

**CHARACTERIZATION OF BIOCHAR, NUTRIENT
RELEASE AND ITS EFFECT ON GROWTH AND
YIELD OF AEROBIC RICE**

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**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL
CHEMISTRY**

UNIVERSITY OF AGRICULTURAL SCIENCES

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AKSHATHA, M. K.

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*Affectionately
dedicated to my
Beloved Family*

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL
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CERTIFICATE

This is to certify that the thesis entitled "CHARACTERIZATION OF BIOCHAR, NUTRIENT RELEASE AND ITS EFFECT ON GROWTH AND YIELD OF AEROBIC RICE" submitted by Ms. AKSHATHA, M. K., ID No. PALB 3296 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 University of Agricultural Sciences, Bengaluru, is a record of research work done by her during the period of her study in this University under my guidance and supervision and the thesis has not previously formed the basis of the award of any other degree, diploma, associateship, fellowship or similar other titles.

Bengaluru
October, 2015


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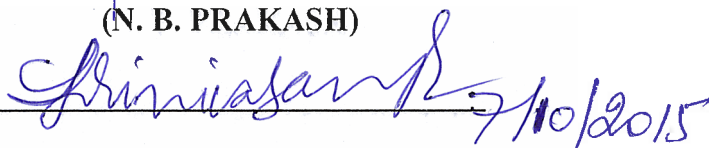
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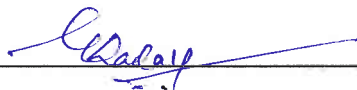
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Akshatha, M. K.

CHARACTERIZATION OF BIOCHAR, NUTRIENT RELEASE AND ITS EFFECT ON GROWTH AND YIELD OF AEROBIC RICE

AKSHATHA, M. K.

ABSTRACT

An experiment was conducted to characterize biochar, nutrient release and its effect on growth and yield of aerobic rice at UAS, GKVK, Bengaluru in 2014. Three different biochars *viz.*, wood (WB), bamboo (BB) and rice husk biochar (RHB) and four levels of application (2, 4, 8 and 16 t ha⁻¹) were the treatments. An incubation study was conducted to know the nutrient and Si release from different biochars in acidic, neutral and alkaline soil at field capacity moisture regime. Among different sources, application of WB recorded higher pH and exchangeable bases while RHB recorded higher available P₂O₅ and 0.01 M CaCl₂ - Si in all soils. Independent of biochar type, increased rate of application increased the pH, available P₂O₅, exchangeable bases and 0.01 M CaCl₂ - Si content of soils. Significant decrease in DTPA extractable Fe and Mn were observed with application of WB in acidic and neutral soil while with RHB in alkaline soil. In a pot culture study, significantly higher yield of straw and grain were recorded with the application of RHB @ 8 and 4 t ha⁻¹ in acidic and neutral soil, respectively while WB @ 4 t ha⁻¹ in alkaline soil. Si and other nutrients content in straw and grain increased with application rates of biochar. With the application of different sources and levels of biochar in different soils, yield responses of straw and grain ranged from -36.56 to 55.18 per cent and -51.00 to 46.47 per cent respectively.

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ಜೈವಿಕ ಇದ್ದಿಲಿನ ಗುಣಲಕ್ಷಣಗಳು, ಪೋಷಕಾಂಶಗಳ ಬಿಡುಗಡೆ ಮತ್ತು ಏರೋಬಿಕ್ ಭತ್ತದ ಬೆಳವಣಿಗೆ
ಹಾಗೂ ಇಳುವರಿಯ ಮೇಲಾಗುವ ಪರಿಣಾಮಗಳು

ಅಕ್ಷತಾ, ಎಂ. ಕೆ.

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಜೈವಿಕ ಇದ್ದಿಲಿನ ಗುಣಲಕ್ಷಣಗಳು, ಪೋಷಕಾಂಶಗಳ ಬಿಡುಗಡೆ ಮತ್ತು ಏರೋಬಿಕ್ ಭತ್ತದ ಬೆಳವಣಿಗೆ ಹಾಗೂ ಇಳುವರಿಯ ಮೇಲಾಗುವ ಪರಿಣಾಮಗಳನ್ನು ತಿಳಿಯಲು ಯು. ಎ. ಎಸ್. ಜಿ.ಕೆ.ವಿ.ಕೆ. ಬೆಂಗಳೂರಿನಲ್ಲಿ ಪ್ರಯೋಗವನ್ನು ೨೦೧೫ರಲ್ಲಿ ಕೈಗೊಳ್ಳಲಾಯಿತು. ಈ ಅಧ್ಯಯನದಲ್ಲಿ ಕಟ್ಟಿಗೆ, ಬಿದಿರು ಹಾಗೂ ಭತ್ತದ ಹೊಟ್ಟಿನ ಜೈವಿಕ ಇದ್ದಿಲನ್ನು ನಾಲ್ಕು ಪ್ರಮಾಣದಲ್ಲಿ (೨, ೪, ೮, ಹಾಗೂ ೧೬ ಟನ್ ಪ್ರತಿ ಹೆ.) ಉಪಯೋಗಿಸಲಾಯಿತು. ಆಮ್ಲ, ತಟಸ್ಥ ಹಾಗೂ ಪ್ರತ್ಯಾಕ್ಷಿಯ ಮಣ್ಣಿನ ಕ್ಷೇತ್ರ ಸಾಮರ್ಥ್ಯದಲ್ಲಿ ವಿವಿಧ ಜೈವಿಕ ಇದ್ದಿಲಿನಿಂದ ಪೋಷಕಾಂಶಗಳು ಮತ್ತು ಸಿಲಿಕಾನ್ ಬಿಡುಗಡೆಯಾಗುವುದನ್ನು ತಿಳಿಯಲು ಇನ್‌ಕ್ಯುಬೇಷನ್ ಅಧ್ಯಯನವನ್ನು ನಡೆಸಲಾಯಿತು. ವಿವಿಧ ಜೈವಿಕ ಇದ್ದಿಲುಗಳಲ್ಲಿ, ಕಟ್ಟಿಗೆ ಇದ್ದಿಲಿನ ಬಳಕೆಯಿಂದಾಗಿ ಮೂರೂ ಮಣ್ಣಿನಲ್ಲಿ ಅಧಿಕ ಮಣ್ಣಿನ ರಸಸಾರ ಮತ್ತು ವಿನಿಮಯ ಪ್ರತ್ಯಾಕ್ಷಿಗಳ ಅಂಶವು ಕಂಡು ಬಂದಿರುತ್ತದೆ. ಹಾಗೆಯೇ ಭತ್ತದ ಹೊಟ್ಟಿನ ಜೈವಿಕ ಇದ್ದಿಲನ್ನು ಉಪಚರಿಸಿದಾಗ, ಲಭ್ಯವಾಗುವ ರಂಜಕ ಹಾಗೂ ೦.೦೧ M CaCl₂ ಸಿಲಿಕಾನ್ ಅಂಶವು ಮೂರೂ ಮಣ್ಣಿನಲ್ಲಿ ಹೆಚ್ಚಾಗಿ ಕಂಡು ಬಂದಿರುತ್ತದೆ. ಆಮ್ಲ ಹಾಗೂ ತಟಸ್ಥ ಮಣ್ಣಿನಲ್ಲಿ ಕಟ್ಟಿಗೆ ಇದ್ದಿಲನ್ನು ಬಳಸಿದಾಗ DTPA ಕಬ್ಬಿಣ ಮತ್ತು ಮ್ಯಾಂಗನಿಸ್ ಪ್ರಮಾಣವೂ ಗಣನೀಯವಾಗಿ ಇಳಿಕೆಯಾಗಿರುತ್ತದೆ. ಹಾಗೆಯೇ ಭತ್ತದ ಹೊಟ್ಟಿನ ಜೈವಿಕ ಇದ್ದಿಲಿನ ಬಳಕೆಯಿಂದಾಗಿ ಪ್ರತ್ಯಾಕ್ಷಿಯ ಮಣ್ಣಿನಲ್ಲಿ DTPA ಕಬ್ಬಿಣ ಮತ್ತು ಮ್ಯಾಂಗನಿಸ್ ಪ್ರಮಾಣವೂ ಕಡಿಮೆಯಾಗಿರುತ್ತದೆ. ಹಸಿರುಮನೆ ಪ್ರಯೋಗದಲ್ಲಿ, ಆಮ್ಲ ಮತ್ತು ತಟಸ್ಥ ಮಣ್ಣಿನಲ್ಲಿ ಭತ್ತದ ಹೊಟ್ಟಿನ ಜೈವಿಕ ಇದ್ದಿಲನ್ನು ಕ್ರಮವಾಗಿ ೮ ಹಾಗೂ ೪ ಟನ್ ಪ್ರತಿ ಹೆ. ಗೆ ಹಾಕಿದಾಗ ಗಮನಾರ್ಹವಾಗಿ ಹೆಚ್ಚಿನ ಭತ್ತದ ಹುಲ್ಲು ಮತ್ತು ಭತ್ತದ ಕಾಳಿನ ಇಳುವರಿಯನ್ನು ಕಾಣಲಾಯಿತು. ಹಾಗೆಯೇ ಪ್ರತ್ಯಾಕ್ಷಿಯ ಮಣ್ಣಿನಲ್ಲಿ ಕಟ್ಟಿಗೆ ಇದ್ದಿಲನ್ನು ೪ ಟನ್ ಪ್ರತಿ ಹೆ. ನಂತೆ ಉಪಚರಿಸಿದಾಗ ಹೆಚ್ಚಿನ ಇಳುವರಿಯನ್ನು ಕಾಣಲಾಯಿತು. ಜೈವಿಕ ಇದ್ದಿಲಿನ ಪ್ರಮಾಣ ಹೆಚ್ಚಿದಂತೆ ಭತ್ತದ ಹುಲ್ಲಿನ ಹಾಗೂ ಭತ್ತದ ಕಾಳಿನ ಪೋಷಕಾಂಶಗಳು ಹಾಗೂ ಸಿಲಿಕಾನ್ ಅಂಶವು ಅಧಿಕವಾಗಿ ಕಂಡು ಬಂದಿರುತ್ತದೆ. ವಿವಿಧ ಬಗೆಯ ಹಾಗೂ ಪ್ರಮಾಣದ ಜೈವಿಕ ಇದ್ದಿಲಿನ ಬಳಕೆಯಿಂದಾಗಿ ಭತ್ತದ ಹುಲ್ಲಿನ ಇಳುವರಿಯ ಪ್ರತಿಕ್ರಿಯೆಯು ಶೇಕಡ -೩೬.೫೬ ರಿಂದ ೫೫.೧೮ ಹಾಗೂ ಭತ್ತದ ಕಾಳಿನ ಇಳುವರಿಯ ಪ್ರತಿಕ್ರಿಯೆಯು ಶೇಕಡ -೫೧.೦೦ ರಿಂದ ೪೬.೪೨ ವರೆಗೂ ದಾಖಲಾಗಿರುತ್ತದೆ.

ಅಕ್ಟೋಬರ್, ೨೦೧೫
ಮಣ್ಣು ವಿಜ್ಞಾನ ಮತ್ತು ಕೃಷಿ ರಸಾಯನಶಾಸ್ತ್ರ ವಿಭಾಗ
ಗಾ.ಕೃ.ವಿ.ಕೆ., ಬೆಂಗಳೂರು-೫೬೦ ೦೬೫

ಮುಖ್ಯ ಸಲಹೆಗಾರರು
(ಎನ್. ಬಿ. ಪ್ರಕಾಶ್)

Effect of Different Biochar on Available Silicon and Exchangeable Bases in Acidic and Alkaline Soils



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Introduction

- The pyrolysed biomass used for soil application is commonly named biochar (Lehmann and Joseph, 2009).
- Biochar is usually considered a win-win solution in terms of sustainable agriculture and the global C-cycle.
- As a soil conditioner its incorporation enhances nutrient balance by supplying, more importantly retaining nutrients in soil-plant system.
- Biochar contain a significant amount of exchangeable bases and Silicon (Xin *et al.*, 2014).
- The purpose of this study was to know the effect of incorporating biochar on soil exchangeable bases and plant available silicon in acidic and alkaline soil.

Objective

- ❖ To study the effect of different biochar on release of silicon and exchangeable bases in acidic and alkaline soils.

Materials and methods

Soil and biochar:

- Acidic and alkaline soils were collected from Sakaleshpura and Hiriyur respectively.
- Acidic soil had initial pH of 5.45, 56.1 ppm of plant available silicon (PAS), 0.39, 6.4, 3.9 0.14 cmol(p⁺) kg⁻¹ of exchangeable K⁺, Ca²⁺, Mg²⁺, and Na⁺ respectively.
- Alkaline soil had initial pH of 9.1, 38.8 ppm of PAS, 0.4, 29.5, 13.3, 6 cmol (p⁺) kg⁻¹ of exchangeable K⁺, Ca²⁺, Mg²⁺ and Na⁺ respectively.
- Three different biochar *viz.*, wood biochar (WB), bamboo biochar (BB), rice husk biochar (RHB) were used in this study (Table1).

Table 1: Chemical properties of biochar

Parameters	Bamboo biochar	Wood biochar	Rice husk biochar
pH (1:5)	10.03	10.5	7.39
K (%)	0.863	1.465	0.964
Ca (%)	0.32	2.3	0.36
Mg (%)	0.38	0.48	0.31
Na (%)	0.034	0.104	0.054
Si (%)	5.22	2.03	32.5
CaCl ₂ -Si (ppm)	20.59	10.63	57.16

Incubation study

An incubation study was conducted to know the dissolution and release of Si and exchangeable bases from biochar in acidic and alkaline soils.

The treatments includes three different biochar at four levels and control. Total of 13 treatments and three replications were laid out in completely randomized design (Plate1).

Destructive soil sampling was done at 15, 30, 60, 90 and 120 days after incubation (DAI) and analysed for pH, PAS and exchangeable bases.

Results

Effect of biochar application on plant available silicon in acidic and alkaline soils :

- Application of biochar increased the PAS in acidic and alkaline soils over the incubation period (Fig 1 & 2)
- In acid soil, higher PAS content was noticed with the application of WB and RHB at 60 DAI
- In alkaline soil, application of RHB @ 16 t ha⁻¹ recorded 3-4 times higher PAS throughout incubation period



Experimental set up for incubation studies

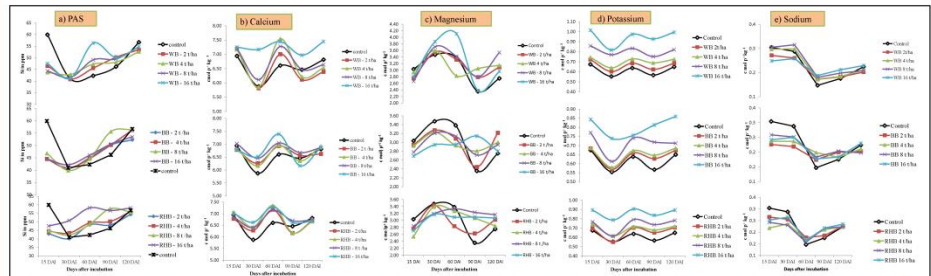


Fig 1: Effect of different types and levels of biochar on a) PAS b) Calcium c) Magnesium d) Potassium e) Sodium in acid soil

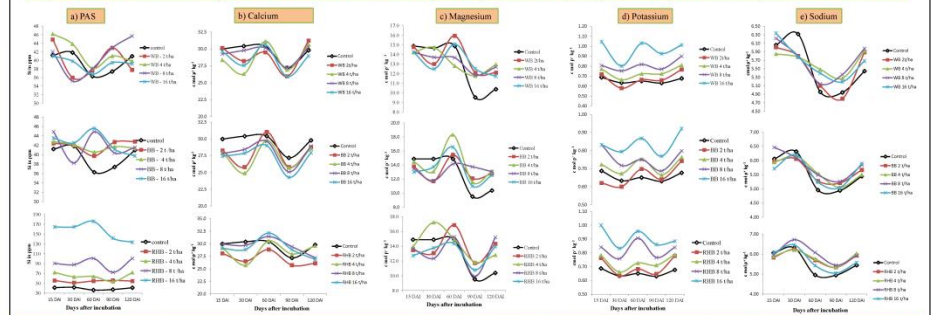


Fig 2: Effect of different types and level of biochar on a) PAS b) Calcium c) Magnesium d) Potassium e) Sodium in alkaline soil

Effect of biochar application on soil exchangeable bases in acidic and alkaline soils:

- A significant variation in content of exchangeable bases were noticed in both the soils over the incubation period
- Exchangeable Na⁺ and Mg²⁺ content were higher at 30 and 60 DAI, respectively in both the soils
- In acid soil, the application of WB @ 16 t ha⁻¹ recorded higher exchangeable Ca²⁺ and K⁺ at all intervals
- In alkaline soil, no definite trend was observed with rate of application of biochar on exchangeable Ca²⁺, Mg²⁺ and Na⁺, but exchangeable K⁺ content increased with increase in rate of application
- Among the different types, wood biochar recorded higher K⁺ content at all incubation periods in both the soils

Discussion

- PAS content depends on duration, type of biochar, level of biochar and soil acidity.
- Higher PAS content was noticed in alkaline soil than acidic soil. Haynes (2014) observed that dissolution rate of phytogenic silica increased with increase in the solution pH.
- The release of Si in acidic soil was dependent on total Si content and ability of biochar to increase the soil pH. In alkaline soil, it is mainly depending on total Si content.
- Exchangeable bases increased with biochar application, which can be attributed to the presence of bases in ash component of biochar.
- David *et al.* (2014) noticed rapid release of bases *viz.* Ca²⁺, Mg²⁺, and K⁺ to soil solution with application of biochar.

