments imposed (Table 18). Significantly higher zinc content in pod (28.77 mg kg^{-1}) and haulm (25.76 mg kg^{-1}) was recorded with 100 per cent Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6). Significantly lower zinc content was observed in control (T_1) (22.60 and 20.53 mg kg^{-1}) followed by T_3 treatment receiving biochar equivalent to FYM, in both pod and haulm (23.27 and 22.13 mg kg^{-1}), respectively.

The copper content in field bean pod and haulm differed significantly due to different treatments imposed (Table 18). Significantly higher copper content in pod (15.50 mg kg^{-1}) and haulm (8.66 mg kg^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6) and followed T_9 (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}) treatments. Significantly lower copper content was observed in control (T_1) (10.93 and 7.40 mg kg^{-1}) and followed by T_3 treatment receiving biochar equivalent to FYM in both pod and haulm (11.30 and 7.13 mg kg^{-1}), respectively.

No significant difference in the manganese content in field bean pod and haulm were recorded due to imposition of different treatments (Table 18). However higher manganese content in pod ($131.06 \text{ mg kg}^{-1}$) and haulm ($113.73 \text{ mg kg}^{-1}$) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6). Lower manganese content was observed in control (T_1) in both pod and haulm (121.96 and 89.10 mg kg^{-1}), respectively.

4.10.4 Macronutrient uptake

The results pertaining to the effect of levels of different levels of biochar along with FYM on available N, P and K uptake by pod and haulm at harvest of field bean is presented in Table 19.

The nitrogen, phosphorus and potassium uptake by field bean pod and haulm differed significantly due to different treatments imposed. Significantly higher nitrogen uptake by pod (25.35 kg ha^{-1}) and haulm (33.92 g kg^{-1}) was recorded in 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6) treatment followed by T_5 (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}) (24.06 and 30.33 kg ha^{-1}). The significantly lower uptake by pod (14.38 kg ha^{-1}) and haulm (15.04 kg ha^{-1}) of nitrogen were found in

Table 18: Effect of different levels of biochar on micronutrients content in Field bean

Treatments	Fe (mg kg ⁻¹)		Zn (mg kg ⁻¹)		Cu (mg kg ⁻¹)		Mn (mg kg ⁻¹)	
	Pod	Haulm	Pod	Haulm	Pod	Haulm	Pod	Haulm
T₁ : Control (only NPK)	58.83	51.87	22.60	20.53	10.93	7.40	125.36	115.83
T₂ : 100 % Rec. FYM + Rec. NPK	59.40	52.87	24.17	22.93	12.13	8.20	125.93	118.76
T₃ :100 % Rec. NPK and AHB equivalent to FYM	57.13	50.33	23.27	22.13	11.30	7.13	121.96	89.10
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	62.67	53.67	25.50	23.50	13.46	7.76	127.76	111.66
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	63.10	54.70	26.60	24.13	14.10	7.93	129.63	112.53
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	67.03	57.23	28.77	25.76	15.50	8.66	131.06	113.73
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	61.90	53.57	23.13	23.13	12.53	7.60	126.36	108.83
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	63.00	54.57	25.77	23.66	13.96	7.86	129.00	110.13
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	65.10	55.17	26.07	24.96	14.90	8.03	130.20	110.76
S. Em ±	1.88	1.05	1.22	0.93	0.88	0.27	6.35	9.47
C.D at 5%	5.65	3.17	3.67	2.79	2.66	0.82	NS	NS

*AHB: Areca husk biochar

Table 19: Effect of different levels of biochar on N, P and K uptake by Field bean

Treatments	Nitrogen			Phosphorus			Potassium		
	(kg ha ⁻¹)								
	Pod	Haulm	Total	Pod	Haulm	Total	Pod	Haulm	Total
T ₁ : Control (only NPK)	14.38	15.04	29.42	2.01	2.84	4.85	7.68	15.01	22.69
T ₂ :100 % Rec. FYM + Rec. NPK	19.82	22.66	42.48	2.74	3.83	6.57	10.31	18.85	29.16
T ₃ :100 % Rec. NPK and AHB equivalent to FYM	16.16	20.05	36.21	2.24	3.25	5.49	8.43	16.46	24.89
T ₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	22.01	26.86	48.87	3.14	4.88	8.02	12.67	22.45	35.12
T ₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	23.69	30.33	54.02	3.34	5.76	9.1	14.09	25.96	40.05
T ₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha ⁻¹	25.35	33.92	59.27	3.73	6.42	10.15	15.84	30.57	46.41
T ₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	20.85	24.56	45.41	2.98	4.18	7.16	11.25	21.36	32.61
T ₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	22.56	27.54	50.1	3.19	5.15	8.34	12.62	23.86	36.48
T ₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha ⁻¹	24.06	29.78	53.84	3.46	5.88	9.34	14.93	28.32	43.25
S. Em+	1.64	1.94	3.08	0.21	0.91	0.71	1.01	1.89	2.14
C.D at 5%	4.92	5.82	9.17	0.65	2.73	2.13	3.04	5.66	6.36

***AHB: Areca husk biochar**

control (T₁) and followed by T₃ treatment receiving biochar equivalent to FYM in both pod and haulm (16.16 and 20.05 kg ha⁻¹), respectively. The highest plant nutrient uptake of total nitrogen by field bean is observed in T₆ treatment (59.27 kg ha⁻¹).

Significantly higher phosphorus uptake by pod (3.73 kg ha⁻¹) and haulm (6.42 kg ha⁻¹) was recorded in 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ T₆ treatment and followed by T₉ (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (3.46 and 5.88 kg ha⁻¹). The significantly lower uptake by pod (2.01 kg ha⁻¹) and haulm (2.84 kg ha⁻¹) of phosphorus were found in control (T₁) and followed by T₃ treatment receiving biochar equivalent to FYM, in both pod and haulm (2.24 and 3.25 kg ha⁻¹), respectively. The highest plant nutrient uptake of total phosphorus by field bean is observed in T₆ treatment (10.15 kg ha⁻¹).

Significantly higher potassium uptake by pod (15.84 kg ha⁻¹) and haulm (30.57 kg ha⁻¹) was recorded with T₆ treatment (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹). Significantly lower uptake of K by pod (7.68 kg ha⁻¹) and haulm (15.01 kg ha⁻¹) were found in control (T₁) followed by T₃ treatment receiving FYM and NPK in both pod and haulm (8.43 and 16.46 kg ha⁻¹), respectively. The highest plant nutrient uptake of total potassium by field bean is observed in T₆ treatment (46.41 kg ha⁻¹).

4.10.5 Secondary nutrients uptake

The results pertaining to the effect of levels of different levels of biochar along with FYM on Ca, Mg and S uptake by pod and haulm at harvest of field bean are presented in Table 20.

Calcium uptake decreased by pod and haulm due to higher application of biochar and over other treatments. However, higher calcium content in pod and haulm was recorded in T₂ (100% Rec. NPK with FYM) (18.12 and 6.25 kg ha⁻¹) followed by T₉ treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) (15.78 and 5.45 kg ha⁻¹) whereas lower calcium uptake was recorded in T₁ (control) (4.41 and 10.10 kg ha⁻¹). The highest plant nutrient uptake of total calcium by field bean is observed in T₂ treatment (24.37 kg ha⁻¹).

No significant difference in the magnesium uptake by field bean pod and haulm were noticed due to different treatments imposed (Table 20). Higher magnesium uptake by pod (3.71 kg ha⁻¹) and haulm (9.49 kg ha⁻¹) was recorded in 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) and followed by T₅ treatment (100 % Rec. FYM + NPK + biochar @ 7.5 t ha⁻¹) in pod and haulm. Lower Mg uptake was recorded in T₁ treatment receiving biochar equivalent to FYM, in both pod and haulm (2.65 and 7.10 kg ha⁻¹). However, the highest plant nutrient uptake of total magnesium by field bean is observed in T₅ treatment (14.89 kg ha⁻¹).

Table 20: Effect of different levels of biochar on Ca, Mg and S uptake by Field bean

Treatments	Calcium			Magnesium			Sulphur		
	Pod	Haulm	Total	Pod	Haulm	Total	Pod	Haulm	Total
T₁ : Control (only NPK)	4.41	10.10	14.51	2.65	7.10	9.75	0.93	1.67	2.60
T₂ : 100 % Rec. FYM + Rec. NPK	6.25	18.12	24.37	3.62	7.03	10.65	1.29	2.61	3.90
T₃ :100 % Rec. NPK and AHB equivalent to FYM	3.68	11.90	15.58	2.69	5.26	7.95	1.02	1.98	3.00
T₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	5.22	15.42	20.64	3.71	9.49	13.20	1.47	2.83	4.30
T₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	5.40	16.02	21.42	3.71	11.18	14.89	1.54	3.17	4.71
T₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha⁻¹	5.43	15.97	21.4	3.85	9.80	13.65	1.81	3.47	5.28
T₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha⁻¹	5.25	16.92	22.17	3.68	8.80	12.48	1.41	2.86	4.27
T₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha⁻¹	5.32	15.22	20.54	3.64	6.36	10.00	1.41	3.00	4.41
T₉ :75 % Rec. FYM + NPK +AHB @ 10 t ha⁻¹	5.45	15.78	21.23	3.65	8.86	12.51	1.66	3.20	4.86
S. Em ±	0.53	1.70	3.30	0.34	1.17	1.76	0.08	0.22	0.32
C.D at 5%	NS	NS	NS	NS	NS	NS	0.25	0.67	0.98

*AHB: Areca husk biochar

The sulphur uptake by field bean pod and haulm differed significantly due to different treatments imposed (Table 20). Significantly higher sulphur uptake by pod (1.81 kg ha^{-1}) and haulm (3.47 kg ha^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} . (T_6) and followed by T_9 treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}). Significantly lower uptake of S in pod (0.93 kg ha^{-1}) and haulm (1.67 kg ha^{-1}) were found in control (T_1) and followed by T_3 treatment receiving biochar equivalent to FYM in both pod and haulm (1.02 and 1.98 kg ha^{-1}), respectively. The highest plant nutrient uptake of total sulphur by field bean is observed in T_6 treatment (5.28 kg ha^{-1}).

4.10.6 Micronutrient uptake

The iron uptake in field bean pod and haulm differed significantly due to different treatments imposed (Table 21). Significantly, higher iron uptake by pod (45.89 g ha^{-1}) and haulm (120.41 g ha^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6 treatment). Lower iron uptake was observed in control treatment (27.46 and 69.52 g ha^{-1} , respectively).

The zinc uptake by field bean pod and haulm differed significantly due to imposition of different treatments (Table 21). Significantly higher zinc uptake by pod (21.81 g ha^{-1}) and haulm (55.68 g ha^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6 treatment) and followed by T_9 treatment (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}) (19.10 and 51.55 g ha^{-1}). Significantly lower zinc uptake was observed in control (T_1) (11.42 and 27.65 g ha^{-1}) followed by T_3 treatment receiving biochar equivalent to FYM, in both pod and haulm (12.28 and 31.86 g ha^{-1} , respectively). The highest plant nutrient uptake of zinc by field bean is observed in T_6 treatment (166.3 g ha^{-1}).

The copper uptake by field bean pod and haulm differed significantly due to imposition of varied treatments (Table 21). Significantly higher copper uptake by pod (11.83 g ha^{-1}) and haulm (17.70 g ha^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6) treatment and followed by T_9 (75 % Rec. FYM + NPK + biochar @ 10 t ha^{-1}) treatments (10.86 and 16.59 g ha^{-1}). Significantly lower copper uptake was observed in control (T_1) (5.56 and 9.85 g ha^{-1}) and followed by T_3 treatment receiving biochar equivalent to FYM by both pod and haulm (6.05 and 10.49 g ha^{-1} , respectively). The highest plant nutrient uptake of copper by field bean is observed in T_6 treatment (17.70 g ha^{-1}).

Table 21: Effect of different levels of biochar on uptake of micronutrients by Field bean