Summary

- The present study emphasis on potential of Si rich biochar as a source of Si in different soil.
- The application of biochar improved the base status of acid soil.

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I INTRODUCTION

Biochar is any source of biomass previously heated in the absence or at low concentration of oxygen with the purpose of application to the soil (Maia *et al.*, 2011). There are different ways of producing biochar from biomass, and the resulting biochar may vary in its physical and chemical composition depending on the kind of biomass and conditions of pyrolysis. The contribution of biochar as a soil amendment is currently being assessed for two main aspects. One is related to its potential to enhance the productivity of agricultural systems and to combat land degradation by improving soil physical, biological, and chemical properties such as reduced acidity, increased cation exchange capacity, enhanced nitrogen retention, increased microbiological activity and mycorrhizal associations (Gaskin *et al.*, 2008). The other is its contribution to carbon sequestration, as it contains carbon in stable forms and consequently, with a longer residence time in the soil (Santos *et al.*, 2012).

The pyrolytic process converts biomass acids into the bio-oil component and the alkalinity is inherited by the solid biochar (Laird *et al.*, 2010b; Yuan & Xu, 2011). During pyrolysis, most of the Ca, Mg, K, P, Si and micronutrients, and about half of the N and S in the biomass feedstock are partitioned into the biochar fraction and thus biochar can act as direct nutrient source when incorporated into soil (Laird *et al.*, 2010b). The high surface charge density, high surface area, internal porosity, and the presence of both polar and non-polar surface sites, enable biochar to adsorb organic molecules and associated nutrients.

There are several lines of evidence that biochar plays an important role in soil fertility and crop productivity. Biochar has been identified as an important soil constituent in fertile Chernozems (Schmitdt *et al.*, 1999) and in anthropogenic enriched dark soil (Terra Preta) found throughout the lowland portion of the Amazon Basin. However, there are considerable variations in plant and soil responses to biochar application that cannot be evaluated in a single study. Interactions with climate, soil type and fertilization status can also contribute to uncertainty in biochar responses (Lori and Stanley, 2013).

Research on biochar is relatively new, when compared to the age of its inspiration, the “*terra preta de índios*” - anthropogenic dark earth of Amazonia. More organized research on Amazonia dark earth from an agricultural point of view was started in early 2000. Biochar research for agricultural purposes is even more recent. Reported crop yield responses with biochar application ranged from 10 to > 200 per cent with application rate varying from < 1 to 100 t ha⁻¹. Improvements in plant growth and yield following biochar application are reported for radish (Chan *et al.*, 2008), common beans (Rondon *et al.*, 2007), soybean (Tague *et al.*, 2008), rice (Asai *et al.*, 2009) and maize (Yamato *et al.*, 2006). But effect of biochar application on upland and aerobic rice is not often reported in literature.

Many of biochar research works are focused on its nutrient content, properties, effect on soil pH, as an amendment and crop responses to its application. However,

dissolution of biochar and release of nutrients at different intervals in soil-biochar mixture are often reported. The characterization and short term soil incubation studies can provide some insight into the short term effect of biochar. Interestingly, depending upon feedstock and burning temperature, biochar may contain significant amount of silicon. The beneficial effect of biochar Si has not been investigated. Here rice crop, a silicon accumulator has been chosen to study the effect of graded levels of different biochar application on growth and yield of aerobic rice. In this research work, an effort is made to know the nutrient and silicon releasing pattern in three different soils by conducting an incubation study and a pot culture experiment to know the effect of different sources and levels of biochar application on growth and yield of aerobic rice. With this background the present investigation was undertaken with the title “Characterization of biochar, nutrient release and its effect on growth and yield of aerobic rice” with following objectives,

1. To characterize biochar for physico-chemical properties
2. To study the release of nutrients and silicon from biochar in acidic, neutral and alkaline soils
3. To study the effect of graded levels of biochar on growth and yield of aerobic rice

II REVIEW OF LITERATURE

The present study was undertaken to study “**Characterization of biochar, nutrient release and its effect on growth and yield of aerobic rice**”. The available reviews related to present investigation are given under following headings.

- 2.1 Biochar as means of carbon sequestration
- 2.2 Physico-chemical properties of biochar
- 2.3 Biochar as a source of nutrients
- 2.4 Effect of biochar application on physical and chemical properties of soil
- 2.5 Effect of biochar application on crop performance
- 2.6 Importance of silicon in agriculture with special reference to rice
- 2.7 Dissolution of silicon from plant derived materials

2.1 Biochar as means of carbon sequestration

The global soil carbon (C) pool of 2500 gigatons (Gt) includes about 1550 Gt of soil organic carbon (SOC) and 950 Gt of soil inorganic carbon (SIC). The soil C pool is 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic pool (560 Gt). Carbon sequestration implies transferring atmospheric CO₂ into long-lived pools and storing it securely without reemitting immediately. Thus, soil C sequestration means increasing soil organic carbon and soil inorganic carbon stocks through judicious land use and recommended management practices.

As regards of carbon sequestration, many different strategies are discussed in the literature, ranging from wide-spread afforestation and reforestation in terrestrial ecosystems (Watson *et al.*, 2000) to pumping of CO₂ into deep ocean and geological layers (Marchetti, 1977 and Doe, 1999). For terrestrial ecosystems, it has been proposed that C sequestration can be increased by increasing soil C stocks (Batjes, 1998; Izaurralde *et al.*, 2001 and Scholes and Noble, 2001). Among all such innovative ideas, the pyrolysis of biomass residue seems impressive as it act as soil amendment and sequesters carbon for longer time (Lehmann, 2007a).

The ability of biochar to act as a feasible climate change mitigation technology, which can be implementable globally (Molina *et al.*, 2009) and can sequester 12 per cent of anthropogenic greenhouse gas (GHG) emissions in ecologically and economically sustainable systems (Woolf *et al.*, 2010).

Sustainable systems have been postulated (Mathews, 2008; Preston, 2009 and Lee *et al.*, 2010) in which biomass is used to simultaneously produce energy and charcoal which upon application to land removes carbon from the short-term photosynthesis-mediated cycle to a long-term reservoir.

The estimated C-residence time of biochar in soil is in the range of hundreds to thousands of years, while that of crop residue is in the range of decades (Lehmann *et al.*, 2006). Consequently, incorporating biochar from such feedstock into soil has potential to reduce reemitting of CO₂ to atmosphere.

The International Biochar Initiative (IBI) promotes ubiquitous use of biochar as a soil amendment, advocates for inclusion of provisions favorable to biochar use in national and global climate mitigation policies which promotes biochar commercialization, and aspires to a global system that sequesters 2.2 Gt C yr⁻¹ by 2050 (IBI, 2013).

In comparison to burning, controlled carbonization converts even larger quantities of biomass organic matter into stable C pools which are assumed to persist in the environment over centuries (Lehmann *et al.*, 2002). Also the weighted average of C recovery from charred woody biomass is relatively high at 50 per cent compared to only 3 per cent after conventional slash and burn technique.

Lehmann *et al.* (2006) estimated an annual sequestration of 0.2 Pg through slash and char and biochar application to soil instead of slash and burn. Furthermore, the study reported that low temperature pyrolysis of biomass combined with the capture of gas and liquid products of bio energy production and soil application of biochar could sequester the equivalent of about 10 per cent of the annual US fossil fuel emission.

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.

Increase in soil aeration and porosity by biochar amendment may decrease production of CH₄ from soil as oxic conditions created may increase oxidation of CH₄ (Van Zwieten *et al.*, 2009). Two mechanisms may be operational *viz* (i) decrease in CH₄ production, and (ii) increase in CH₄ oxidation by methanotrophs in the soil-biochar system depending on specific conditions (Karhu *et al.*, 2011).

Lehmann *et al.* (2009) suggested a double exponential decay model for biochar carbon loss in soil in which two first-order loss processes occur simultaneously *viz* rapid decay (half-life, $\lambda \approx 0.54$ years) of labile carbon followed by slow ($\lambda \approx 1,600$ years) mineralization of fixed biochar carbon. Subsequently, Kimetu and Lehmann (2010) demonstrated that biochar addition stabilizes soil organic carbon better than green manure labile carbon. *Tithonia diversifolia* green manure additions increased CO₂ C loss by 22 per cent while biochar addition reduced soil CO₂ carbon loss by 27 per cent and increased intra-aggregate C per respired C by 6.8 times relative to the green manure.

In the longer term, Downie *et al.* (2011), studying soils in ancient Australian aboriginal oven mounds, showed that historic charcoal additions, between 650 and 1,609 years old, resulted in long-lived, significantly elevated soil carbon stocks, relative to the

adjacent soil. The application of charcoal will lead to higher C sequestration in comparison to the application of equal amounts of non-charred organic matter. Compared to slash-and-burn techniques, “slash and char” significantly increases the C sequestration to soil by a mean factor of 17 (Glaser *et al.*, 2002).

2.2 Physico-chemical properties of biochar

The impact of biochar as an amendment depends on its properties or attributes. Biochar properties can be significantly influenced by feedstock source and pyrolysis conditions. This warrants detailed characterization of biochar for their application to improve soil fertility and sequester carbon (Singh *et al.*, 2010). Biochar characterization is essential to improve the understanding of its production property relationships and to allow for its pre-application (Brewer *et al.*, 2009 and Novak *et al.*, 2009). Although it is clear that the behavior of biochar in soil is related to the characteristics created during the pyrolysis process, little attention has been given to link its behavior in the agro-ecosystem to its properties. Thus, it is important to examine the properties of different biochar derived from different feedstock, pyrolysed over a range of temperatures and residence times and to relate these variables to its function in soil.

Biochar made from diverse biomass species (feedstock) are characterized by different morphological and chemical properties but also characteristically differ based on specific pyrolysis conditions *i.e.*, final pyrolysis temperature or peak temperature, rate of charring or ramp rate, and duration of charring time (Mukherjee, 2011; Mukherjee *et al.*, 2011 and Zimmerman, 2010).

The results of the experiment conducted by (Mc Beath and Smernik, 2009) confirmed that aromatic condensation in biochar increased with increasing pyrolysis temperature. Activated biochar contain the most highly condensed aromatic structures, but also showed the importance of feed stock and retention time on aromatic condensation. Further, manure based biochar synthesized at low temperature may comprise a considerable proportion of aliphatic C and low proportion of aromatic aryl C and thus can easily mineralized than wood based biochars.

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

Weixiang *et al.* (2012) observed that degree of carbonization for biochar was accelerated with increasing pyrolysis temperature. As the pyrolysis progressed, oxygen and hydrogen were removed, leaving the remaining carbon to form aromatic carbon bonds. The experimental results of TGA, FTIR, NMR and XRD indicated that the formation of highly ordered aromatic structures of biochar began at 400 °C (Kim *et al.*, 2012). Increase in aromaticity with increase in temperature was supported by decrease in molar H:C and O:C ratios (Spoaks, 2010).

The decrease in biochar yield with increase in pyrolysis temperature was reported by Yuan *et al.* (2011). Increase in pyrolysis temperature increases the pyrolysis of

cellulose and hemicellulose and combustion of organic material resulting in decreased biochar yield and increased ash content (Novak *et al.*, 2009).

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

Brown *et al.* (2006) reported lower surface area ($\sim 10 \text{ m}^2 \text{ g}^{-1}$) of biochars produced at lowest (300 °C) and highest (> 1000 °C) pyrolysis temperature. While, higher surface area of $\sim 400 \text{ m}^2 \text{ g}^{-1}$ was recorded at intermediate pyrolysis temperature of 650 to 850 °C (Lua and Guo, 1998).

The results of 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 high pH of biochar has been attributed to hydrolysis of salts of Ca, Mg and K (Tryon, 1948).

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.

Wang *et al.* (2013) found that for a given feedstock, increasing pyrolysis temperature from 500 °C to 700 °C increased the ash content, BET surface area, pH, total P and Ca contents and decreased the biochar yield, cation exchange capacity (CEC), total acid and N. Increase in residence time from 4 to 8 or 16 hour, increased the BET surface area and ash content of biochar but decreased the biochar yield. FTIR analysis showed that more recalcitrant and aromatic structures were formed in the biochar at higher temperature.

Gaskin *et al.* (2008) evaluated agronomic potential of biochar. The total and Mehlich I extractable nutrients of feedstock were concentrated in biochar upon pyrolysis. Depending on feed stock some biochar were potential to serve as nutrient as well as carbon sequester.

Fungai *et al.* (2013) conducted FTIR spectral analysis for surface functional groups of biochar. Ratio of peak intensities relative to the aromatic C=H stretch at 870 cm^{-1} revealed significant differences in the wood vs non-wood-derived biochar. Most notably, the non-wood biochars had less aromatic and greater aliphatic character than the wood biochars on the basis of the ratio of the peaks $870:1029 \text{ cm}^{-1}$, $870:1417 \text{ cm}^{-1}$ and $870:1587 \text{ cm}^{-1}$.

The X-ray diffraction spectra of the biochar suggested that carbonates were the major alkaline components in the biochars generated at the high temperature. The data of

FTIR-PAS and zeta potentials indicated that the functional groups such as -COO^- (-COOH) and -O^- (-OH) contained by the biochars contributed greatly to the alkalinity of the biochar, especially for those generated at the lower temperature (Yuan *et al.*, 2011)

Chan and Xu (2009) reported that the porosity and surface area of a biochar had significant effect on its nutrient retention capacity by surface binding of both cation and anions.

Downie *et al.* (2009) found highly variable pore size distribution of biochar and encompasses nano- (<0.9 nm), micro- (<2 nm) to macro-pores (>50 nm). Brewer *et al.* (2014) reported biochar porosity varied from 0.55 to 0.86 and mostly depending upon feedstock and less dependent on pyrolysis temperature.

Biochar has lower bulk density than mineral soil with values on par with organic soils. Similarly, Deluca and Aplet (2008) reported that biochar and charcoal recorded low bulk density of 1300 kg m^{-3} .

2.3 Biochar as source of nutrient

The capacity to retain and apparently recycle nutrients during prolonged periods of cultivation is the outstanding feature that distinguishes the charcoal rich terra preta soil from surrounding *Oxisols*. During pyrolysis, most of the Ca, Mg, K, P and plant micronutrients and half of N and S in biomass feedstock are partitioned into biochar (Laird *et al.*, 2010b). Information regarding availability of nutrients is particularly relevant to understand potential biochar benefits to plant growth (Gundale and De Luca, 2007).

Nutrient composition and availability in biochar varied widely depending on the nature of feedstock and pyrolysis conditions (Chan and Xu, 2009 and Singh *et al.*, 2010). Whereas the availability of nutrients from biochar is related to the type of bonds associated with the element involved (De Luca *et al.*, 2009 and Yao *et al.*, 2010).

Total P and K were increased significantly with increase in pyrolysis temperature while total N followed reverse trend (Zheng *et al.*, 2013). Similarly differences in pyrolysis temperature using the same feedstock (chicken manure) produced biochars with very different properties including, EC, pH and P and N concentrations (Chan *et al.*, 2008).

Zheng *et al.* (2013) investigated nutrient value of gaint reed (*Arundo donax*) biochar produced at different temperature. The XRD data showed presence of various different mineral components depending upon pyrolysis temperature. Of different minerals identified, sylvine was found in all biochar samples, corresponding peak intensity increasing with increase in pyrolysis temperature indicated well crystallization of sylvine in biochar produced at higher temperature. Biochar produced at high temperature showed peaks corresponding to larnite (Ca_2SiO_4), enstatite ($\text{Mg}_2\text{Si}_2\text{O}_6$) and wollastonite (CaSiO_3), suggesting loss of carbonate and formation of silicates increased with increase in pyrolysis temperature.