Treatments	Iron (g ha ⁻¹)			Zn (g ha ⁻¹)			Cu (g ha ⁻¹)			Mn (g ha ⁻¹)		
	Pod	Haulm	Total	Pod	Haulm	Total	Pod	Haulm	Total	Pod	Haulm	Total
T ₁ : Control (only NPK)	27.46	69.52	96.98	11.42	27.65	39.07	5.56	9.85	15.41	64.03	153.73	217.76
T ₂ : 100 % Rec. FYM + Rec. NPK	35.84	86.10	121.94	15.50	37.54	53.04	7.71	14.16	21.87	80.85	193.72	274.57
T ₃ :100 % Rec. NPK and AHB equivalent to FYM	29.19	77.67	106.86	12.28	31.86	44.14	6.05	10.49	16.54	64.16	130.95	195.11
T ₄ :100 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	39.95	102.11	142.06	17.52	44.61	62.13	9.27	14.85	24.12	88.15	215.60	303.75
T ₅ :100 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	41.55	114.41	155.96	19.05	50.58	69.63	10.03	16.59	26.62	92.44	239.19	331.63
T ₆ :100 % Rec. FYM + NPK + AHB @ 10 t ha ⁻¹	45.89	120.41	166.3	21.81	55.68	77.49	11.83	17.70	29.53	99.07	244.83	343.90
T ₇ :75 % Rec. FYM + NPK + AHB @ 5 t ha ⁻¹	38.40	96.58	134.98	15.53	41.70	57.23	8.45	13.75	22.2	85.08	198.13	283.21
T ₈ :75 % Rec. FYM + NPK + AHB @ 7.5 t ha ⁻¹	39.92	108.71	148.63	17.74	47.05	64.79	9.61	15.69	25.3	88.85	217.75	306.60
T ₉ :75 % Rec. FYM + NPK + AHB @ 10 t ha ⁻¹	44.05	114.03	158.08	19.10	51.55	70.65	10.86	16.59	27.45	19.10	228.48	247.58
S. Em ±	2.73	8.51	8.13	1.15	3.71	5.17	0.80	1.16	1.82	5.76	18.68	12.5
C.D at 5%	8.18	25.51	24.56	3.46	11.13	15.36	2.41	3.48	5.41	17.29	56.02	37.3

*AHB: Areca husk biochar

The manganese uptake by field bean pod and haulm differed significantly due to different treatments imposed (Table 21). However higher manganese uptake by pod (99.07 g ha^{-1}) and haulm (244.83 g ha^{-1}) was recorded with 100 % Rec. FYM + NPK + biochar @ 10 t ha^{-1} (T_6 treatment). Lower manganese uptake was observed in control (T_1) in both pod and haulm (64.03 and 153.73 g ha^{-1} , respectively). The highest plant nutrient uptake of manganese by field bean is observed in T_6 treatment (343.90 g ha^{-1}).

DISCUSSION

V DISCUSSION

A field experiment was conducted to assess the effect of different levels of biochar on carbon fractions and growth and yield of field bean. In the succeeding paragraphs, an attempt is made to explain the variations noticed in the results with a view on the application of biochar on field bean productivity.

5.1 Effect of different levels of biochar on bulk density and water holding capacity of soil under field bean

Results on the effect of biochar with FYM on bulk density and maximum water holding capacity is presented in Table 4. There was a non-significant difference in bulk density of soil whereas significant difference in water holding capacity of soil in field bean was observed due to application of various levels of biochar with FYM. At harvest higher values were recorded in higher biochar levels with 100% Rec. FYM treatment than the treatments receiving no biochar.

Among the treatments, application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded highest bulk density (1.38 Mg m⁻³) and water holding capacity (37.19 %) followed by application of 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₉) as compared to other treatments at harvest. Lowest available status at all the stages was recorded in control (T₁).

It has been suggested that the porous structure of biochar can influence its impact on soil bulk density and water holding capacity (Day *et al.*, 2005, Ogawa *et al.*, 2006 and Yuan *et al.*, 2011). Brady and Weil (2004) observed that biochar has a lower bulk density (0.3 Mg m⁻³) than mineral soil and thus can reduce soil bulk density. With regard to soil physical properties, biochar addition improved soil water holding capacity (WHC) and plant available water (PAW) in the soil (Bruun *et al.*, 2014; Martinsen *et al.*, 2014). Biochar has recently been shown to form organic pore coatings that improve water retention (Hagemann *et al.*, 2017) by reducing pore space (lowering capillary rise) and boosting hydrophilicity.

5.2 Effect of different levels of biochar on soil pH and electrical conductivity

Results of the study revealed the significant effect of application of different levels of biochar on soil pH in soils (Table 5). Application of higher rates of biochar recorded significant effect on soil pH at harvest. Application level of biochar at 10 t ha⁻¹ along with Rec. FYM (T₆) recorded significantly higher pH than other levels soil whereas lower pH is observed in control (T₁) treatment in which no FYM and biochar is applied.

Increased rate of application of biochar increased soil pH in soil during harvest. Biochar application is known to increase pH of acidic soils which are base poor soil. The soil pH ranged from 6.05 to 6.78 due to application of various rates of biochar application. The observed changes in pH of soil applied with biochar can be ascribed to the release of alkaline compounds, which neutralized the soil acidity and thus increased the soil pH. During pyrolysis, cations (primarily K, Ca, Si and Mg) present in the feedstock formed metal oxides and once applied to soil, these oxides can react with H^+ and monomeric Al species and thus alleviate soil pH. As biochar contain significant quantity of Ca, it can replace the monomeric Al species from soil exchange complex in acidic soil (Novak *et al.*, 2009). As the soil pH increases the soluble and exchangeable Al^{3+} precipitates as insoluble hydroxyl Al-species. The Al concentration can be reduced drastically by addition of biochar that acts as a liming agent in most of the degraded soils (Glaser *et al.*, 2002; Major *et al.*, 2010; Martinsen *et al.*, 2014; Vanzwieten *et al.*, 2010; Yamato *et al.*, 2006). The inorganic carbonate and organic anion contribution of biochar cause the increase in soil pH (Yuan *et al.*, 2011).

Increased rate of biochar application increased the addition of bases and there by recorded higher pH in the present investigation. The research results in the present study are also in line with Chintala *et al.* (2014); Anteneh *et al.* (2014) and Hass *et al.* (2012). The basic cations can be exchanged with the exchangeable Al^{3+} and H^+ on soil exchange complex and thus decreased exchangeable acidity in acidic and neutral soils. Anteneh *et al.* (2014) observed reduction in exchangeable Al^{3+} with increased levels of eucalyptus biochar application. The application of 0 to 12 t ha⁻¹ of biochar reduced exchangeable acidity from 0.60 to 0.39 cmol (p⁺) kg⁻¹.

Application level of biochar at 10 t ha⁻¹ along with Rec. FYM recorded significantly higher EC than other levels soil whereas lower EC is observed in control (T₁) treatment in which no FYM or biochar is applied. This trend in electrical conductivity might be due to mineralization of biochar which could release different salts and might have resulted in increase in salt content reflecting in increased electrical conductivity. Application of various levels of biochar varied soil EC to a significant level and was often reported in literature (Chintala *et al.*, 2014; Glaser *et al.*, 2000; Gundale and De luca, 2007 and Chan *et al.*, 2008).

Incorporation of biochar into acidic soil caused an increase in EC due to the release of weakly bound nutrients (cations and anions) of biochar into the soil solution, which are available for plant uptake (Glaser *et al.* 2000; Gundale and DeLuca 2007; Chan *et al.*, 2008). Raison (1979) attributed the increase in EC of soil due to application of biochar are generally dominated by carbonates of alkali, silica,

phosphates and small amounts of organic and inorganic N. Similar results were also reported by Khanna *et al.* (1994).

5.3 Effect of different levels of biochar application on nutrient status in soils

5.3.1 Available macronutrients status in soils

The data pertaining to available N, P and K status of soil as affected by biochar application are presented in Table 6. No significant differences were observed in the available nitrogen status of soil. However higher (271.79 kg ha⁻¹) available nitrogen content of soil was recorded with the application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆).

This might be due to the fact that addition of bio-char to soil have shown definite increases in the availability of major cations and phosphorus indicating biochar addition increased the mineralization of organic matter. This might have provided more N to plants (Glaser *et al.*, 2002 and Lehmann *et al.*, 2003). Lehmann (2007) reported that biochar alters the N dynamics in soil. Co-application of biochar and mineral N led to an enhanced N mineralization rate compared with the control, biochar only or urea only treatments; probably mostly by stimulating microbial activity (Amonette and Joseph, 2009). The availability and rate of mineralization of organic N found in biochar applied to soil provides an indication of the ability of biochar as a slow release N fertilizer as reported by Chan and Xu (2009) and Steiner *et al.* (2008). Biochar application can reduce nutrient leaching from soil with resulting increase in fertiliser use efficiency (Downie *et al.*, 2009 and Novak *et al.*, 2009). Increased retention of N with biochar addition was also observed earlier (Lehman and Joseph, 2009 and Novak *et al.*, 2009).

The results on available P status of soil (Table 6.) during harvest of crop indicate that application of biochar significantly influenced the available P status of soil. Application of biochar @ 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) registered significantly highest (83.30 kg ha⁻¹) available P status in soil. This may be due to the high concentrations of available P found in the biochar. The increased P concentration could derive from enhanced availability of P in the soil due to increased pH upon biochar addition. Chan *et al.* (2008) and Vanzwieten *et al.* (2010) also reported the increase in available phosphorus in soil after the application of biochar. The possible mechanism for increased P availability with biochar application in soil can be attributed due to presence of soluble and exchangeable phosphate in biochar, modifier of soil pH and ameliorator of P complexing metals (Al³⁺, Fe³⁺), promoter of microbial activity and hastening P mineralization. Xu *et al.* (2013) found that among different fractions of P, Ca-P was greatly enhanced with biochar application. Since biochar can change the pH of a soil (Vanzwieten *et al.*,

2010), it can be used to make the pH of the soil more suitable for P bio-availability. $\text{PO}_4\text{-P}$ is tightly bound in highly weathered tropical soils that are often rich in Fe and Al oxides (Hale *et al.*, 2013). Under such conditions, biochar addition increases soil pH which makes $\text{PO}_4\text{-P}$ more bio-available in soil solution (Asai *et al.*, 2009; Novok *et al.*, 2009).

Exchangeable soil K increased significantly with addition of biochar in the soil at all application rates (Table 6). However highest available K status is observed in treatment T_6 (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹). Silber *et al.* (2010) studied the kinetics of release of K, Ca and Mg from corn straw in which he observed that application of biochar there was an increase in exchangeable K status in the soils. The increase in K was due to the high concentration of K found in the biochar (Chan *et al.*, 2007). For many biochars, an increase in soil K availability may be due to reduced K leaching upon biochar addition (Laird *et al.*, 2010; Martinsen *et al.*, 2014). Higher K availability by biochar application has also been reported by Major *et al.* (2010), which might be from the considerable amounts of K that were added along with the biochar from which it is readily available.

5.3.2 Available secondary nutrients status in soils

Significant effect of application of different levels of biochar on secondary nutrients in soil (Table 6) was observed. Exchangeable bases such as Ca and Mg status in soil varied significantly with application of varied levels of biochar combined with FYM at harvest stage due its high cation exchange capacity. The highest content of exchangeable bases were recorded in T_6 treatment in which higher rate of biochar and FYM was applied (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) and lowest was recorded in control (T_1).

The increased levels of biochar increased the calcium and magnesium in soil during harvest which may be due to the higher concentration of Ca, Mg and exchangeable bases in biochar. This might be due to high porosity and surface/volume ratio and can improve Ca and Mg availability (Chan *et al.*, 2007 and Yamato *et al.*, 2006). Biochar surface chemistry can lead to the retention of nutrients by cation exchange associated with acidic functional groups formed during oxidation process on biochar surfaces; therefore retain most cations like Ca, Mg, K, and Na (Clough, 2013). Alteration of soil pH has implications on nutrient availability (especially phosphorus) and mineralization and thus further nutrient delivery (especially N and base cations such as Ca^{2+} , Mg^{2+} , and K^+). The addition of biochar increases nutrient retention capacity and soil CEC (Chan *et al.*, 2008; Liang *et al.*, 2006) and thus reduces nutrient leaching (Hale *et al.*, 2013; Laird *et al.*, 2010; Martinsen *et al.*, 2014; Steiner *et al.*, 2007).

Increase in exchangeable bases in soil can be attributed to release of basic cations from biochar. During pyrolysis, biomass acids are converted into bio-oil and alkalinity is inherited by solid biochar (Laird *et al.*, 2010). Most of the Ca, Mg, K, P and plant micronutrients in feedstock are partitioned into the biochar ash fraction during pyrolysis. Ash in biochar rapidly releases free bases such as Ca, Mg and K to the soil solution thereby not only increases soil pH but also exchangeable bases. Such observations were also noticed by Lehmann *et al.* (2003) and Chan *et al.* (2008).

Sulphur status in soil varied significantly with application of different levels of biochar with FYM at harvest of crop (Table 6). Significantly higher sulphur status of soil was recorded with the application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆), which was on par with the other treatments receiving biochar along with FYM and lowest was seen in control (T₁) in which no biochar or FYM is applied. This may be due to the contribution of available sulphur to soil after the mineralization of organic sulphur in biochar and also due to application of FYM. The results suggest that biochar also improves the bioavailability of sulphur; which mainly depends on mineralization of organic forms of sulphur to cycle through soils (De Luca *et al.*, 2009).

5.3.3 Available micronutrients status in soils

It was noticed that micronutrient status of soil increased with increased levels of biochar and FYM with their different combination over no biochar or FYM applied treatments (Table 7). Significantly higher micronutrient status content of soil was recorded with the application of 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆), whereas lower micronutrient status was seen in T₃ treatment in which higher rate of biochar without FYM is applied.