Wu *et al.* (2012) found that, in comparison to original feedstock, 29.1 % P, 79.3 % K, 31.8 % Ca, 57.2 % Na and 24.4 % Mg of total content still preserved as available form in rice straw derived biochar and suggested for the use of rice straw biochar as potential fertilizer and amendment for soil.

Lehmann *et al.* (2002) reported that most of the cations in the ash component of biochar were not bound by electrostatic forces but present as dissolved salts and thus act as a conditioner and fertilizer itself.

Hass *et al.* (2012) evaluated the potential of chicken manure biochar as nutrient source for acid Appalachian soil. The results revealed that increase in production temperature increased availability of Cu, K, Mg and Zn, while decreased that of Fe, Mn and S. Further increase in production temperature and activation reduced the availability of K, P and S, while availability of Cu and Zn was improved.

Enders *et al.* (2012) reported that biochar contains large amounts of carbon and macro or micro-nutrients depending on feedstock and pyrolysis temperature. As a result, biochar may directly supply plant-available nutrients once applied to the soil (Gaskin *et al.*, 2007). It is uncertain whether these soluble nutrients are released instantaneously or over a time once added to the soil (Sohi *et al.*, 2010).

2.4 Effect of biochar application on soil physical and chemical properties

2.4.1 Physical properties

The physical properties of soil determine their adaptability to cultivation and the level of biological activity that can be supported by soil. The positive effect of biochar that are reported on soil nutrient status, C- sequestration, microbial community and green house gas emission are related to physical properties of soil. Soil physical properties also largely determine the soil's water and air supplying capacity of soil to plants.

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).

The porous nature of biochar increased the soil water retention by 18 per cent upon addition of 45 per cent (by volume) to a sandy soil (Tryon, 1948). Glaser *et al.* (2002) reported that charcoal-rich *Anthrosols* whose surface areas were three times higher than those of surrounding soils increased the field capacity by 18 per cent.

Tryon (1948) also 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.

The changes in soil physical properties such as soil water retention and aggregation (Piccolo and Mbagwu 1990 and Piccolo *et al.*, 1996), enhanced the water availability to crops and decreased the erosion (Piccolo *et al.*, 1997).

Increase in water retention capacity of soil improved available water content (Emmanuel *et al.*, 2010 and Brigs *et al.*, 2012). Application of biochar increased the available water capacity by 97 per cent, saturated water content by 56 per cent, and reduced hydraulic conductivity with increasing moisture content when compared to unamended soil (Uzoma *et al.*, 2011a).

Amonette and Joseph (2009b) showed that incorporation of biochar influenced soil structure, porosity and density and thereby potentially altered air oxygen content, water storage capacity and microbial and nutrient status of soil within plant rooting zone.

Asai *et al.* (2009) studied the effect of biochar application on soil physical properties. Biochar application improved the saturated hydraulic conductivity of the top soil and xylem sap flow of the rice plant.

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.

Ouyang *et al.* (2013) conducted a study to know the effect of biochar amendment on soil aggregate formation and their stability in two different textured soils. Macro aggregate formation was more profound in the sandy loam soil than in the silty clay soil.

Application of biochar, increased soil organic matter, water holding capacity, bioavailable nutrients and significantly enhance the microbial activities and thereby the soil aggregate formation and stability (Downie *et al.*, 2009). Glaser *et al.* (2002) reported that the formation of complexes of biochar with minerals, as a result of interactions between oxidized carboxylic acid groups at the surface of biochar particles, was responsible for the improved soil aggregate stability.

Incorporation of biochar can enhance specific surface area up to 4.8 times that of adjacent unamended soils (Liang *et al.*, 2006). A long-term soil column incubation study conducted by Laird *et al.* (2010a) indicated increases in specific surface area of an amended clayey soil from 130 to 150 m² g⁻¹ when biochar derived from mixed hardwoods was applied at rates of 0 to 20 g kg⁻¹.

In addition to improvement in surface area, porosity and soil aeration were also improved upon biochar application (Sean *et al.*, 2012). Jones *et al.* (2011) in a study

found that significant increase in mesoporosity at the expense of macropores in waste-derived biochar-amended soil compared to control.

An experiment conducted by Mankasingh *et al.* (2011) showed that soil bulk density decreased from 1.66 to 1.53 g cm⁻³. Similarly Laird *et al.* (2010a) in a column incubation study noticed significantly lower bulk density in biochar-amended soil columns compared to no-biochar controls.

2.4.2 Chemical properties of soil

The unique properties of stable C rich biochar such as high surface area, high charge per unit area, occurrence of various surface functional groups and ash content had a positive effect on soil chemical properties. Application of biochar increased SOC, pH, EC, CEC and exchangeable bases (Hass *et al.*, 2012; Laird *et al.*, 2010b; Liang *et al.*, 2006; Anteneh *et al.*, 2014 and Warnock *et al.*, 2007) and decreased exchangeable acidity and exchangeable aluminium (Novak *et al.*, 2009; Qian *et al.*, 2013; Qian and Chen, 2013 and Wan *et al.*, 2014)

One consistent effect of biochar application was found to increase in soil pH which implied a liming value of biochar (Major *et al.*, 2010 and Yuan *et al.*, 2011). Collins (2008) found nearly a unit increase in soil pH with biochar derived from herbaceous feedstock and 0.5 to 1 unit increase in the soil pH with biochar derived from woody sources. Rondon *et al.* (2007) credited the improvement of bean productivity due to elevation of soil pH and other soil nutrient as a consequence of use of biochar.

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).

A study was taken up 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.

The effect of aging on amelioration of soil acidity by biochar was investigated by Rudong *et al.* (2015). Biochar positively affected soil acidity by decreasing exchangeable Al³⁺ and exchangeable acidity as well as increasing pH and exchangeable bases. However, the effect declined to a certain extent when biochar went short term aging without soils.

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

An incubation experiment was conducted by Liu and Zhang (2012) to determine the effects of biochar on the pH of alkaline soils. The application of alkaline biochar did not increase the soil pH but instead decreased pH, especially with higher rates of application. Acidic materials produced by the oxidation of biochar and organic matter decreased the pH. The high soil cation exchange capacity caused by the biochar application might restrict the soil salinization process to some extent.

Incorporation of biochars into acidic soil caused an increase in EC due to the release of weakly bound nutrients (cations and anions) of biochars into the soil solution (Glaser *et al.*, 2000; Gundale and De Luca, 2007 and Chan *et al.*, 2008).

CEC of soils increased by 50 per cent with the addition of charcoal materials (Mbagwu and Piccolo 1997). The increase of soil pH due to the application of biochar makes the soil surface more negative (Steiner *et al.*, 2007). The increased CEC of soil-biochar mixtures may be due to slow oxidation of biochar material as the result of biotic and abiotic factors during incubation which can oxygenate the functional groups of biochar surface and enhance the formation of organo-mineral complexes (Ma *et al.*, 1979; Glaser, 1999 and Glaser *et al.*, 2001). The charge density per unit surface of biochar was generally high and its incorporation increased the cation sorption by soils (Liang *et al.*, 2006).

Danish *et al.* (2015) studied the effect of biochar application on SAR and RSC of sandy soil. Application at higher rate significantly increased SAR (2.6 folds) and RSC (1.84 folds) of sandy soil as compared to control and they also suggested to discourage application of biochar with high Na^{+1} as amendment in saline and sodic soils.

2.4.3 Effect of biochar application on soil nutrient status

The presence of biochar either as legacy of ancient Amerindian practices or adding during modern scientific investigations appears to play a critical role in increasing nutrient availability and reducing nutrient leaching (Lehmann *et al.*, 2007; Steiner *et al.*, 2007 and Steiner *et al.*, 2008). The Terra Preta soils of the Amazon contain significantly more C, N, Ca, K and P and have higher cation-exchange capacities, pH values and base saturations than the surrounding soils (Zech *et al.*, 1990; Glaser *et al.*, 2000 and Lima *et al.*, 2002). The high surface charge density, surface area, internal porosity, and the presence of both polar and non-polar surface sites enable biochar to adsorb organic molecules and associated nutrients (Liang *et al.*, 2006).

Nutrient bioavailability can also be affected by increasing cation exchange capacity, altering soil pH, or direct nutrient contributions from biochar (Cheng *et al.*, 2006; De Luca *et al.*, 2009; Enders *et al.*, 2012; Yuan and Xu, 2011 and Peng *et al.*, 2012). Novak *et al.* (2009) observed variation in Mehlich-1 extractable plant nutrient concentration at 0 and 67 day reflected the combined effect of nutrients added through biochar, leaching of nutrients and adsorption of nutrients by biochar and soil.

Lehmann *et al.* (2003) found that nutrient retention was caused by adsorption to an exchange complex created by biochar addition. Oxidation of functional group on

biochar particle could lead to high CEC and charge density to retain cations (Liang *et al.*, 2006).

Increase in Mehlich-3 extractable macro (P, K, S, Ca and Mg) and micronutrients (Cu, Zn, Mn and Fe) as a result of biochar application was noticed by Hass *et al.* (2012). However increased application rate decreased the Mehlich-3 extractable Mn and Fe possibly due to liming effect of biochar.

Zheng *et al.* (2013) studied the effect of solution pH on release of N, P and K from biochar. The results showed that release of PO_4^{3-} and NH_4^+ were pH-dependent, while that of K^+ and NO_3^- were not. Generally, the content of PO_4^{3-} and NH_4^+ released from the biochars decreased with increasing pH until pH 10, whereas that of K^+ remained relatively stable from pH 2 to 7 and significantly decreased at pH 8-12.

Silber *et al.* (2010) studied the pH dependent release of nutrient and its agronomic implication from cornstrow biochar. The results revealed that kinetics of element release was characterized by rapid H^+ consumption and pH dependent P, Ca and Mg release, followed by zero order H^+ consumption and mineral dissolution reaction. P and K release were significant, having the potential to substitute substantial proportion of P and K fertilizer.

Study conducted by Steiner *et al.* (2008) using soils in Amazonian field trials, have confirmed that biochar can act as an adsorbent reducing N leaching and increasing N use efficiency. Dempster *et al.* (2012) in a lysimeter study using *Eucalyptus* biochar observed a 25 per cent reduction in NO_3^- leaching over control.

Laird *et al.* (2010a) in a 500 day incubation study observed significant increases in total N (up to 7 %), organic C (up to 69 %) and Mehlich-3 extractable P, K, Ca, and Mn with the amount of biochar added. The biochar treatments had no significant effect on Mehlich-3 extractable Mg, Cu and Zn. The increases in Mehlich-3 extractable K, Ca and Mn with increasing levels of biochar were most likely due to the presence of these nutrients in the biochar itself.

Van Zwieten *et al.* (2010) observed an increase in soil exchangeable K content with application of wood waste chip biochar at 10 Mg ha^{-1} . Similarly, Gaskin *et al.* (2010) observed a linear increase in soil-extractable K content after adding peanut hull biochar into Tifton sand in first year of study. However, in the second year, the K effect diminished, suggesting that biochar served only as a temporary source of K or that the soil failed to retain K.

Ippolito *et al.* (2012) compared the effects of switchgrass biochar produced at two different temperatures (250 or 500°C) on nutrient leaching and the soil fertility levels of *Aridisols*. Overall, biochar produced at 250°C decreased the Ca and Mg leaching, increased the K leaching. These observations were likely due to greater total negative surface charge in the biochar produced at 250°C versus the 500°C. The high negative surface charges favored divalent cation sorption.

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 exchangeable acidity, S and Zn. 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).

Parvage *et al.* (2013) conducted a study to understand the effect of wheat residue biochar addition on water soluble P concentration in a wide range of biochar amended soils. Experiments with different rates of 0.5, 1, 2 and 4 per cent; w/w biochar addition revealed that the highest concentration of water soluble P was achieved at an application rate of 1 per cent. At higher application rates, P concentrations decreased which coincided with a pH increase of 0.3 - 0.7 units.

Biochar can alter P availability directly through its anion exchange capacity or by influencing activity/ availability of the cations that interact with P. An increase in pH can increase alkaline metal (Mg^{2+} , Ca^{2+} and K^+) oxides which reduces soluble forms of aluminum suggested to be most significant biochar factor affecting P solubility (De Luca *et al.* 2009).

2.5 Effect of biochar application on crop performance

The research field of biochar is expanding rapidly, much of interest in biochar comes from studies in Amazonian soils, with significant improvement in soil quality and positive effect on crop yield with the added bonus of climate change mitigation through carbon sequestration (Glaser *et al.*, 2002 and Jeffery *et al.*, 2011). Such positive effects are attributed to effect of biochar to increased CEC and associated nutrient retention (Lehmann *et al.*, 2002; Asai *et al.*, 2009; Hossain *et al.*, 2010 and Steiner *et al.*, 2008), increased pH and base saturation (Chintala *et al.*, 2014; Laird *et al.*, 2010b and Liang *et al.*, 2006), increased available P (Major *et al.*, 2010; Ma and Matsunaka, 2013 and De Luca *et al.*, 2009), and increased plant-available water (Novak *et al.*, 2012 and Glaser *et al.*, 2002).

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.

Chan *et al.* (2007) conducted a pot culture study to investigate the effect of biochar produced from green waste on the yield of radish. In the absence of N fertilizer, application of biochar to the soil did not increase radish yield even at the highest rate of 100 t ha^{-1} . However, a significant interaction between biochar and N fertilizer was

observed, in that yield increased with increasing rates of biochar application, highlighting the role of biochar in improving N fertilizer use efficiency of the plant.

Chan *et al.* (2008) evaluated two biochar produced from poultry litter under different condition in a pot experiment by assessing yield of radish. The yield increase was largely due to the ability of biochar to increase nutrient availability, particularly N and other beneficial effects of biochar on soil quality. In this regard, the non activated (450 °C) poultry litter biochar was more effective than the activated (550 °C) biochar. These results highlight the importance of feedstock and process conditions during pyrolysis in determining the soil amendment values of biochars.

Asai *et al.* (2009) studied the effect of biochar application on grain yield of upland rice at ten different sites, combining different rate biochar and fertilizer application (N and P) and two cultivars. Biochar application resulted in higher grain yields at the sites with low P availability. In the absence of N fertilizer and at highest rate of biochar application, there was reduction leaf chlorophyll content indicating biochar application is highly dependent on soil fertility and fertilizer management.

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 thereby 16 - 35 per cent improvement in grain yield over control.

Rondon *et al.* (2007) demonstrated the potential for increasing the N input by BNF into agroecosystems in highly weathered and acid soils by biochar applications. Nitrogen fixation was significantly improved by moderate rates of biochar additions. The reason for the improved BNF was mostly an effect of the improved availability of B and likely of Mo and to a lesser extent, a decreased N availability and increased availability of K, Ca, and P and higher pH as well as lower Al saturation.

Kloss *et al.* (2014) investigated the effect of application of three different biochar on nutrient dynamics, crop yield and soil quality in temperate soil over three cropping seasons. Despite the improvement in soil nutrient status, yields of first crop and to less extent of second crop were reduced as result of biochar application, but not so for third crop. The initial yield reduction was accompanied by notable decrease in micronutrient cation concentration while nitrogen content was hardly affected.

Liu *et al.* (2014) demonstrated role of biochar to improve silicon availability and uptake by rice in acid and slightly acidic soil. Varying with site condition, plant available Si content of soil increased significantly with biochar application. Significant increase in rice shoot Si was detected in four out of six sites, which was well correlated to concurrent increase in soil pH and direct addition from biochar.

Carter *et al.* (2013) assessed the effect of rice husk biochar application on the growth of transplanted lettuce and Chinese cabbage over three crop cycle. The biochar treatments were found to increase the final biomass, root biomass, plant height and

number of leaves in all cropping cycles in comparison to no biochar treatments. Over the cropping cycle the impact of biochar on biomass production was reduced to 363 per cent in third lettuce cycle in comparison to first cycle (483 %).

Dong *et al.* (2015) reported amendment with rice straw biochar resulted in higher rice yields than that of 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.

Maize yield and nutrient uptake were significantly improved with increasing rate of biochar application. Application of biochar at 15 and 20 t ha⁻¹ significantly increased maize grain yield by 150 and 98 per cent respectively as compared with the control (Uzoma *et al.*, 2011b).