Available iron, zinc and copper status were significantly influenced by the effect of applied biochar and FYM in the crop whereas manganese status in soil differed non-significantly. It was noticed that micronutrient status of soil increased with increased levels of biochar and FYM with their different combination over no biochar or FYM application treatments. However, application of levels of biochar alone reduced the micronutrients status in soil over combined application of biochar and FYM. However, in the present study maximum micronutrient availability is observed in only FYM and combined biochar as compared to biochar applied treatment alone. Increase in available micronutrient status in soil treated with biochar and FYM might also be due to enhanced solubilisation of native minerals. As pH of soil and micronutrients availability was negatively correlated, immobilization of micronutrient occurs in soil. But the micronutrient status in soil increased with the application of biochar in combination with FYM. This may be due to the mineralization of micronutrients from organic matter and the release of

micronutrients during decomposition of organic manures. Increase in the status of micronutrients at harvest of crop might be due to higher availability of the plant nutrients from the soil nutrient reservoir and additional quantity of nutrients supplied through farm yard manure (Sharma and Dixit, 1987).

Slight increase in copper status with the addition of biochar and FYM might be due to high extractability of micronutrients and Cu is strongly chelated by organic carbon and is less subjected to adsorption process. Similar observations were made by Bandara *et al.* (2017). There was an increase in Cu status with biochar application. Application of biochar might have increased the soluble organic carbon; thereby resulting in the mobilization of Cu. Cu is strongly chelated by organic carbon and is less subjected to adsorption process. Beesley and Marmiroli (2011) also reported dependence of Cu content on soluble C and pH.

5.4 Effect of different levels of biochar application on carbon fractions in soil

On a perusal of the data presented in Table 8, 9 and 10 revealed that treatment receiving application of 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded significantly higher total carbon and total organic carbon at 60 DAS and at harvest, respectively and was followed by the other biochar applied treatments, whereas non-significant results were observed with respect to soil total inorganic carbon.

In this study, biochar application increased the soil organic carbon status, possibly because biochar contained high carbon (C) content and could protect organic carbon from utilization (Glaser *et al.*, 2002; Cayuela *et al.*, 2013). The increase in carbon fractions might be due to addition of FYM and biochar and due to the native soil organic matter status of the 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. Biochar improves soil productivity, C storage and soils ability to hold the nutrients (Lehmann and Joseph, 2009). In addition to representing a carbon store of its own, biochar would enhance the intrinsic soil organic carbon storage capacity of soil, by affecting the turnover of indigenous carbon (Wardle *et al.*, 2008 and Jerry, 2009). Addition of biochar is also reported to increase microbial activity in the soil which may increase the organic carbon contents in soil. (Agbede *et al.*, 2008) It also appears that adding biochar to soil may be one way by which the fundamental capacity of soils to store and sequester organic matter could be increased. The greater proportion of the total carbon may comprise an accumulated store of the products of burning or fire (Skjemstad *et al.*, 2001). It has been suggested from visual observation of the biochar could also lead to a net stabilisation of other organic matter (Sohi *et al.*, 2006; Lehmann and Sohi 2008). Results demonstrated that biochar incorporation into soils could enhance the conservation of soil organic carbon in both macro and micro-aggregate size fractions (Liu *et al.*, 2014) thereby aiding the enhancement of SOC

sequestration in the soil through physical protection (Hartley and Waterson 2016; Liu *et al.*, 2014). It was found that application of biochar results usually in an increase in total soil carbon as found in the present study and thus acted as a short-term C sequestration potential in soil. Biochar application has been shown to have positive effects on soil C stability, especially in soil with low native organic matter contents (Ketterings *et al.*, 2000; Sohi *et al.*, 2010; Riaz *et al.*, 2017).

5.5 Effect of different levels of biochar on enzyme activities in soil at different growth stages in field bean

5.5.1 Dehydrogenase activity

The dehydrogenase activity in soil at different growth stages of field bean varied significantly. Due to the effect of biochar levels on dehydrogenase activity in soil is presented in Table 11. Among the treatments, application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded highest dehydrogenase activity values (16.06, 22.36 and 13.77 µgTPF h⁻¹ g⁻¹ soil at 30, 60 DAS and at harvest, respectively) followed by application of 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ as compared to other treatments at different crop growth stages.

At all the stages, higher values of dehydrogenase activity were recorded in higher rate of biochar application along with 100 % Rec. FYM. This is mainly due to increase of enzymes activity with addition of organic carbon through FYM and application of biochar to the soil. Because biochar has porous nature, high surface area and its ability to adsorb soluble organic matter and inorganic nutrients, provides a highly suitable habitat for microbes and enzymes. Increase in dehydrogenase activity is considered to be correlated with the availability of organic matter in the soil (Serra-Wittling *et al.*, 1995). Marinara *et al.* (2006) suggested that higher dehydrogenase activity is due to higher metabolic activity of microorganisms in FYM applied treatment in combination with biochar treatments and soil organic carbon contents may potentially explain increased enzyme activities. The results are in accordance with the findings of Kamalesh Kukreja *et al.* (1991) and Bolton *et al.* (1985).

5.5.2 Acid phosphatase activity

The acid phosphatase activity in soil at different growth stages of field bean varied significantly and presented in Table 12. At all the crop growth stages, higher values were recorded in higher rate of biochar application along with 100 per cent Rec. FYM. Among the treatments, application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded highest phosphatase enzyme values (35.43, 35.43 and 38.35 µg PNP g⁻¹ hr⁻¹) of soil at 30, 60 DAS and at harvest, respectively)

followed by application of 75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₉) compared to other treatments at different crop growth stages. Lowest available status at all the stages was recorded in no biochar and FYM applied T₁ treatment.

The higher values of phosphatase enzyme activity are recorded with higher rate of biochar application in combination with FYM. Marinara *et al.* (2006) also reported that higher soil organic carbon contents may potentially explain increased enzyme activities. The results of higher values of phosphatase enzyme activity are in accordance with the findings of Kamalesh Kukreja *et al.* (1991) and Bolton *et al.* (1985). It is also due to the fact that due to addition of both biochar and FYM, there was a better root growth that contributed for higher acid phosphatase activity and it is well known that acid phosphatases are mainly root originated. The increased pH values in the original low pH soil could also enhance the availability of nutrients and consequently increase soil microbial biomass (Atkinson *et al.* 2010; Warnock *et al.* 2010). Activities of certain enzymes like, alkaline phosphatase, aminopeptidase and N- acetyl glucosaminidase have been reported to increase due to biochar application (Bailey *et al.*, 2010).