2.6 Importance of silicon in agriculture with special reference to rice

Seven out of ten most produced crops (ranked by quantity) in the world are Si accumulators (with Si/Ca ratio >1). Thus understanding the role of Si in crop production is important. It is also currently assumed that Si is not limiting in soils. But an uptake of 300 kg ha⁻¹ year⁻¹ of Si by sugar cane (Meyer and Keeping, 2001), 500 Kg⁻¹ year⁻¹ of Si by rice (Makabe *et al.*, 2009) may deplete soil Si levels. Indeed, Savant *et al.* (1997a) suggested that non- reincorporation of the straw to the field may lead to a depletion of plant available Si in soils which could decline cereal yield.

Silicon accumulation varies among species, with some plants containing only trace amounts, in rice, silicon constitutes up to 10 per cent of plant dry mass (Epstein, 1999). The benefits of Si fertilization are generally observed in rice and sugarcane grown on weathered tropical soils and histosols which are Si deficient (Korndorfer *et al.*, 1999 and Takahashi *et al.*, 1990).

Silicate fertilizer, which is a by-product of steel industry and contains high amount of active iron oxide, could be used as an oxidizing agent in rice farming. Moreover, it provides adequate silicon which is necessary for healthy rice growth (Ma *et al.*, 1989), besides increasing yield potential (Yoshida, 1981) and developing resistance to pathogens (Deren *et al.*, 1994).

It has been reported that silicon suppresses insect pests such as stem borers, brown plant hopper, green leaf hopper, white backed plant hopper and non-insect pests such as spider mites (Savant *et al.* 1997b and Ma and Takahashi, 2002). The beneficial effect of Si have been thought to be due to precipitation of amorphous silica in plants which act as a mechanical barrier for incidence of pest and disease infestation (Cheng, 1982 and Jones and Handreck, 1967)

Silicon-fertilisation has been shown to alleviate sodium uptake in rice, wheat and barley (Savant *et al.*, 1997b). Si interaction with Na⁺, reduced its uptake and transport to

shoots and consequently improved cane yield and juice quality in salt-sensitive and salt-tolerant sugarcane genotypes under salt stress (Ashraf *et al.*, 2010).

Ehsan *et al.* (2011) demonstrated the interaction of Si and P to mitigate Mn toxicity in rice grown in highly weathered soil. Although Si application affected the P uptake, yield increase were more likely associated with reduced Mn toxicity, particularly as the P/Mn and P/Fe ratios increased with increased Si application.

Optimization of Si nutrition increased the weight and volume of roots by 20 per cent to 200 per cent and enhanced drought and salt resistance of cultivated plants (Matichenkov *et al.*, 2001). Adequate supply of silicon to rice from tillering to elongation stage increased the number of grains per panicle and the percentage of ripening (Korndorfer *et al.*, 2001).

The presence of Si in nutrient solutions affected the absorption and translocation of several macro and micro-nutrients (Epstein, 1994). Brenchley and Maskell (1972) found that Si fertilization increased yield of barley mainly when P fertilization was limiting. It was concluded that Si fertilization increased the availability of P to plants. Ma and Takahashi (2002) observed that Si increased the oxidizing capacity of roots, which converted the ferrous iron into ferric iron, thereby preventing a large uptake of iron and limiting its toxicity.

Mali and Aery (2008) observed a better absorption of N and Ca for cowpea and wheat fertilized with increasing doses of sodium meta silicate as well as better nodulation and apparently better N₂ fixation in cowpea.

Savant *et al.* (1997b) reported that an adequate supply of Si increased the number of panicles, the number of grains per panicle, the percentage ripening and the light-receiving posture of rice plants, thereby improving photosynthesis. Application of Si in rice was found to increase the grain yield by increasing spikelets number per panicles, mature grain percentage and 1000 grain weight (Takahashi, 1996 and Singh *et al.*, 2005).

Cheng (1982) and Savant *et al.* (1997b) noted beneficial effects of Si on plant growth in terms of increased number of leaves, tillers and alleviation of disorders like bronzing and Akiochi in rice. Ma *et al.* (1989) observed that addition of 100 ppm SiO₂ as silicic acid during the reproductive stage markedly increased straw yield.

2.7 Dissolution of plant derived silicon in soil

Silicon is taken up by plants and mainly deposited in transpiration sites where polymerization of hydrated amorphous silica occurs to form phytoliths (Epstein, 1999 and Marschner, 1995). Plant derived Si is called as phytogenic Si. Disappearance of amorphous structure of phytoliths occurs at 500 to 800°C (Krull *et al.*, 2003) but pyrolyzed biomass below this temperature still contain unmodified amorphous phytoliths. The solubility of amorphous silica such as phytoliths is higher (1.8-2 mM Si) than quartz.

Traditionally soil solution Si is viewed as being supplied by dissolution of primary and secondary minerals and buffered by adsorption and desorption of silicate on to surfaces of Al and Fe hydrous oxides. But in recent year, it has been realised that phytogenic cycling of silica drives soil solution Si concentration in natural and grass land ecosystem (Keller *et al.*, 2012).

Frayse *et al.* (2009) compared the Si release rate from phytogenic Si to that of typical primary (olivine, diopside) and secondary (illite, kaolinite) silicate minerals and found that at common soil pH values (4-8) phytogenic Si was 10^2 to 10^4 times more soluble than the other minerals.

Dissolution of phytogenic Si increases with increase in soil pH, decreasing particle size and is promoted by moist soil conditions and removal of soil solution Si (Dress *et al.*, 1989). Further dissolution rate of phytogenic Si originating from different plants (larch, elm, fern, horsetail and bamboo) over the same pH range were similar (Frayse *et al.*, 2006 and 2009).

Frayse *et al.* (2009) calculated the half- life of phytogenic Si in soil assuming 100 per cent water saturation over the year, to be 26-156 weeks at pH 4-5 and only 7-10 weeks at pH 6-7. Similarly, Nguyen *et al.* (2014) showed that Si release from phytogenic si in rice straw was an order of magnitude greater at pH 6.5 than at 3.

The sorption of di and trivalent metals (Al^{3+} , Fe^{3+} , Zn^{2+} and Cu^{2+}) to the surfaces of phytogenic Si is known to reduce its solubility (McKeague and Cline, 1963; Dove, 1995 and Wilding *et al.*, 1979). Since the solubility of Al and Fe increases greatly with decreasing pH, their adsorption to the surfaces of phytogenic Si is favoured at low pH and this reinforce the increasing solubility of phytogenic Si with increasing pH.

The dynamics of Si release from rice straw and adsorption by soil was studied by Wickramasinghe and Rowell (2006) using silica adsorption isotherms as a means of determining the amounts of Si dissolved. These experiments indicated that up to 38 per cent of the amorphous silica and up to 20 per cent of the straw-silica was dissolved. Compared to the rate of release Si from straw into solution without soil and with soil, the release of Si into soil suspensions was increased during the first 20 days, but was then reduced probably due to effect of Fe and Al.

The Si dissolution from straw is slower than from amorphous silica presumably as a result of the protective of silica by the plant matrix (Jones and Handreck, 1963). Nguyen *et al.* (2014) studied the effect of soil solution composition on Si release from rice straw. Monovalent cations and organic anions suppressed the Si release more strongly than divalent and inorganic anions.

Xin *et al.* (2014) studied transformation and dissolution of Si from Si rich biochar. Biochars are prepared from rice straw at different pyrolysis temperature ranging from $150^{\circ}C$ to $700^{\circ}C$. The released Si from biochar produced at low temperature increased linearly with dissolution time. On other hand those produced at high

temperature released Si non linearly and sharply increased with dissolution time. In other words silicon dissolving rate and quantity are connected to pyrolysis temperature, which leads to variation in pH, structure, Si form and other properties of biochar. Further, batch extraction studies were conducted to the continuous release of Si from rice straw derived biochar. The highest Si content was recorded at 30 days and then decreased for the biochar produced at higher temperature. While those produced at low temperature showed an increasing trend throughout study period.

Fraysse *et al.* (2006) studied the horsetail and pine litter degradation in acidic, neutral, and alkaline solution. Results revealed that the release of Si was fastest in basic condition and slowest in acidic condition. Both litter showed a higher Si content at 15 days in alkaline solution and there after Si concentration decreased. On other hand in neutral and acidic solution dissolution continues till the end of study period (60 days).

III MATERIALS AND METHODS

The research entitled “**Characterization of biochar, nutrient release and its effect on growth and yield of aerobic rice**” was undertaken during 2014. In this study, incubation and pot culture experiments were conducted at Department of Soil Science and Agricultural Chemistry, UAS, GKVK, Bengaluru. The details of the materials used and methodologies adopted during the investigation are presented below.

3.1 Soil and biochar collection

3.1.1 Soil

Three soils with contrasting pH were used in this study. Acidic soil with pH 5.45 was collected from Sakaleshpura representing hilly zone and taxonomically classified as *Ultic paleustalfs*. The neutral soil with pH of 6.45 was collected from Kathalgera representing southern transition zone and taxonomically classified *Udicrhodustalf*. The alkaline soil with pH of 9.15 was collected from Hiriyur representing central dry zone and taxonomically classified as *Chromic haplusterts*. The texture of acidic, neutral and alkaline soils as determined by standard pipette method was found to be sandy clay loam, sandy clay loam and clay loam, respectively. Collected soils were air dried and sieved through two mm sieve and used for both incubation and pot culture studies. Bulk of all the soils were analysed for initial properties by following standard procedures given in Table 1 and the data are presented in Table 2.

3.1.2 Biochar

Three different biochars viz wood biochar (WB), bamboo biochar (BB) and rice husk biochar (RHB) were used in present investigation. The WB and BB were produced relatively at higher temperature (around 550 °C) while RHB was produced at relatively lower temperature (around 400 °C). All the biochars were ground to pass through 0.2 mm sieve and used in both incubation and pot culture experiments. WB was procured from Pointec Pencil Energy Pvt. Lit., Attibele, Bengaluru. BB biochar from Indo-French centre, IISc while RHB was produced in the green house.

3.2 Studies on characterize biochar for physico-chemical properties.

To know the different properties of biochar materials used in this study such as, bulk density, particle density, porosity, water holding capacity, color, ash content, pH, EC, CEC, calcium carbonate equivalence (CCE) and total elemental composition were determined by adopting standard procedure. The procedures employed for analysis of these parameters are given in Table 1.

3.3 Studies on release of nutrients and silicon from biochar in acidic, neutral and alkaline soil

3.3.1 Incubation study

To know the dissolution and release of nutrients and silicon from biochar, an incubation study was conducted in three different soils (acidic, neutral and alkaline). Two hundred gram of different soils was filled in a separate plastic pot with graded level of

biochar and incubated at field capacity for 120 days. The experiment consisted of 13 treatments replicated thrice and was laid out in a completely randomized design. Moisture content was maintained at field capacity by weighing the pots periodically and weight loss due to evaporation was made by adding distilled water.

Destructive sampling of soil was done at 15, 30, 60, 90 and 120 days after incubation and samples were analyzed for pH, EC, primary nutrients (phosphorus and potash) exchangeable bases (calcium, magnesium and sodium) micronutrient cations (zinc, iron, manganese and copper) and plant available silicon by adopting standard procedures (Table 1). The treatment details of the experiment are given below.

3.3.1.1 Experimental details:

Type of soils	: Three
	<ul style="list-style-type: none">• Sakaleshpura (pH 5.45)• Kathalagere (pH 6.45)• Hiriyur (pH 9.15)
Design	: FCRD (Factorial Completely Randomized Design)
No. of treatments	: 13
No. of Replications	: 03
Biochar levels	: 04 (2, 4, 8, and 16 t ha ⁻¹)
Types of biochar	: Three
	<ul style="list-style-type: none">• Wood biochar (WB),• Bamboo biochar (BB),• Rice husk biochar (RHB)
Moisture level	: Field capacity (FC)

3.3.3 Treatment details

- T₁: Control (without biochar)
- T₂: WB @ 2 t ha⁻¹
- T₃: WB @ 4 t ha⁻¹
- T₄: WB @ 8 t ha⁻¹
- T₅: WB @ 16 t ha⁻¹
- T₆: BB @ 2 t ha⁻¹
- T₇: BB @ 4 t ha⁻¹
- T₈: BB @ 8 t ha⁻¹
- T₉: BB @ 16 t ha⁻¹

- T₁₀: RHB @ 2 t ha⁻¹
 T₁₁: RHB @ 4 t ha⁻¹
 T₁₂: RHB @ 8 t ha⁻¹
 T₁₃: RHB @ 16 t ha⁻¹

3.4 Studies on different sources and levels of biochar application on growth and yield of aerobic rice

A pot experiment was conducted to know the effect of different sources and levels biochar on growth and yield of aerobic rice. Study was conducted by taking 5 kg of soil from Sakaleshpura (acidic), Kathalagere (neutral) and Hiriyur (alkaline) location and filled in plastic pots. Along with graded level of biochar, calculated amount of basal dose of fertilizer was applied. Nitrogen was applied in three splits *viz.*, 50, 25 and 25 per cent at basal, 30 DAS and 60 DAS, respectively.

Three seeds of Anagha variety of rice were directly sown into pots and thinned to one seedling after 10 days. Moisture content was maintained at field capacity to assure aerobic method of rice cultivation.

Biometric observations such as plant height, number of tillers per plant and SPAD reading were recorded at 30, 45, 60, and 90 DAS. At the time of harvest plant height, number of panicles per plant, panicle length, grain and straw yield were recorded. The plant samples were collected at harvest and analysed for nutrients and silicon by adopting standard procedures (Table 1).

3.4.1 Experiment details:

Types of Soils	: Three
	<ul style="list-style-type: none"> • Sakaleshpura (pH 5.45) • Kathalagere (pH 6.45), • Hiriyur (pH 9.15)
Design	: FCRD (Factorial Completely Randomized Design)
No. of treatments	: 13
Biochar levels	: 04 (2, 4, 8, and 16 t ha ⁻¹)
Moisture levels	: Field capacity (FC)
No. of Replications	: 03
Types of biochar	: Three
	<ul style="list-style-type: none"> • Wood biochar (WB) • Bamboo biochar (BB) • Rice husk biochar (RHB)

Table 1: Methods of soil, biochar and plant analysis

Sl. No.	Parameter	Procedure	Method & Reference
1	Particle size analysis	Soil was predigested with H ₂ O ₂ , dispersed with sodium hexa metaphosphate, sand with decantation procedure, silt and clay in the suspension was measured after pipetting with Robinson pipette.	International pipette method, Jackson (1973)
2	B.D, P.D, MWHC and Porosity	BD, PD, MWHC and Porosity of test samples were measured by following Keen's cup method.	Keen rackzowski method, Baruah and Barthakur (1997)
3	Field capacity	Field capacity was measured by using Pressure plate apparatus.	Page <i>et al.</i> (1982)
4	Colour	Munsell color chart	Jackson (1973)
5	Cation exchange capacity	a) For soil with pH less than 7, sample was leached with 1N (pH 7) ammonium acetate followed by washing with alcohol to remove free ammonium and again leaching with 1 N KCl. Ammonium in the leachate was determined by distillation method. b) For soils with pH more than 7, sample was leached with 1N sodium acetate followed by washing with alcohol and again leached with 10 % KCl and Na in the leachate was estimated using flame photometry.	Distillation method Page <i>et al.</i> (1982)
6	Calcium carbonate equivalent	A known weight of sample was heated with 0.5 M HCl and then filtered. The filtrate was then titrated against standard NaOH using phenolphthalein indicator.	AOAC method (1984)
7	Soil reaction	pH was measured using pH meter in soil water suspension of 1:2.5.	Potentiometry, Jackson (1973)
8	Electrical conductivity	Electrical conductivity was measured using conductivity bridge	Conductometry Jackson (1973)

Sl. No.	Parameter	Procedure	Method & Reference
9	Organic carbon	Soil was digested with $K_2Cr_2O_7$ and Conc. H_2SO_4 , the unutilized $K_2Cr_2O_7$ was back titrated against ferrous ammonium sulphate using diphenyl amine indicator.	Wet oxidation, Walkley and Black (1934)
10	Available nitrogen	Soil was oxidized and distilled with alkaline potassium permanganate. The liberated ammonia was trapped in boric acid containing mixed indicator and then against standard acid.	Subbaiah and Asija (1949)
11	Available phosphorus	Acid to neutral soil was extracted with Brays - I and alkaline soil by Olsen's extraction estimated by heteropoly - molybdenum blue method	Brays and Krutz (1945) and Watanabe and Olsen (1965)
12	Available potassium	Soil was extracted with 1 N (pH 7) ammonium acetate and estimated using flame photometer.	Flame photometry, Jackson (1973)
13	Available Calcium and Magnesium	Extraction of soil with 1 N (pH 7) ammonium acetate followed by complexometric titration for estimation.	Complexometric titration method, Baruah and Barthakur (1997)
14	DTPA extractable micronutrients	Soil was extracted with DTPA and micronutrients were quantified by using Atomic Absorption Spectrophotometer.	Lindsay and Norvell (1978)
15	Available Boron	Soil was extracted by hot water and estimated by colorimetric using Azomethane - H reagent method.	Gupta (1979)
16	Available silicon	Soil was extracted with 0.1M Calcium chloride, the Si in the extract was determined by using UV- visible spectrophotometer at 820nm.	Haysom and Chapman (1975)

Sl. No.	Parameter	Procedure	Method & Reference
17	Total plant nitrogen	<p>a) Biochar samples were combusted at about 950 °C in CHNS analyzer and total nitrogen was quantified using EDTA as standard.</p> <p>b) Plant samples were digested using H₂SO₄ + Selenium mixture followed by estimation in continues flow analyzer</p>	<p>a) Dry Combustion (CHNS, LECO)</p> <p>b) Krom (1980)</p>
18	Total plant phosphorus	Phosphorus in di acid digested plant sample was estimated by forming yellow colour phospho vanado molybdate complex using spectrophotometer at 430nm.	Yellow phosphovanado molybdate complex method, Baruah and Barthakur (1997)
19	Total plant potassium	Potassium in diacid digested plant sample was estimated with flame photometer	Flame photometry, Jackson (1973)
20	Total plant calcium and magnesium	Calcium and magnesium in diacid digested plant sample was estimated by complexometric titration method.	Complexometric titration method, Baruah and barthakur (1997)
21	Total plant sulphur	Sulphur in di acid digested sample was quantified by using BaCl ₂ to develop turbidity following estimation.	Piper, 1966
22	Total plant micronutrient cations	Micronutrient cations in di acid digested plant samples were determined by using Atomic Absorption Spectrophotometer using appropriate hallow cathode lamps	Lindsay and Norvell (1978)

3.4.2 Treatment details

- T₁: Control (RDF alone)
- T₂: RDF + WB @ 2 t ha⁻¹
- T₃: RDF + WB @ 4 t ha⁻¹
- T₄: RDF + WB @ 8 t ha⁻¹
- T₅: RDF + WB @ 16 t ha⁻¹
- T₆: RDF + BB @ 2 t ha⁻¹
- T₇: RDF + BB @ 4 t ha⁻¹
- T₈: RDF + BB @ 8 t ha⁻¹
- T₉: RDF + BB @ 16 t ha⁻¹
- T₁₀: RDF + RHB @ 2 t ha⁻¹
- T₁₁: RDF + RHB @ 4 t ha⁻¹
- T₁₂: RDF + RHB @ 8 t ha⁻¹
- T₁₃: RDF + RHB @ 16 t ha⁻¹

3.5 Analytical methods followed for soil and plant analysis

3.5.1 Analytical methods for soil

The analytical methods followed for soil are presented in Table 1.

3.5.1.1 Extraction of plant available silicon in soils by 0.01M CaCl₂ extractant

Two grams of soil with 20 ml of 0.01M CaCl₂ was taken in a 50 ml centrifuge tube. After continuous end to end shaking in a mechanical shaker for 16 hours, the solution was centrifuged at 3000 rpm for 3 minutes and then filtered.

3.5.1.2 Estimation of plant available silicon in soils

Silicon in the filtrate was determined by transferring 1 ml of filtrate into plastic centrifuge tube and then subsequently 2.5 ml of 0.5 M sulfuric acid and 2.5 ml of ammonium molybdate solution (pH 7) were added. After vortex stirring for 5 minutes, 1.25 ml of tartaric acid was added. After allowing for additional two minutes, 0.25 ml reducing agent (ANSA) was added. After 30 minutes following addition of the reducing agent, absorbance was measured at 820 nm using UV visible spectrophotometer (Shimadzu Pharma UV- 1700 UV visible spectrophotometer). Simultaneously Si standards (0, 0.5, 1, 2, 3, 4, 5 and 6 mg l⁻¹) prepared in the same matrix were also measured using UV visible spectrophotometer (Haysom and Chapman, 1975).

3.5.2 Analysis of plant samples

3.5.2.1 Plant sampling and its preparation

The collected plant samples of rice from the pot culture experiment were separated into straw and grain. Rice straw samples were initially washed with tap water followed by distilled water (twice) to remove any surface contaminants. The rice straw and grain samples were dried in the hot air oven at 72 °C for 48 hours. The dried straw samples were cut into small pieces and powdered in a ball mill. The dried grain samples were also powdered in a ball mill. The powdered samples are diacid digested and used for estimation of nutrients.

3.5.2.2 Determination of plant nutrients

The procedure followed for analysis of plant samples are presented in Table 1.

3.5.2.3 Determination of silicon in plant samples

Plant sample digestion

The powdered sample (0.1 g) was digested in a mixture of 7 ml of HNO₃ (70 %), 2 ml of H₂O₂ (30 %) and 1 ml of HF (40 %) using microwave digestion system (Milestone-start D) with following steps: 1000 watt for 17 minutes with a ramping rate of 7 °C m⁻¹ and 1000 watt for 10 minutes at 150 °C and venting for 10 minutes. The digested samples were diluted to 50 ml with 4 per cent boric acid (Ma *et al.*, 2002).

Estimation of silicon in plant samples

The Si concentration in the digested solution was determined as described below: 0.5 ml of digested aliquot was transferred to a plastic centrifuge tube, to this 3.75 ml of 0.2 N HCl, 0.5 ml of 10 % ammonium molybdate ((NH₄)₆Mo₇O₂) and 0.5 ml of 20 % tartaric acid and 0.5 ml of reducing agent (Amino naphtholsulphonic acid - ANSA) was added and the volume was made up to 12.5 ml with distilled water. After one hour, the absorbance was measured at 600 nm with a UV-visible spectrophotometer (Shimadzu Pharma UV- 1700 UV visible spectrophotometer) (Ma *et al.*, 2002). Similarly, standards (0, 0.2, 0.4, 0.8 and 1.2 ppm) were prepared by following the same procedure.

3.6 Statistical analysis

The data obtained from this study were subjected to statistical analysis as per the procedure given by Sundaraj *et al.* (1972).

Table 2: Physico-chemical properties of acidic, neutral and alkaline soils

Parameters		Acidic soil	Neutral soil	Alkaline soil
Location		Sakhleshpura	Khathalgere	Hiriyur
pH (1:2.5)		5.45	6.45	9.15
EC (dS m ⁻¹) (1:2.5)		0.172	1.58	0.530
Organic carbon (%)		0.75	0.88	0.32
CEC [cmol (p ⁺) kg ⁻¹]		10.8	12.4	51.08
Particle size distribution	Sand (%)	60.32	62.47	41.45
	Silt (%)	22.94	19.07	30.40
	Clay (%)	16.74	18.46	28.15
Textural class		Sandy clay loam	Sandy clay loam	Clay loam
Field capacity (%)		18.46	19.07	28.21
0.01M CaCl ₂ - Si (ppm)		56.13	104.10	38.81
Available N (kg ha ⁻¹)		200.74	671.00	313.6
Available P ₂ O ₅ (kg ha ⁻¹)		141.15	171.35	10.30
Available K ₂ O (kg ha ⁻¹)		405.08	380.58	408.12
Exch. Ca [cmol (p ⁺) kg ⁻¹]		6.40	8.20	29.50
Exch. Mg [cmol (p ⁺) kg ⁻¹]		3.90	3.80	13.50
Available sulphur (ppm)		12.07	51.67	10.56
DTPA extractable micronutrient cations (ppm)				
Fe		20.50	46.50	5.74
Mn		34.60	34.20	6.80
Zn		0.85	1.40	0.47
Cu		3.15	4.10	1.4

IV EXPERIMENTAL RESULTS

The present investigation entitled “**Characterization of biochar, nutrient release and its effect on growth and yield of aerobic rice**” was undertaken during 2014 at Bengaluru. In this investigation, incubation and pot culture experiment was conducted in greenhouse at Department of soil science and agricultural chemistry, UAS, GKVK, Bengaluru. The results of present study are presented in this chapter.

4.1 Characterization of biochar for physic-chemical properties

Three types of biochar *viz* wood biochar, bamboo biochar and rice husk biochar used in the present study were initially characterized for physical and chemical properties.

4.1.1 Characterization of biochar for physical properties

The physical properties such as bulk density, particle density, porosity, maximum water holding capacity, colour and ash content varied considerably depending upon feedstock used (Table 3). The WB, BB and RHB recorded a bulk density of 0.31, 0.61 and 0.53 g cm⁻³ respectively. Maximum water holding capacity was higher (213.31 %) in WB followed by RHB (131.41 %) and BB (93.71 %). The ash content of different biochars was in decreasing order of RHB (39.4 %) > WB (8.8 %) > BB (6.9 %). Colour of three different biochars samples recorded same value (5 YR 2/1).

4.1.2 Characterization of biochar for chemical properties

The pH values of biochar differed depending on feedstock and production temperature (Table 4). Biochar produced from wood (10.50) and bamboo (10.03) recorded higher pH value while biochar produced from rice husk recorded lower pH (7.39). Higher EC value of 4.99 dS m⁻¹ was observed in WB and lower EC values of 1.98 and 1.62 dS m⁻¹ were recorded in BB and RHB respectively. Cation exchange capacity of 26.25, 23.43 and 38.63 cmol (p⁺) kg⁻¹ were observed for WB, BB and RHB respectively. Calcium carbonate equivalent of 31.00, 27.50 and 30.5 per cent were recorded in the biochar produced from wood, bamboo and rice husk feedstock respectively.

4.1.3 Nutrient composition of biochar

Total elemental composition of different biochars produced from wood, bamboo and rice husk feedstock is presented in Table 5. Carbon content of 72.50, 75.50 and 39.33 per cent was observed for biochar produced from wood, bamboo and rice husk feedstock respectively. Of different elements, higher exchangeable bases (Ca, Mg, K and Na), Mn and Cu were recorded in wood biochar while higher P, Si, Zn and Fe were recorded in rice husk biochar.

Table 3: Physical properties of biochar produced from different feed stocks

Sl. No.	Biochar materials	BD (g cm ⁻³)	PD (g cm ⁻³)	Porosity (%)	MWHC (%)	Colour	Ash content (%)
1	Wood biochar	0.31	1.32	73.83	213.31	5 YR 2/1	8.8
2	Bamboo biochar	0.61	1.43	57.27	93.71	5 YR 2/1	6.9
3	Rice husk biochar	0.53	1.76	69.85	131.41	5 YR 2/1	39.4

Table 4: Chemical properties of biochar produced from different feed stocks

Sl. No.	Biochar materials	pH (1:5)	EC (1:5) (dS m ⁻¹)	CEC [cmol (p ⁺) kg ⁻¹]	CCE (%)
1	Wood biochar	10.50	4.99	26.25	31.00
2	Bamboo biochar	10.03	1.98	23.43	27.50
3	Rice husk biochar	7.39	1.62	38.63	30.50

Table 5: Total nutrient content of biochar produced from different feedstock

Sl. No.	Elements	Wood biochar	Bamboo biochar	Rice husk biochar
1	Carbon (%)	72.50	75.50	39.33
2	Nitrogen (%)	0.13	0.38	0.78
3	C:N ratio	557.69	198.68	50.42
4	Phosphorous	0.15	0.06	0.24
5	Potassium	1.47	0.86	0.96
6	Calcium	2.30	0.32	0.36
7	Magnesium	0.48	0.38	0.31
8	Sulphur	0.07	0.10	0.05
9	Sodium	0.10	0.03	0.05
10	Silicon	2.03	5.22	32.50
11	Zinc	23.90	58.60	63.00
12	Copper	36.60	32.70	31.00
13	Manganese	630.80	393.50	554.00
14	Iron	553.70	692.70	775.30
15	Boron	24.42	3.44	8.36

4.2 Dissolution and release of nutrients and silicon from biochar in acidic, neutral and alkaline soils

The results of incubation study conducted to know the releasing pattern of different nutrients and silicon from various biochars in three different soils are presented below.

4.2.1 Effect of different sources and levels of biochar application on pH in different soils

Effect of different sources and levels of biochar application on pH in acidic, neutral and alkaline soils are presented in Tables 6, 7 and 8 respectively.

In general a significant effect of source of biochar was seen at all intervals and in all studied soils. Application of WB recorded higher pH at all intervals and in all studied soils. Increase in pH was roughly proportional to application rate in both acidic and neutral soils while non significant effect of levels of application was observed in alkaline soil.

In acidic soil, the pH ranged from 5.56 to 5.24, 5.37 to 5.05 and 5.36 to 4.99 with the application of WB, BB and RHB respectively over a period of incubation (Table 6). Higher pH was observed at 30 DAI and there after a gradual decreasing trend was noticed with time of incubation. Application of WB @ 16 t ha⁻¹ recorded significantly higher pH at all intervals and ranged from 5.51 to 5.85 during 120 days of incubation.

Application of different types and levels of biochar showed a significant effect on soil pH at all intervals except at 15 and 60 DAI in neutral soil (Table 7). Higher pH was observed at 15 DAI and lowest at 30 DAI. Though pH of incubated soil decreased in all treatments when compared to its initial, significantly higher pH was observed with the application of biochar in comparison to control. Among the different treatment combinations, application of BB @ 4 t ha⁻¹ recorded higher pH (5.84) at 15 DAI and application of RHB @ 8 t ha⁻¹ recorded lower pH (5.14) at 30 DAI.

In case of alkaline soil, application of different sources of biochar recorded a significant effect on soil pH at all intervals except 60 and 120 DAI (Table 8). However, a non significant effect of levels of biochar application was observed at all intervals. In general, higher pH was recorded at 30 DAI and later there was a gradual decrease in pH throughout incubation period. Application of WB @ 16 t ha⁻¹ recorded higher pH (9.17 to 9.36) and application of RHB @ 16 t ha⁻¹ recorded lower pH (9.06 to 9.16) at all intervals of incubation.

4.2.2 Effect of different sources and levels of biochar application on EC (dS cm⁻¹) in different soils

The data on effect of different sources and levels of biochar application on EC of different soils are presented in Tables 6-8.