5.5.3 Urease activity

The urease activity in soil at different growth stages of field bean varied significantly and presented in Table 13. At all the crop growth stages, higher values were recorded in higher rate of biochar application along with 100 per cent Rec. FYM. Among the treatments, application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded highest urease enzyme values 137.22, 122.17 and 71 µg NH₄⁺ - N g⁻¹ hr⁻¹, respectively) of soil at 30, 60 DAS and at harvest, respectively. Followed by application of 75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₉) compared to other treatments at different crop growth stages. Lowest available status at all the stages was recorded in no biochar and FYM applied T₁ treatment.

Higher urease activity in soils treated with biochar addition might be due to the increase in oxidative capacity of soil microorganisms and the hydrolysis reactions of urea. Also it may be due to increase of enzymes activity with addition of organic carbon through FYM and biochar to the soil. The increase in organic C content activates the urease enzyme in soils. Similar results were observed by Du *et al.* (2014). The present research results are also in conformity with those of Thies and Rillig (2009), Hammes & Schmidt (2009) and Krull *et al.* (2010).

5.6 Effect of different levels of biochar on growth and yield parameters of Field bean

5.6.1 Growth attributes of field bean

Different growth attributes such as plant height, number of leaves and dry matter accumulation recorded at 30 and 60 DAS, differed significantly with application of different levels of biochar. Data presented in Table 14 indicate that all the growth parameters were significantly influenced by the imposed treatments at 60 DAS of field bean. Application of higher levels of biochar with FYM significantly increased the growth parameters in field bean. Among different treatment combinations (T₆) 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ recorded significantly higher plant height, number of leaves and dry matter accumulation and lowest biometric observations was recorded in control (T₁) treatment, respectively.

There were many factors contributing to the improvement of growth attributes of crop with biochar application. These factors can either work individually or simultaneously. The rise of soil pH, slow release of nutrients, increased plant available water and improved microbial activity would have contributed for improvement of growth parameters of biochar treated plants over control in soil. All such improvements in physical and chemical properties of soil in biochar amended soils might have improved the growth of the crop and results are in line with other studies of Liang *et al.*, 2006; Gundale and De Luca, 2007; Warnock *et al.*, 2007 and Amonette and Joseph, 2009. Higher availability of N has been witnessed in the soil of present investigation due to application of biochar. Nitrogen being a structural component of the plant would help in cell growth and enlargement. Similarly, Barbosa Filho (1991), Navin *et al.* (1996) and Mauad *et al.* (2003) reported higher number of leaves due to increased N availability.

On the other hand, significant effect of biochar application on growth attributes over control can be attributed due to creation of favorable pH and addition of nutrients such as Ca in soil. Dong *et al.* (2015) reported higher stem length and grain yield of rice treated with rice straw derived biochar than bamboo biochar due to higher N content of rice straw derived biochar. Also, Singh *et al.* (2010) reported higher nutrient and CEC with grass biochar than wood biochar and thereby improved retention and supply of nutrients. An increase in plant height and leaf area to an extent of 39 and 25 per cent were recorded with application of nutrient poor wood derived biochar by Graber *et al.* (2010). Beneficial effects of biochar application were attributed to shift in microbial community to plant growth promoting rhizobacteria and fungi.

5.6.2 Yield attributes of field bean

Results presented in Table 15 indicate the yield parameters such as number of pods per plant, pod length, 100 seed weight and pod weight also differed significantly due to the application of varied levels of biochar along with Rec. FYM treatment. Significant differences were noticed among the treatments for pods per plant, pod length, 100 seed weight and pod weight. Application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) treatment significantly increased the yield parameters of field bean over control.

Higher yield attributes in field bean could be attributed to better total uptake of essential nutrients and its translocation to economic parts as well as improvement in yield attributing characters like number of pods per plant, 100 seed weight and pod weight. Biochar application has found to increase fertilizer use efficiency as reported by Dong *et al.* (2015); Chan *et al.* (2007); Chan *et al.* (2008) and Taghizadeh- Toosi *et al.* (2012).

5.6.3 Pod and haulm yield

Significant differences were observed with respect to pod and haulm yield due to imposed treatments (Table 15). Pod and haulm yields increased with increasing levels of biochar application as compared to control treatment. Significantly highest pod and haulm yield were recorded in the treatment where 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ is applied. Significantly lower pod yield was recorded in control (T₁) followed by T₃ treatment receiving biochar equivalent to FYM.

Increase in crop productivity with application of biochar can be attributed to increased CEC of soil, pH and base saturation, available P, nutrient retention and increased plant-available water. The application of biochar also helps in increased porosity in soils. This could be applicable to soils to enhance plant root growth, ultimately leading to greater crop production. Bruun *et al.* (2014) found that the addition of biochar improved root growth by which it could allow for increased yields with minimal cost to the grower. Yield increase with biochar application have been documented in controlled condition as well as in field (Blackwell *et al.*, 2007; Chan and Xu, 2009; Rondon *et al.*, 2007) and reported that yield advantage ranged from 10 to > 200 per cent with application rate varying from < 1 to 100 t ha⁻¹. Addition of more nutrients through combination of biochar, FYM and inorganic fertilizers resulted in higher grain and stover yield. Many research works have reported biochar-induced yield increases in the field for sugarcane, rice and maize production. Improvements in plant growth and yield by biochar application also been reported for radish (Chan *et al.*, 2008), common beans (Rondon *et al.*, 2007), soybean (Tagoe *et al.*, 2008), rice (Asai *et al.*, 2009) and maize (Yamato *et al.*, 2006).

In the present study, application of biochar improved the soil pH to and there by improved the nutrition of P, Ca and Mg and contributed for higher yield advantages. Possible reason for higher yield with application of biochar may be due to higher availability of nutrients especially P which was also reflected in tissue P content of biochar treated plants. Increased availability of P through biochar application is thought to be cause for yield advantages in many of the studies (Haeefe *et al.*, 2011; Major *et al.*, 2010; Dong *et al.*, 2015; Ma and Matsunaka, 2013; Deluca *et al.*, 2009; Chan *et al.*, 2007; Lehmann *et al.*, 2003). Jeffery *et al.* (2011) conducted a meta-analysis to investigate soil constraints, and reported 25 per cent average crop yield increase in tropical soils upon biochar addition, mostly through liming and nutrient effects (N and K retention, P availability and direct K addition).