Table 6: Effect of different sources and levels of biochar application on soil pH and EC in acidic soil at different intervals

	pH					EC (dS m ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	5.44	5.56	5.42	5.31	5.24	0.172	0.194	0.171	0.208	0.237
BB	5.18	5.37	5.29	5.15	5.05	0.172	0.181	0.182	0.206	0.224
RHB	5.12	5.36	5.25	5.12	4.99	0.184	0.190	0.180	0.214	0.235
SEm±	0.01	0.03	0.02	0.01	0.01	0.003	0.003	0.002	0.001	0.006
CD at 0.05	0.03	0.08	0.07	0.04	0.03	0.008	0.008	0.007	0.004	NS
Levels of biochar										
2 t ha ⁻¹	5.13	5.32	5.22	5.09	5.00	0.179	0.183	0.172	0.207	0.242
4 t ha ⁻¹	5.18	5.40	5.24	5.15	5.06	0.175	0.186	0.188	0.219	0.237
8 t ha ⁻¹	5.27	5.42	5.35	5.19	5.10	0.172	0.195	0.172	0.211	0.220
16 t ha ⁻¹	5.39	5.58	5.47	5.34	5.22	0.179	0.190	0.178	0.199	0.227
SEm±	0.01	0.03	0.03	0.02	0.01	0.003	0.003	0.003	0.002	0.007
CD at 0.05	0.04	0.09	0.08	0.05	0.03	NS	NS	0.008	0.005	NS
Interaction										
Control	5.18	5.24	5.03	5.10	5.03	0.180	0.214	0.196	0.230	0.239
WB @ 2 t ha ⁻¹	5.23	5.34	5.13	5.11	5.07	0.175	0.201	0.163	0.214	0.239
WB @ 4 t ha ⁻¹	5.30	5.46	5.25	5.19	5.13	0.171	0.191	0.184	0.215	0.240
WB @ 8 t ha ⁻¹	5.49	5.59	5.49	5.31	5.24	0.165	0.195	0.156	0.204	0.218
WB @ 16 t ha ⁻¹	5.72	5.85	5.81	5.63	5.51	0.179	0.189	0.179	0.199	0.249
BB @ 2 t ha ⁻¹	5.13	5.27	5.30	5.07	4.96	0.174	0.187	0.194	0.205	0.242
BB @ 4 t ha ⁻¹	5.15	5.34	5.19	5.10	5.02	0.171	0.181	0.190	0.213	0.232
BB @ 8 t ha ⁻¹	5.18	5.38	5.32	5.13	5.09	0.169	0.188	0.182	0.217	0.209
BB @ 16 t ha ⁻¹	5.25	5.49	5.36	5.30	5.14	0.175	0.170	0.159	0.187	0.210
RHB @ 2 t ha ⁻¹	5.04	5.33	5.22	5.10	4.95	0.188	0.162	0.158	0.202	0.244
RHB @ 4 t ha ⁻¹	5.11	5.40	5.29	5.17	5.02	0.182	0.185	0.189	0.230	0.238
RHB @ 8 t ha ⁻¹	5.14	5.30	5.24	5.13	4.98	0.183	0.202	0.176	0.214	0.234
RHB @ 16 t ha ⁻¹	5.21	5.40	5.25	5.10	5.00	0.183	0.211	0.197	0.210	0.223
SEm±	0.02	0.05	0.05	0.03	0.02	0.005	0.005	0.005	0.003	0.012
CD at 0.05	0.07	0.15	0.13	0.08	0.06	NS	0.016	0.014	0.009	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 7: Effect of different sources and levels of biochar application on soil pH and EC in neutral soil at different intervals

Sources* of biochar	pH					EC (dS m ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	5.59	5.31	5.38	5.43	5.41	1.64	1.79	1.55	1.88	1.83
BB	5.59	5.24	5.33	5.35	5.35	1.64	1.75	1.69	1.84	1.89
RHB	5.37	5.21	5.31	5.31	5.34	1.69	1.75	1.58	1.87	1.88
SEm±	0.08	0.02	0.03	0.01	0.01	0.02	0.02	0.01	0.02	0.03
CD at 0.05	NS	0.06	NS	0.04	0.03	NS	NS	0.04	NS	NS
Levels of biochar										
2 t ha ⁻¹	5.52	5.28	5.33	5.34	5.34	1.62	1.77	1.70	1.92	1.91
4 t ha ⁻¹	5.52	5.21	5.32	5.38	5.33	1.66	1.71	1.40	1.87	1.86
8 t ha ⁻¹	5.45	5.21	5.32	5.33	5.37	1.73	1.77	1.57	1.86	1.83
16 t ha ⁻¹	5.58	5.30	5.38	5.42	5.42	1.62	1.80	1.76	1.80	1.86
SEm±	0.09	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.02	0.04
CD at 0.05	NS	0.07	NS	0.05	0.03	0.08	0.06	0.05	0.05	NS
Interaction										
Control	5.37	5.32	5.35	5.30	5.31	1.62	1.88	1.68	1.76	1.83
WB @ 2 t ha ⁻¹	5.55	5.29	5.31	5.36	5.35	1.65	1.79	1.68	1.94	1.84
WB @ 4 t ha ⁻¹	5.47	5.19	5.31	5.42	5.35	1.65	1.67	1.39	1.90	1.88
WB @ 8 t ha ⁻¹	5.55	5.30	5.40	5.41	5.40	1.70	1.84	1.44	1.90	1.82
WB @ 16 t ha ⁻¹	5.78	5.46	5.49	5.55	5.56	1.58	1.87	1.71	1.79	1.76
BB @ 2 t ha ⁻¹	5.58	5.28	5.33	5.35	5.35	1.57	1.79	1.71	1.94	2.01
BB @ 4 t ha ⁻¹	5.84	5.19	5.35	5.43	5.33	1.63	1.64	1.61	1.95	1.85
BB @ 8 t ha ⁻¹	5.43	5.19	5.30	5.27	5.34	1.70	1.68	1.66	1.73	1.81
BB @ 16 t ha ⁻¹	5.50	5.29	5.34	5.34	5.38	1.66	1.88	1.77	1.74	1.87
RHB @ 2 t ha ⁻¹	5.42	5.26	5.33	5.30	5.32	1.64	1.73	1.72	1.87	1.88
RHB @ 4 t ha ⁻¹	5.26	5.26	5.31	5.29	5.33	1.69	1.82	1.20	1.78	1.84
RHB @ 8 t ha ⁻¹	5.37	5.15	5.27	5.30	5.36	1.78	1.80	1.60	1.95	1.86
RHB @ 16 t ha ⁻¹	5.45	5.16	5.31	5.36	5.33	1.64	1.66	1.81	1.88	1.95
SEm±	0.16	0.04	0.05	0.03	0.02	0.05	0.03	0.03	0.03	0.07
CD at 0.05	NS	0.12	NS	0.08	0.06	NS	0.10	0.08	0.09	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 8: Effect of different sources and levels of biochar application on pH and EC in alkaline soil at different intervals

	pH					EC (dS m ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	9.22	9.34	9.31	9.28	9.14	0.401	0.402	0.391	0.376	0.399
BB	9.20	9.31	9.17	9.26	9.18	0.367	0.410	0.371	0.337	0.371
RHB	9.15	9.23	9.17	9.17	9.16	0.349	0.401	0.367	0.337	0.352
SEm±	0.01	0.02	0.01	0.01	0.02	0.011	0.008	0.006	0.004	0.007
CD at 0.05	0.03	0.06	0.04	0.04	NS	0.031	NS	0.018	0.012	0.019
Levels of biochar										
2 t ha ⁻¹	9.20	9.30	9.21	9.23	9.14	0.377	0.391	0.387	0.348	0.372
4 t ha ⁻¹	9.19	9.30	9.24	9.23	9.15	0.398	0.414	0.379	0.352	0.373
8 t ha ⁻¹	9.18	9.29	9.20	9.25	9.19	0.352	0.407	0.361	0.350	0.379
16 t ha ⁻¹	9.18	9.28	9.22	9.24	9.16	0.361	0.406	0.378	0.350	0.372
SEm±	0.01	0.02	0.01	0.02	0.03	0.012	0.009	0.007	0.005	0.008
CD at 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction										
Control	9.16	9.26	9.30	9.26	8.91	0.424	0.390	0.411	0.358	0.422
WB @ 2 t ha ⁻¹	9.24	9.33	9.27	9.23	9.03	0.389	0.385	0.389	0.366	0.409
WB @ 4 t ha ⁻¹	9.21	9.35	9.29	9.26	9.17	0.411	0.408	0.401	0.382	0.394
WB @ 8 t ha ⁻¹	9.21	9.33	9.30	9.28	9.20	0.386	0.407	0.380	0.382	0.395
WB @ 16 t ha ⁻¹	9.23	9.35	9.36	9.36	9.17	0.417	0.408	0.393	0.373	0.399
BB @ 2 t ha ⁻¹	9.20	9.25	9.15	9.23	9.17	0.366	0.419	0.366	0.346	0.365
BB @ 4 t ha ⁻¹	9.22	9.30	9.16	9.27	9.08	0.383	0.421	0.372	0.319	0.378
BB @ 8 t ha ⁻¹	9.19	9.34	9.12	9.26	9.22	0.342	0.410	0.374	0.352	0.387
BB @ 16 t ha ⁻¹	9.21	9.34	9.26	9.29	9.25	0.376	0.392	0.371	0.332	0.354
RHB @ 2 t ha ⁻¹	9.18	9.31	9.21	9.22	9.23	0.376	0.370	0.405	0.330	0.341
RHB @ 4 t ha ⁻¹	9.15	9.25	9.26	9.17	9.20	0.400	0.413	0.364	0.356	0.349
RHB @ 8 t ha ⁻¹	9.15	9.19	9.17	9.21	9.15	0.329	0.403	0.331	0.316	0.355
RHB @ 16 t ha ⁻¹	9.11	9.16	9.06	9.08	9.06	0.289	0.416	0.369	0.345	0.364
SEm±	0.02	0.04	0.02	0.03	0.04	0.021	0.015	0.013	0.008	0.013
CD at 0.05	NS	NS	0.07	0.08	0.13	NS	NS	NS	0.024	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

EC values differed significantly in acidic soil with the application of different sources of biochar at all intervals except 120 DAI (Table 6). However, rates of application remained significant only at 60 and 90 DAI. Among the sources, application of RHB recorded higher EC values at all intervals. A gradual increase in EC was observed from 15 DAI to 120 DAI, except a slight decrease at 60 DAI. Among the different treatment combinations, application of WB @ 16 t ha⁻¹ recorded higher EC values (0.249 dS m⁻¹) at 120 DAI.

A significant effect of source of biochar on EC was observed in neutral soil only at 60 DAI (Table 7). Though the levels of application differed significantly at all intervals except 120 DAI no definite trend was observed. Among different treatment combinations, application of RHB @ 4 t ha⁻¹ recorded lowest EC values (1.20 dS m⁻¹) at 60 DAI and highest (2.01 dS m⁻¹) with BB @ 2 t ha⁻¹ at 120 DAI.

Application of WB recorded higher EC values in alkaline soil at all the intervals (Table 8). However, application at different rates recorded a non significant effect on EC at all intervals and interaction effect was found to be significant at 90 DAI only. Application of WB both @ 4 and 8 t ha⁻¹ recorded highest EC (0.382 dS m⁻¹) and lowest (0.316 dS m⁻¹) with application of RHB @ 8 t ha⁻¹ at 90 DAI.

4.2.3 Effect of different sources and levels of biochar application on available P₂O₅ (kg ha⁻¹) in different soils

The data on effect of different sources and levels of biochar application on available P₂O₅ content at different intervals in acidic, neutral and alkaline soils are presented in Tables 9, 10 and 11 respectively.

Addition of all sources of biochar and at all levels decreased the available P₂O₅ at 120 DAI when compared to 15 DAI in acidic soil (Table 9). Available P₂O₅ content of acidic soil as influenced by different sources of biochars was found to be significant at all intervals of incubation except at 30 and 90 DAI, while application levels was found to be significant at 15, 30 and 120 DAI. Although, there was a significant difference in the available P₂O₅ content with different sources and levels of biochar application when compared to control, the highest content (172.86 kg ha⁻¹) was recorded with the application of RHB @ 16 t ha⁻¹ and lowest (149.85 kg ha⁻¹) with BB @ 2 t ha⁻¹ at 120 DAI.

In case of neutral soil, application of all three sources of biochar was found to have significant influence on available P₂O₅ content at all intervals of incubation (Table 10). However, application of biochar at different levels was found to be non significant only at 30 DAI. In general, there was a significant increase in the available P₂O₅ content from 15 DAI to 120 DAI with all the sources and levels of biochar including control and ranged from 130.85 to 233.98 kg ha⁻¹. The highest available P₂O₅ content was recorded with the application of RHA @ 16 t ha⁻¹ at 60 DAI and the lowest with WB @ 2 t ha⁻¹ on 90 DAI.

Table 9: Effect of different sources and levels of biochar application on available P₂O₅ and exchangeable K in acidic soil at different intervals

Sources* of biochar	Available P ₂ O ₅ (kg ha ⁻¹)					Exchangeable K [cmol (p ⁺) kg ⁻¹]				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	168.18	158.21	167.04	157.95	155.39	0.492	0.417	0.475	0.441	0.476
BB	168.97	159.28	160.59	156.62	155.11	0.442	0.368	0.417	0.414	0.432
RHB	176.52	159.4	169.17	164.05	166.11	0.465	0.378	0.459	0.428	0.457
SEm±	1.87	1.08	1.54	2.21	1.18	0.002	0.003	0.004	0.002	0.002
CD at 0.05	5.43	NS	4.46	NS	3.42	0.006	0.010	0.011	0.006	0.005
Levels of biochar										
2 t ha ⁻¹	166.76	154.68	164.41	154.92	152.83	0.413	0.338	0.403	0.374	0.406
4 t ha ⁻¹	169.36	158.07	163.25	158.20	159.60	0.430	0.361	0.416	0.396	0.419
8 t ha ⁻¹	172.79	162.11	165.76	162.2	159.71	0.473	0.392	0.465	0.434	0.455
16 t ha ⁻¹	175.99	160.99	168.99	162.83	163.34	0.549	0.461	0.518	0.507	0.540
SEm±	2.16	1.25	1.78	2.56	1.36	0.002	0.004	0.004	0.002	0.002
CD at 0.05	6.27	3.62	NS	NS	3.95	0.007	0.011	0.013	0.007	0.005
Interaction										
Control	168.32	145.73	166.26	152.06	151.35	0.400	0.327	0.376	0.334	0.383
WB @ 2 t ha ⁻¹	171.16	151.47	172.99	154.60	151.33	0.426	0.355	0.405	0.368	0.404
WB @ 4 t ha ⁻¹	166.53	157.35	166.69	155.77	150.44	0.438	0.377	0.430	0.406	0.428
WB @ 8 t ha ⁻¹	166.79	159.78	166.26	160.51	158.03	0.511	0.455	0.492	0.444	0.484
WB @ 16 t ha ⁻¹	168.26	164.26	162.23	160.92	161.75	0.594	0.482	0.575	0.547	0.587
BB @ 2 t ha ⁻¹	165.33	154.84	159.65	155.09	149.85	0.393	0.335	0.389	0.370	0.397
BB @ 4 t ha ⁻¹	163.03	155.03	161.65	155.51	159.44	0.414	0.341	0.396	0.381	0.404
BB @ 8 t ha ⁻¹	174.7	161.37	158.87	156.25	155.74	0.459	0.361	0.437	0.424	0.420
BB @ 16 t ha ⁻¹	172.83	165.88	162.19	159.62	155.43	0.501	0.436	0.446	0.479	0.507
RHB @ 2 t ha ⁻¹	163.78	157.72	160.58	155.07	157.31	0.421	0.325	0.415	0.384	0.416
RHB @ 4 t ha ⁻¹	178.51	161.83	161.41	163.33	168.92	0.438	0.363	0.422	0.400	0.424
RHB @ 8 t ha ⁻¹	176.9	165.19	172.15	169.84	165.37	0.450	0.362	0.467	0.434	0.461
RHB @ 16 t ha ⁻¹	186.89	152.84	182.55	167.96	172.86	0.550	0.464	0.534	0.494	0.527
SEm±	3.74	2.16	3.08	4.43	2.36	0.004	0.007	0.008	0.004	0.003
CD at 0.05	10.86	6.28	8.92	NS	6.85	0.012	0.019	0.022	0.012	0.009

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 10: Effect of different sources and levels of biochar application on available P₂O₅ and exchangeable K in neutral soil at different intervals

Sources* of biochar	Available P ₂ O ₅ (kg ha ⁻¹)					Exchangeable K [cmol (p ⁺) kg ⁻¹]				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	153.77	199.02	205.94	146.27	178.37	0.328	0.336	0.405	0.360	0.402
BB	164.5	222.56	206.55	143.67	175.5	0.298	0.361	0.387	0.356	0.400
RHB	155.06	202.94	216.63	157.98	198.89	0.312	0.349	0.394	0.355	0.410
SEm±	1.02	2.13	2.02	1.05	1.9	0.003	0.005	0.003	0.002	0.002
CD at 0.05	2.96	6.17	5.86	3.04	5.49	0.008	0.015	0.009	NS	0.007
Levels of biochar										
2 t ha ⁻¹	151.22	206.51	202.85	141.15	177.14	0.288	0.333	0.377	0.339	0.386
4 t ha ⁻¹	163.53	210.13	200.52	148.55	183.02	0.307	0.339	0.385	0.349	0.397
8 t ha ⁻¹	160.17	208.7	213.91	153.47	190.2	0.314	0.354	0.402	0.363	0.406
16 t ha ⁻¹	156.19	207.35	221.54	154.05	186.67	0.341	0.369	0.417	0.376	0.426
SEm±	1.18	2.46	2.33	1.21	2.19	0.003	0.006	0.004	0.003	0.003
CD at 0.05	3.42	NS	6.77	3.5	6.34	0.009	0.017	0.011	0.008	0.008
Interaction										
Control	146.74	180.9	181.57	138.98	170.13	0.279	0.331	0.367	0.320	0.363
WB @ 2 t ha ⁻¹	136.8	188.6	192.2	130.85	180.87	0.286	0.306	0.388	0.330	0.375
WB @ 4 t ha ⁻¹	154.91	191.83	202.32	139.47	178.73	0.312	0.319	0.397	0.345	0.397
WB @ 8 t ha ⁻¹	155.3	205.28	216.16	155.02	178.37	0.328	0.344	0.413	0.369	0.403
WB @ 16 t ha ⁻¹	168.07	210.39	213.08	159.74	175.52	0.387	0.374	0.422	0.395	0.431
BB @ 2 t ha ⁻¹	170.26	227.14	214.14	135.74	171.39	0.288	0.366	0.360	0.346	0.396
BB @ 4 t ha ⁻¹	167.06	224.85	187.73	143.41	167.35	0.298	0.351	0.387	0.351	0.393
BB @ 8 t ha ⁻¹	168.92	222.05	206.77	145	180.25	0.296	0.359	0.397	0.362	0.395
BB @ 16 t ha ⁻¹	151.74	216.2	217.57	150.54	183.03	0.309	0.369	0.405	0.365	0.416
RHB @ 2 t ha ⁻¹	146.59	203.8	202.22	156.85	179.17	0.290	0.327	0.382	0.341	0.388
RHB @ 4 t ha ⁻¹	168.61	213.7	211.51	162.76	202.97	0.312	0.347	0.373	0.352	0.400
RHB @ 8 t ha ⁻¹	156.28	198.78	218.8	160.41	211.99	0.318	0.359	0.396	0.359	0.421
RHB @ 16 t ha ⁻¹	148.75	195.47	233.98	151.87	201.45	0.327	0.365	0.425	0.368	0.432
SEm±	2.04	4.25	4.04	2.09	3.79	0.006	0.010	0.006	0.005	0.005
CD at 0.05	5.92	12.33	11.72	6.07	10.99	0.016	NS	NS	0.014	0.014

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 11: Effect of different sources and levels of biochar application on available P₂O₅ and exchangeable K in alkaline soil at different intervals

	Available P ₂ O ₅ (kg ha ⁻¹)					Exchangeable K [cmol (p ⁺) kg ⁻¹]				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	18.81	21.56	14.72	15.14	13.33	0.492	0.414	0.455	0.445	0.499
BB	21.43	22.15	14.07	15.28	14.26	0.452	0.410	0.452	0.407	0.475
RHB	23.56	29.35	18.82	18.96	18.11	0.499	0.426	0.482	0.440	0.485
SEm±	0.39	0.23	0.22	0.37	0.33	0.004	0.005	0.004	0.003	0.005
CD at 0.05	1.14	0.67	0.63	1.08	0.97	0.012	NS	0.010	0.009	0.015
Levels of biochar										
2 t ha ⁻¹	19.96	17.68	11.68	15.56	14.15	0.416	0.359	0.402	0.383	0.449
4 t ha ⁻¹	20.6	24.31	14.48	15.74	14.44	0.447	0.393	0.433	0.413	0.464
8 t ha ⁻¹	21.95	26.75	17.17	16.52	15.72	0.487	0.438	0.486	0.437	0.489
16 t ha ⁻¹	22.55	28.67	20.14	18.01	16.63	0.575	0.477	0.532	0.491	0.543
SEm±	0.45	0.27	0.25	0.43	0.39	0.005	0.006	0.004	0.004	0.006
CD at 0.05	1.31	0.77	0.72	1.25	1.12	0.013	0.018	0.012	0.011	0.017
Interaction										
Control	16.89	9.95	11.87	15.24	11.84	0.397	0.348	0.384	0.372	0.399
WB @ 2 t ha ⁻¹	17.58	15.35	11.16	15.2	12.79	0.423	0.350	0.391	0.388	0.452
WB @ 4 t ha ⁻¹	18.5	23.79	14.97	15.53	13.18	0.454	0.391	0.426	0.427	0.478
WB @ 8 t ha ⁻¹	19.82	22.73	17.08	15.06	13.9	0.475	0.444	0.482	0.454	0.502
WB @ 16 t ha ⁻¹	19.36	24.36	15.66	14.77	13.47	0.617	0.473	0.522	0.512	0.563
BB @ 2 t ha ⁻¹	22.19	16.09	11.46	15.24	13.66	0.374	0.354	0.412	0.378	0.437
BB @ 4 t ha ⁻¹	21.54	20.99	13.43	14.92	13.66	0.426	0.397	0.444	0.392	0.450
BB @ 8 t ha ⁻¹	21.23	25.2	14.98	15.62	15.12	0.491	0.423	0.442	0.405	0.471
BB @ 16 t ha ⁻¹	20.74	26.32	16.41	15.35	14.62	0.519	0.468	0.511	0.453	0.544
RHB @ 2 t ha ⁻¹	20.11	21.59	12.42	16.25	15.99	0.450	0.374	0.403	0.381	0.459
RHB @ 4 t ha ⁻¹	21.75	28.15	15.04	16.78	16.48	0.462	0.390	0.428	0.419	0.465
RHB @ 8 t ha ⁻¹	24.82	32.3	19.46	18.89	18.16	0.496	0.447	0.534	0.452	0.495
RHB @ 16 t ha ⁻¹	27.56	35.34	28.35	23.91	21.8	0.589	0.491	0.564	0.507	0.522
SEm±	0.78	0.46	0.43	0.75	0.67	0.008	0.011	0.007	0.006	0.010
CD at 0.05	2.27	1.33	1.25	2.17	1.94	0.023	NS	0.020	0.019	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Application of different sources and levels of biochar on available P_2O_5 content was found to be significant at all intervals of incubation in alkaline soil (Table 11). Application of biochar of different types and levels significantly increased the available P_2O_5 content recording highest (35.34 kg ha^{-1}) with RHB @ 16 t ha^{-1} and lowest (9.95 kg ha^{-1}) with control at 30 DAI during study period.

4.2.4 Effect of different sources and levels of biochar application on exchangeable K [$\text{cmol (p}^+) \text{ kg}^{-1}$] in different soils

A significant increase in exchangeable K content was observed with application of different sources and levels of biochar at all intervals and in all studied soils (Table 9 - 11).

In acidic soil Exchangeable K content of 0.417 to 0.492, 0.368 to 0.442 and 0.378 to 0.465 $\text{cmol (P}^+) \text{ kg}^{-1}$ was observed with application of WB, BB and RHB respectively, over a period of incubation (Table 9). The higher exchangeable K content was noticed at 15 DAI [0.393 to $0.594 \text{ cmol (p}^+) \text{ kg}^{-1}$] and lower at 30 DAI [0.327 to $0.482 \text{ cmol (p}^+) \text{ kg}^{-1}$]. Among the different treatments, application of WB @ 16 t ha^{-1} recorded highest exchangeable K content and ranged from 0.482 to $0.594 \text{ cmol (p}^+) \text{ kg}^{-1}$ and lowest content in control which ranged from 0.327 to $0.400 \text{ cmol (p}^+) \text{ kg}^{-1}$ at different intervals.

Exchangeable K content significantly differed with application of different sources of biochar at all intervals except 90 DAI in neutral soil (Table 10). However, a significant effect of levels of biochar application was observed at all intervals. Increase in exchangeable K content was observed with incubation time recording higher at 120 DAI. Of all the treatment combination, RHB @ 16 t ha^{-1} recorded higher exchangeable K content of $0.432 \text{ cmol (p}^+) \text{ kg}^{-1}$ at 120 DAI and lower [$0.279 \text{ cmol (p}^+) \text{ kg}^{-1}$] with WB @ 2 t ha^{-1} at 15 DAI.

Application of different sources of biochar recorded a significant effect on exchangeable K content at all intervals except 30 DAI in alkaline soil (Table 11). Increased rate of application significantly increased exchangeable K content at all intervals. Among the different treatment combination, application of WB @ 16 t ha^{-1} recorded highest available K_2O [$0.671 \text{ cmol (p}^+) \text{ kg}^{-1}$] content and lowest in control [$0.348 \text{ cmol (p}^+) \text{ kg}^{-1}$] over period of incubation.

4.2.5 Effect of different sources and levels of biochar application on exchangeable Ca [$\text{cmol (p}^+) \text{ kg}^{-1}$] in different soils

The data on effect of different sources and levels of biochar application on soil exchangeable Ca content in acidic, neutral and alkaline soils are presented in Table 12, 13 and 14 respectively.

In acidic soil, a significant effect of sources of biochar on exchangeable Ca content was observed at 15 DAI only (Table 12). However, the levels of application recorded a significant effect at all intervals except 15 DAI. Among different sources and levels, application of WB and application rate of 16 t ha^{-1} recorded higher exchangeable Ca at all intervals. Although, there was significant differences in exchangeable Ca

Table 12: Effect of different sources and levels of biochar application on exchangeable Ca and Mg in acidic soil at different intervals

	Exchangeable Ca [cmol (p ⁺) kg ⁻¹]					Exchangeable Mg [cmol (p ⁺) kg ⁻¹]				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	7.24	6.24	7.32	6.44	6.75	2.79	3.68	3.42	2.83	3.19
BB	6.89	6.35	7.08	6.44	6.82	2.83	3.16	3.03	2.94	2.99
RHB	6.96	6.43	7.24	6.41	6.69	2.71	3.30	3.13	3.19	3.15
SEm±	0.06	0.06	0.07	0.07	0.04	0.07	0.05	0.05	0.04	0.04
CD at 0.05	0.17	NS	NS	NS	NS	NS	0.14	0.14	0.11	0.10
Levels of biochar										
2 t ha ⁻¹	6.89	6.12	7.04	6.28	6.57	2.82	3.42	3.08	2.85	3.11
4 t ha ⁻¹	7.08	6.15	7.29	6.25	6.71	2.80	3.41	3.01	3.03	3.00
8 t ha ⁻¹	7.07	6.32	7.16	6.60	6.74	2.76	3.37	3.30	3.01	3.22
16 t ha ⁻¹	7.08	6.77	7.38	6.59	7.00	2.74	3.33	3.39	3.07	3.11
SEm±	0.07	0.07	0.08	0.08	0.05	0.08	0.05	0.05	0.04	0.04
CD at 0.05	NS	0.19	0.25	0.22	0.13	NS	NS	0.16	0.13	0.12
Interaction										
Control	6.98	5.88	6.61	6.46	6.81	3.03	3.48	3.38	2.37	2.75
WB @ 2 t ha ⁻¹	7.11	5.81	7.01	6.11	6.39	2.75	3.56	3.33	2.80	3.09
WB @ 4 t ha ⁻¹	7.24	5.86	7.55	6.21	6.53	2.94	3.60	2.83	3.04	3.15
WB @ 8 t ha ⁻¹	7.35	6.11	7.27	6.47	6.64	2.67	3.71	3.42	2.80	3.54
WB @ 16 t ha ⁻¹	7.25	7.17	7.45	6.97	7.45	2.81	3.87	4.11	2.68	2.97
BB @ 2 t ha ⁻¹	6.79	6.26	6.93	6.57	6.63	2.95	3.28	3.08	2.79	3.22
BB @ 4 t ha ⁻¹	6.97	6.16	6.97	6.35	6.92	2.92	3.23	2.93	2.97	3.00
BB @ 8 t ha ⁻¹	7.02	6.46	7.05	6.68	6.87	2.78	3.21	3.14	2.78	2.95
BB @ 16 t ha ⁻¹	6.78	6.52	7.39	6.17	6.88	2.69	2.95	2.95	3.24	2.80
RHB @ 2 t ha ⁻¹	6.78	6.28	7.18	6.16	6.70	2.77	3.43	2.84	2.95	3.02
RHB @ 4 t ha ⁻¹	7.02	6.42	7.35	6.18	6.67	2.54	3.39	3.27	3.07	2.84
RHB @ 8 t ha ⁻¹	6.85	6.40	7.15	6.66	6.73	2.84	3.19	3.33	3.44	3.17
RHB @ 16 t ha ⁻¹	7.20	6.63	7.29	6.62	6.68	2.71	3.17	3.10	3.31	3.57
SEm±	0.12	0.11	0.15	0.13	0.08	0.14	0.09	0.10	0.08	0.07
CD at 0.05	NS	0.33	NS	0.38	0.23	NS	0.27	0.28	0.22	0.21

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 13: Effect of different sources and levels of biochar application on exchangeable Ca and Mg in neutral soil at different intervals

Sources* of biochar	Exchangeable Ca [cmol (p ⁺) kg ⁻¹]					Exchangeable Mg [cmol (p ⁺) kg ⁻¹]				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	9.47	8.54	8.28	9.11	9.25	6.91	5.96	5.58	6.19	6.61
BB	9.08	8.11	7.98	9.14	8.97	7.36	5.03	4.20	6.67	8.32
RHB	9.10	7.63	8.13	9.24	9.32	7.66	4.54	4.92	5.42	7.02
SEm±	0.11	0.11	0.08	0.06	0.07	0.03	0.06	0.10	0.05	0.06
CD at 0.05	0.32	0.32	0.22	NS	0.22	0.09	0.17	0.30	0.15	0.18
Levels of biochar										
2 t ha ⁻¹	9.29	8.25	8.13	8.78	8.60	7.23	5.10	4.94	6.39	7.48
4 t ha ⁻¹	9.29	7.93	7.96	9.32	9.14	7.22	5.28	4.73	6.14	7.13
8 t ha ⁻¹	9.34	8.24	8.27	9.35	9.43	7.59	5.32	4.73	6.17	7.45
16 t ha ⁻¹	8.96	7.96	8.15	9.19	9.55	7.20	5.01	5.20	5.67	7.20
SEm±	0.13	0.13	0.09	0.07	0.09	0.04	0.07	0.12	0.06	0.07
CD at 0.05	NS	NS	NS	0.19	0.25	0.11	0.20	0.35	0.18	0.20
Interaction										
Control	9.18	8.63	8.43	8.43	7.89	6.77	7.39	5.00	6.81	7.59
WB @ 2 t ha ⁻¹	9.07	7.65	8.12	8.80	8.75	7.04	6.12	5.93	5.75	6.08
WB @ 4 t ha ⁻¹	9.21	8.25	7.96	9.05	9.42	6.97	6.48	6.55	7.08	6.47
WB @ 8 t ha ⁻¹	9.89	8.97	9.06	9.50	9.44	7.03	6.01	4.37	6.62	7.31
WB @ 16 t ha ⁻¹	9.72	9.27	7.97	9.07	9.38	6.61	5.25	5.48	5.29	6.58
BB @ 2 t ha ⁻¹	9.36	8.82	7.48	8.63	8.45	7.58	4.95	3.66	7.06	8.33
BB @ 4 t ha ⁻¹	9.55	8.12	8.03	9.41	8.88	7.46	4.78	3.61	7.02	8.25
BB @ 8 t ha ⁻¹	9.19	7.89	7.93	9.38	9.04	7.55	5.18	5.06	6.49	8.16
BB @ 16 t ha ⁻¹	8.23	7.62	8.47	9.13	9.52	6.87	5.20	4.49	6.12	8.54
RHB @ 2 t ha ⁻¹	9.43	8.26	8.80	8.91	8.61	7.08	4.24	5.21	6.36	8.04
RHB @ 4 t ha ⁻¹	9.11	7.42	7.87	9.51	9.12	7.23	4.57	4.04	4.32	6.68
RHB @ 8 t ha ⁻¹	8.95	7.86	7.83	9.17	9.82	8.19	4.77	4.78	5.39	6.89
RHB @ 16 t ha ⁻¹	8.92	6.98	8.02	9.36	9.74	8.13	4.58	5.64	5.60	6.49
SEm±	0.22	0.22	0.15	0.11	0.15	0.06	0.12	0.21	0.10	0.12
CD at 0.05	0.65	0.64	0.44	0.33	NS	0.19	0.34	0.60	0.30	0.35

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 14: Effect of different sources and levels of biochar application on exchangeable Ca and Mg in alkaline at different intervals

	Exchangeable Ca [cmol (p ⁺) kg ⁻¹]					Exchangeable Mg [cmol (p ⁺) kg ⁻¹]				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	29.33	27.46	30.34	26.50	30.27	14.36	13.48	14.37	12.05	12.37
BB	27.87	26.76	29.87	25.22	28.55	13.68	12.56	15.51	12.12	12.87
RHB	29.08	27.69	30.75	27.99	27.43	13.44	14.09	15.34	11.06	14.06
SEm±	0.64	0.41	0.34	0.30	0.28	0.40	0.21	0.19	0.34	0.49
CD at 0.05	NS	NS	NS	0.87	0.82	NS	0.60	0.55	NS	NS
Levels of biochar										
2 t ha ⁻¹	28.83	26.84	29.79	25.83	28.69	14.01	12.59	16.08	11.97	13.05
4 t ha ⁻¹	28.52	24.97	30.48	26.85	29.61	14.20	14.90	14.54	11.73	12.95
8 t ha ⁻¹	28.99	29.30	30.41	27.25	28.79	13.78	12.71	14.35	11.84	13.65
16 t ha ⁻¹	28.70	28.10	30.59	26.34	27.92	13.32	13.32	15.33	11.43	12.75
SEm±	0.74	0.48	0.39	0.35	0.33	0.46	0.24	0.22	0.39	0.56
CD at 0.05	NS	1.38	NS	1.01	0.95	NS	0.69	0.63	NS	NS
Interaction										
Control	29.98	30.40	30.42	25.24	29.79	14.88	14.67	14.88	11.64	10.38
WB @ 2 t ha ⁻¹	30.12	28.20	29.49	25.94	31.22	14.77	13.00	15.94	12.08	12.10
WB @ 4 t ha ⁻¹	28.36	24.29	31.12	26.90	30.66	14.22	14.39	12.81	11.76	12.95
WB @ 8 t ha ⁻¹	29.23	29.77	30.14	27.25	30.25	14.22	14.03	13.66	11.84	12.69
WB @ 16 t ha ⁻¹	29.62	27.56	30.62	25.91	28.97	14.22	12.49	15.07	12.51	11.73
BB @ 2 t ha ⁻¹	28.28	25.80	31.04	25.81	28.77	13.79	11.71	15.45	12.11	12.78
BB @ 4 t ha ⁻¹	27.96	24.90	29.75	25.69	28.57	14.46	13.08	15.90	11.58	13.11
BB @ 8 t ha ⁻¹	27.83	28.45	29.66	25.09	28.93	13.47	11.76	14.15	13.76	13.06
BB @ 16 t ha ⁻¹	27.42	27.89	29.01	24.28	27.94	13.02	13.70	16.55	11.01	12.54
RHB @ 2 t ha ⁻¹	28.09	26.51	28.85	25.73	26.07	13.46	13.06	16.85	11.71	14.27
RHB @ 4 t ha ⁻¹	29.24	25.71	30.57	27.97	29.60	13.94	17.22	14.93	11.86	12.80
RHB @ 8 t ha ⁻¹	29.92	29.70	31.44	29.41	27.21	13.65	12.34	15.23	9.91	15.20
RHB @ 16 t ha ⁻¹	29.08	28.86	32.14	28.83	26.86	12.72	13.76	14.35	10.77	13.97
SEm±	1.29	0.82	0.68	0.60	0.57	0.80	0.41	0.38	0.68	0.98
CD at 0.05	NS	NS	1.96	1.74	1.64	NS	1.19	1.10	NS	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

content with different sources and levels of biochar application, the highest content [7.55 cmol (p⁺) kg⁻¹] was recorded with application of WB @ 4 t ha⁻¹ at 60 DAI and lowest [5.81 cmol (p⁺) kg⁻¹] with WB @ 2 t ha⁻¹ at 30 DAI during study period.