5.7 Effect of different levels of biochar application on primary nutrient content and uptake by field bean

There was a significant difference in nitrogen content in pod and haulm had significant difference in nitrogen uptake by field bean due to application of different levels of biochar and FYM (Table 16 and 19). The highest N content and uptake both in pod and haulm were recorded in T₆ (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) treatment and this treatment was found on par with T₉ and T₅. There is significant variation in N uptake both in pod and haulm because of different levels biochar and FYM application suggesting application of biochar with FYM had an influence on content and uptake of nitrogen. In fact the nitrogen content both in pod and haulm found marginally lower in control treatments. This may be due to biochar application which helped microbial activity improving N availability and increases the content and uptake of N by field bean.

Results of enhanced uptake of nutrients due to the application of biochar were reported by Lehmann *et al.* (2003). Addition of bio-char to soil has shown definite increase in the availability of major cations and phosphorus as well as in total nitrogen and phosphorus concentrations Glaser *et al.* (2002) and Lehmann *et al.* (2003). Chan *et al.* (2007) observed an increase in the uptake of N at higher levels of biochar. Higher N and K content in rice plants might be due to their retention in soil by biochar surfaces as reported by Widowati *et al.* (2014). Higher N uptake might have led to higher N availability and N-use efficiency under biochar treatments (Zhang *et al.*, 2018).

The phosphorus content and uptake by field bean crop varied significantly increased due to application of biochar with FYM treatment. The highest content and uptake value recorded in T₆ (100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹) treatment and lowest was observed in T₁ (control). There is significant variation in uptake both in pod and haulm because of different levels biochar and FYM

application suggesting application of biochar with FYM had positive influence on content and uptake of phosphorus.

This could be attributed to the fact that besides acting as an amendment, biochar also provides nutrients for better uptake. Biochar also seems to represent a significant source of available P for crops (Lehmann *et al.*, 2003; Asai *et al.*, 2009). According to Atkinson *et al.* (2010) enhanced availability and plant uptake of P after biochar addition to soil attributed to its role as source of soluble P salts and exchangeable P forms, it avoids P precipitation by modifying soil pH (bonding or sorbing elements which precipitate P) or enhances microbial activity leading to changes in P availability. Evident Increased N and P uptake with crop residue application over control has also been noticed. It could be ascribed to greater availability of mineralized N during the growing season due to the improvement in N-supplying power of soil under straw retention compared to straw removed (Malhi *et al.*, 2011).

The potassium content and uptake varied significantly both in pod and haulm due to application of different levels of biochar and FYM. Uptake of potassium also varied significantly due to treatments. Potassium content and uptake was found to be highest in T₆ treatment receiving 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ and lowest was recorded in T₁ (control).

The higher uptake may be due to the higher biomass production. Similar observations were found by Rao and Bharadwaj (1981) and Hariprasad *et al.* (1990). Application of higher level of biochar increased tissue N, P and K content in both haulm and pod. Increased nutrient retention by biochar application will improve its availability to plants. Most of nutrient (N, P and K) uptake will increase with increased water availability. Increased assimilation of N will also improve uptake of other essential nutrients (Santonoceto *et al.*, 2002) as it increases root growth, leading to the increased absorption of nutrients (Chamorro *et al.*, 2002). Direct addition of nutrients by biochar is of great significance in nutrient poor soil for increased nutrient content in biochar treated plants. Increase in pH of acidic soils may decrease Al activity, hence better root growth and nutrient uptake can be expected.

5.8 Effect of different levels of biochar application on secondary nutrient content and uptake by field bean

There is significant variation in uptake, both in pod and haulm with different levels of biochar applied along FYM, suggesting treatment in which biochar is applied influence much on content and uptake of Mg and S by field bean whereas lower content and uptake of Ca was recorded due to higher rate of biochar application. (Table 17 and 20). The highest Ca content and uptake both in haulm and

pod were recorded in T₂ (NPK + FYM) and lowest calcium content and uptake was observed in T₃ treatment in which higher rate of biochar is applied. Higher Mg and S content in pod and haulm and its uptake is observed in T₆ treatment receiving 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹.

Potassium concentration in plant tissues indicated high consumption, thus the content of Ca could be depressed by antagonistic interaction mechanism of these two elements, which is seated in the translocation step from the root to the shoot (Ohno and Grunes, 1985). The same effect of biochar on the Ca content was found in corn ear-leaf and soybean plants (Brantley *et al.* 2016, Waqas *et al.* 2017).

Nutrient uptake is a function of nutrient content and biomass production. High K content in the biochar contributed to luxury K consumption adversely impacting Ca nutrition of the corn plants. This was shown by deficient levels of Ca in the corn tissue, which were considerably lower than the critical levels (Reuter and Robinson, 1997). Lehmann *et al.* (2003) noticed higher uptake of P, K, Ca, Zn, and Cu by the plants with increased level of biochar additions due to reduced leaching losses and increased fertilizer use efficiency. The increase in microbial activity due to biochar application could also be the reason for the highest total nutrient contents (Ca, Mg and S). Xu *et al.* (2013) with application of rice straw biochar recorded a cumulative uptake of N concentration by 10.8 to 15.4 per cent, P by 23.4 to 38.6 per cent, K by 32 to 33.2 per cent, Ca by 20.1 to 25.4 per cent and Mg by 26.8 to 35.8 per cent in successive four cropping season of rice-wheat system due to improvement in physical and chemical properties of soil.

The results suggest that biochar also improves the bioavailability of sulphur, which mainly depends on mineralization of organic forms of sulphur to cycle through soils (DeLuca *et al.*, 2009). This could be attributed to the high cation exchange capacity of biochar (Lehmann *et al.*, 2003). Because of its high porosity and surface/volume ratio, biochar can improve plant nutrients uptake and availability in soil (Chan *et al.*, 2007 and 2008).

5.9 Effect of different levels of biochar application on micronutrient content and uptake by field bean

Result on the effect of biochar levels and FYM on micronutrient content and uptake by field bean at different growth stages and is presented in Table 18 and 21. At harvest of field bean, higher values of micronutrient contents were recorded in higher biochar application with FYM treatment as compared to no biochar applied treatment. Among the treatments, application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded highest micronutrient content and uptake followed by application of 75 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₉) compared

to other treatments at different crop growth stages. But manganese content in pod and haulm of field bean is found to be non- significant. Lowest micronutrient content at all the crop growth stages was recorded in control (T₁) treatment.

The application of biochar differed micronutrient content and uptake by haulm and pod significantly in different treatments. In general, application of biochar improved Cu content and uptake in both haulm and pod of field bean. Application of biochar at higher rates, in comparison to control significantly increased the Mn content and uptake in both pod and haulm in acidic and neutral soils. Though Zn content in pod and haulm were increased due to biochar application Fe content of pod and haulm decreased.

Decreased micronutrient availability of only biochar amended soil was usually noticed due to liming effect. Application of biochar is accompanied by increase in soil pH and reduced mobility of micronutrients. But in presence of plant, which actively releases organic compounds in rhizosphere may mobilize the micronutrients, Cu which always forms a stable complex with organic matter is thus less affected with biochar addition. Evangelou *et al.* (2014) found that the biochar application increased significantly K and Zn content in plant shoots. Lehmann *et al.* (2003) noticed higher uptake of P, K, Ca, Zn, and Cu by the plants with increased level of biochar additions due to reduced leaching losses and increased fertilizer use efficiency.

Conclusions

1. Application of higher levels of biochar in combination with FYM performed better as compared to treatment without biochar and FYM with respect to growth, yield and yield attributes. Also, there is a considerable increase in the carbon pools due to the application of biochar in soil.
2. Highest available nutrient status in soil was noticed with higher rate of biochar application with FYM as compared to control which is not receiving either biochar or FYM.
3. Application of biochar in combination with FYM reported higher nutrient status in soil.
4. Hence, application of biochar with FYM can be used for field bean cultivation under acidic soil condition.

Future line of work

- ✓ Cost effective biochar production technologies have to be developed.
- ✓ Amount of biochar needed to crops for meeting the crop nutrient demand.
- ✓ Mechanism of nutrient release from biochar.
- ✓ Long term effect of biochar application on crop growth, nutrient retention and its availability in different soils.
- ✓ Influence of biochar on soil microbial properties and shift in microbial communities.

SUMMARY

VI SUMMARY

An investigation entitled “Influence of levels of areca husk biochar on carbon fractions and growth and yield of field bean” was conducted during *Rabi* season of 2018, to investigate the effect of different levels of biochar and FYM on the distribution of C fractions and productivity of maize. Different levels of biochar @ 5, 7.5 and 10 t ha⁻¹ and FYM @ 100 and 75 per cent recommended dose with 9 treatment combinations along with recommended dose of NPK is used in a RCBD design with three replications. During experimentation, the soil and plant samples collected were analyzed for various parameters. The data obtained with respect to yield, yield parameters and analytical results of soil and plants were subjected to statistical analysis and interpreted. The results of the investigation are summarized in this chapter.

1. Application of higher biochar levels with FYM treatment significantly increased the plant height, number of leaves and total dry matter accumulation per plant in field bean at harvest of the crop and yield attribute viz., number of pods per plant, test weight, pod weight, pod yield and haulm yield. Application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆) recorded significantly higher morphological characters and yield attributes compared to other treatments and was on par with 75 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₉) and lowest was recorded in no biochar and FYM applied treatment (T₁).
2. Significantly higher soil pH, electrical conductivity was observed with application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆). Lowest values of pH and EC were recorded in control T₁ treatment in which only Rec. NPK was applied.
3. Available N, P and K status of soil increased with increasing biochar levels with FYM at harvest of field bean. There is a non-significant difference observed in available N status in soil whereas significantly highest available P and K status of soil recorded in the treatment 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ treatment (T₆) as compared to other treatments. Lowest values of available N, P and K were recorded in no biochar and FYM applied T₁ treatment.
4. Significantly higher exchangeable Ca and Mg, available sulphur and DTPA-extractable micronutrients (Fe, Zn, Cu and Mn) were recorded at harvest stage with application of 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ (T₆ treatment). Lowest values of Ca, Mg, available sulphur were recorded in no biochar and FYM applied T₁ treatment and DTPA-extractable micronutrients (Fe Zn, Cu and Mn) were observed in higher rate of biochar application.

5. The different carbon fractions of soil viz., total carbon, total organic carbon and total inorganic carbon increased with increasing biochar levels with FYM at harvest of field bean. There is a non-significant difference observed in total inorganic carbon in soil whereas significantly highest carbon status recorded in the treatment 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ treatment (T₆) as compared to other treatments. Lowest values of the carbon fractions were recorded in control T₁ treatment.
6. The content and uptake of N, P and K by pod, and haulm infield bean increased due to biochar application with FYM. The content and uptake by pod and haulm in field bean were higher in the T₆treatment receiving 100 per cent Rec. FYM + NPK + biochar @ 10 t ha⁻¹ compared to other treatments and were on par with other treatments in which biochar along with FYM was applied. Lowest content and uptake values of N, P and K were recorded in T₁ treatment with no FYM and biochar application.
7. The Ca content and uptake by field bean crop also varied due to application of biochar levels. There was a decrease in content and uptake of calcium with increase in biochar levels. Highest Ca content and uptake were recorded in T₂ (Rec. NPK and FYM). The content and uptake of Mg and S by pod, and haulm in field bean increased due biochar application with FYM and bean were higher in the treatment 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ treatment (T₆) compared to other treatments and were on par with other treatments in which biochar along with FYM was applied. Lowest content and uptake values of Mg and K were recorded in T₁ treatment with no FYM and biochar application.
8. Dehydrogenase, acid phosphatase and urease activity in soil at different growth stages varied significantly due to application of biochar along with FYM over control. However, significantly higher enzyme activities were noticed in treatment T₆ with application of 100 % Rec. FYM + NPK + biochar @ 10 t ha⁻¹ treatment. Lowest enzyme activity was recorded in control treatment (T₁) in which no FYM and biochar treatment.

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VII REFERENCES

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APPENDIX

VIII APPENDIX

Appendix- I Monthly meteorological data for the experimental year 2018 recorded at AHRS, Bhavikere, Tarikere, Karnataka.

Months	Rainfall (mm)	Max. Temp. (°C)	Min. Temp.	Wind speed (km h ⁻¹)	Rainy days
January	0	31.3	15.2	4.0	0
February	0	34.3	18.1	4.5	0
March	22	37.5	21.0	5.3	1
April	55.2	39.1	23.1	7.0	3
May	187	36.3	23.2	7.2	12
June	202	30.0	21.8	7.4	13
July	254.2	28.4	21.6	7.7	22
August	224	29.1	21.3	7.9	21
September	113	29.8	19.7	6.3	8
October	115.6	30.6	18.1	4.3	7
November	22	30.5	14.7	3.4	1
December	0	30.7	15.0	3.6	0