The exchangeable Ca content in neutral soil differed significantly with the application of various types of biochar at all intervals except 90 DAI (Table 13). Application of graded levels of biochar showed a significant effect on exchangeable Ca at 90 and 120 DAI only. A continuous decreasing trend of exchangeable Ca content was observed from 15 DAI to 60 DAI and then increasing trend was observed till 120 DAI, with a maximum at 15 DAI [8.23 to 9.89 cmol (p⁺) kg⁻¹]. The exchangeable Ca content varied with the application of different sources and levels of biochar over a incubation time recording lowest [7.48 cmol (p⁺) kg⁻¹] with BB @ 2 t ha⁻¹ at 60 DAI and highest [9.89 cmol (p⁺) kg⁻¹] with WB @ 8 t ha⁻¹ at 15 DAI.

In alkaline soil, application of different sources of biochar recorded a significant effect on exchangeable Ca at 90 and 120 DAI while, application levels recorded significant effect at 30, 90 and 120 DAI (Table 14). Higher exchangeable Ca content was observed at 60 DAI and ranged from 28.85 to 32.14 cmol (p⁺) kg⁻¹ in different treatments and was lowest at 90 DAI and ranged from 24.28 to 29.41 cmol (p⁺) kg⁻¹ in different treatments. Application of different sources and levels of biochar varied exchangeable Ca content over a incubation period recording highest [32.14 cmol (p⁺) kg⁻¹] with the application of RHB @ 16 t ha⁻¹ at 60 DAI and lowest with BB @ 16 t ha⁻¹ [(24.28 cmol (p⁺) kg⁻¹).

4.2.6 Effect of different sources and levels of biochar application on exchangeable Mg [cmol (p⁺) kg⁻¹] in different soils

The data on influence of different sources and levels of biochar application on soil exchangeable Mg content in acidic, neutral and alkaline soils are presented in Table 12, 13 and 14 respectively.

In acidic soil, addition of all sources and levels of biochar showed a significant effect on exchangeable Mg at all intervals except 15 DAI; In addition levels of application remained non significant at 30 DAI (Table 12). Exchangeable Mg content increased from 15 DAI to 30 DAI and there after a decreasing trend was observed till 90 DAI. Higher exchangeable Mg content was observed at 30 DAI and values ranged from 2.95 to 3.87 cmol (p⁺) kg⁻¹. Over a period of incubation, application of WB @ 16 t ha⁻¹ recorded highest [4.11 cmol (p⁺) kg⁻¹] exchangeable Mg content at 60 DAI and lowest with control [2.37 cmol (p⁺) kg⁻¹] at 90 DAI.

Exchangeable Mg content in neutral soil differed significantly as a result of application of various types and levels of biochar at all intervals (Table 13). In general, exchangeable Mg content showed a decreasing trend from 15 DAI to 60 DAI and there after an increasing trend was observed till 120 DAI. Changes in exchangeable Mg content as a result of application of different sources and levels of biochar over period of incubation ranged from 4.04 to 8.19 cmol (p⁺) kg⁻¹ recording lowest with application of RHB @ 4 t ha⁻¹ at 60 DAI and highest with RHB @ 8 t ha⁻¹ at 15 DAI.

Application of different sources and levels of biochar was found to be significant at 30 and 60 DAI in alkaline soil (Table 14). Higher exchangeable Mg content was recorded at 60 DAI and lower at 90 DAI. Of all the treatment combination application of RHB @ 2 t ha⁻¹ recorded highest [16.85 cmol (p⁺) kg⁻¹] exchangeable Mg content at 60 DAI and lower with RHB @ 8 t ha⁻¹ [9.91 cmol (p⁺) kg⁻¹] at 90 DAI.

In general, though a significant difference in exchangeable Mg content was noticed with application of different sources and levels of biochar application, no definite trend was observed during study period in all soils.

4.2.7 Effect of different sources and levels of biochar application on exchangeable sodium [cmol (p⁺) kg⁻¹] in different soils

Data pertaining to the effect of different sources and levels of biochar application on exchangeable Na content in acidic, neutral and alkaline soils are presented in Tables 21, 22 and 23 respectively.

Significant influence of sources of biochar on exchangeable Na was observed in acidic soil at all intervals (Table 21). Application of WB recorded higher exchangeable Na content at 15, 30 and 60 DAI. However, at 90 and 120 DAI RHB recorded significantly higher exchangeable Na content. Application at different rates recorded significant effect at 90 and 120 DAI only. Exchangeable Na was found to decrease from 15 DAI to 60 DAI and then an increasing trend was observed till 120 DAI. Of all the treatments, application of WB @ 8 t ha⁻¹ recorded highest exchangeable Na content [0.32 cmol (p⁺) kg⁻¹] at 30 DAI and lowest [0.15 cmol (p⁺) kg⁻¹] with control at 60 DAI over a period of incubation.

In neutral soil, exchangeable Na content as influenced by application of different sources and levels of biochar recorded a significant effect at all intervals (Table 22). However, application rates remained non significant at 90 DAI. Exchangeable Na content of 1.32 to 1.75, 1.39 to 1.73 and 1.40 to 1.78 cmol (p⁺) kg⁻¹ were recorded with application of WB, BB and RHB, respectively over a period of incubation. Although, exchangeable Na content was increased significantly with application of all types and levels of biochar, highest exchangeable Na content were observed with application of RHB @ 2 t ha⁻¹ [2.00 cmol (p⁺) kg⁻¹] at 15 DAI and lower with control [1.16 cmol (p⁺) kg⁻¹] at 90 DAI.

A significant effect of sources and levels of biochar application on exchangeable Na was noticed in alkaline soil at all intervals except 120 DAI (Table 23). Exchangeable Na content of 5.16 to 6.10, 5.14 to 6.13 and 5.29 to 6.41 cmol (p⁺) kg⁻¹ were recorded with application of WB, BB and RHB respectively, at different intervals of incubation. Of different application rates, application at 8 t ha⁻¹ recorded higher exchangeable Na content [5.36 to 6.21 cmol (p⁺) kg⁻¹] at all intervals. Changes in exchangeable Na content as influenced by different sources and levels of biochar ranged from 4.80 to 6.73 cmol (p⁺) kg⁻¹. Higher exchangeable Na content were noticed with application of RHB @ 8 t ha⁻¹ at 30 DAI and lower with WB @ 2 t ha⁻¹ at 90 DAI.

4.2.8 Effect of different sources and levels of biochar application on DTPA extractable Zn content (mg kg^{-1}) in different soils

The DTPA extractable Zn content in acidic, neutral and alkaline soils as influenced by different types and levels of biochar application at different intervals are presented in Tables 15, 16, and 17 respectively.

In acidic soil, with the application of various types and levels of biochar a significant effect was noticed on DTPA extractable Zn content in at all intervals except 30 DAI (Table 15). However, application at different rates recorded significant effect only at 30 and 60 DAI. Independent of biochar application, decrease in Zn content was observed with incubation time and lower Zn content were observed at 60 DAI and higher at 15 DAI. The Zn content in different treatments ranged from 0.72 to 0.93 mg kg^{-1} at 60 DAI and 1.12 to 1.36 mg kg^{-1} at 15 DAI.

The DTPA extractable Zn content in neutral soil differed significantly with the application of various types of biochar at 90 and 120 DAI (Table 16). Though application at different rates differed Zn content significantly at all intervals except 30 DAI, no definite trend was observed. Higher Zn content of soil was observed at 15 DAI (0.84 to 0.95 mg kg^{-1}) and lower at 90 DAI (0.35 to 0.71 mg kg^{-1}) over a period of incubation. The Zn content as influenced by different sources and levels of biochar addition recorded either significantly lower or on par with control at all intervals except 120 DAI. Among different treatment combinations, highest Zn content (0.80 mg kg^{-1}) was noticed with application of BB @ 8 t ha^{-1} and lowest (0.65 mg kg^{-1}) with WB @ 8 t ha^{-1} at 120 DAI.

In case of alkaline soil, significant differences were noticed with application of different sources and levels of biochar application at different intervals. Among the levels, application level of 8 t ha^{-1} recorded lower DTPA extractable Zn content (0.15 to 0.55 mg kg^{-1}) at all intervals. However, no definite pattern was observed with source of application. In comparison to control, application of biochar of all types and rates significantly reduced the Zn content at all intervals except 60 DAI. With application of WB @ 2 t ha^{-1} highest Zn content (0.31 mg kg^{-1}) was noticed and lowest (0.23 mg kg^{-1}) with BB @ 16 t ha^{-1} .

4.2.9 Effect of different sources and levels of biochar application on DTPA extractable Cu content (mg kg^{-1}) in different soils

Data on effect of different types and levels of biochar application on DTPA extractable Cu content in acidic, neutral and alkaline soils are presented in Tables 15, 16 and 17 respectively.

Application of various types of biochar in acidic soil varied DTPA extractable Cu content significantly at 60, 90 and 120 DAI (Table 15). However, significant effect of application of graded levels was observed at all intervals except 15 DAI. Higher Cu content was recorded at 15 DAI and then followed a decreasing trend till 120 DAI except a slight increase at 90 DAI in all the treatments. Application rate of 16 t ha^{-1} recorded significantly lower (2.81 to 3.55 mg kg^{-1}) Cu content at all intervals. Changes in Cu

Table 15: Effect of different sources and levels of biochar application on DTPA extractable Zn and Cu content in acidic soil at different intervals

Sources* of biochar	Zn (mg kg ⁻¹)					Cu (mg kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	1.24	0.88	0.83	0.82	0.88	3.67	3.06	2.97	3.09	3.17
BB	1.22	0.87	0.83	0.89	0.87	3.73	2.99	2.97	3.47	3.28
RHB	1.16	0.87	0.87	1.05	0.81	3.65	3.02	3.10	3.72	3.14
SEM±	0.02	0.01	0.01	0.01	0.01	0.07	0.02	0.02	0.03	0.04
CD at 0.05	0.05	NS	0.03	0.04	0.04	NS	NS	0.05	0.08	0.10
Levels of biochar										
2 t ha ⁻¹	1.19	0.86	0.83	0.90	0.87	3.83	3.08	3.03	3.55	3.30
4 t ha ⁻¹	1.20	0.90	0.86	0.91	0.87	3.72	3.01	3.10	3.39	3.25
8 t ha ⁻¹	1.19	0.91	0.89	0.94	0.82	3.63	3.17	3.01	3.45	3.19
16 t ha ⁻¹	1.26	0.84	0.80	0.93	0.85	3.55	2.81	2.93	3.31	3.05
SEM±	0.02	0.02	0.01	0.02	0.02	0.08	0.03	0.02	0.03	0.04
CD at 0.05	NS	0.05	0.04	NS	NS	NS	0.08	0.06	0.09	0.12
Interaction										
Control	1.26	0.85	0.82	0.98	1.09	3.66	3.04	3.29	3.59	3.34
WB @ 2 t ha ⁻¹	1.23	0.87	0.81	0.88	0.89	3.73	3.26	3.01	3.38	3.31
WB @ 4 t ha ⁻¹	1.25	0.93	0.88	0.84	0.90	3.66	3.09	3.04	3.05	3.17
WB @ 8 t ha ⁻¹	1.12	0.91	0.85	0.78	0.91	3.73	3.08	3.08	3.09	3.20
WB @ 16 t ha ⁻¹	1.36	0.83	0.79	0.79	0.82	3.56	2.80	2.77	2.82	2.99
BB @ 2 t ha ⁻¹	1.18	0.88	0.80	0.83	0.89	4.08	3.03	3.07	3.56	3.44
BB @ 4 t ha ⁻¹	1.22	0.85	0.89	0.89	0.90	3.74	2.91	3.20	3.45	3.37
BB @ 8 t ha ⁻¹	1.24	0.93	0.93	1.02	0.84	3.49	3.15	2.74	3.54	3.20
BB @ 16 t ha ⁻¹	1.25	0.83	0.72	0.81	0.84	3.61	2.86	2.86	3.35	3.11
RHB @ 2 t ha ⁻¹	1.15	0.82	0.89	0.98	0.83	3.68	2.97	3.00	3.70	3.16
RHB @ 4 t ha ⁻¹	1.12	0.92	0.81	1.00	0.80	3.78	3.03	3.05	3.68	3.20
RHB @ 8 t ha ⁻¹	1.21	0.90	0.90	1.02	0.72	3.66	3.29	3.20	3.73	3.16
RHB @ 16 t ha ⁻¹	1.16	0.85	0.89	1.19	0.89	3.47	2.77	3.17	3.75	3.06
SEM±	0.04	0.03	0.02	0.03	0.03	0.14	0.05	0.03	0.05	0.07
CD at 0.05	0.11	NS	0.06	0.08	0.08	NS	0.14	0.10	0.16	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 16: Effect of different sources and levels of biochar application on DTPA extractable Zn and Cu content in neutral soil at different intervals

Sources* of biochar	Zn (mg kg ⁻¹)					Cu (mg kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	0.88	0.65	0.70	0.54	0.69	2.06	2.07	1.90	1.73	1.93
BB	0.90	0.67	0.73	0.61	0.76	2.04	2.20	1.84	1.88	2.07
RHB	0.89	0.67	0.72	0.61	0.74	2.00	2.12	1.86	2.06	2.06
SEm±	0.01	0.01	0.01	0.02	0.01	0.04	0.02	0.01	0.04	0.02
CD at 0.05	NS	NS	NS	0.06	0.03	NS	0.06	NS	0.13	0.06
Levels of biochar										
2 t ha ⁻¹	0.94	0.68	0.68	0.45	0.70	2.05	2.14	1.96	1.84	2.04
4 t ha ⁻¹	0.87	0.65	0.72	0.63	0.75	2.11	2.21	1.89	1.89	2.03
8 t ha ⁻¹	0.89	0.67	0.73	0.63	0.72	2.02	2.14	1.85	1.94	2.04
16 t ha ⁻¹	0.86	0.67	0.74	0.63	0.76	1.95	2.03	1.77	1.88	1.97
SEm±	0.01	0.02	0.01	0.02	0.01	0.04	0.03	0.02	0.05	0.02
CD at 0.05	0.04	NS	0.04	0.06	0.04	NS	0.07	0.05	NS	NS
Interaction										
Control	0.90	0.73	0.77	0.46	0.67	2.24	2.14	2.05	1.74	1.94
WB @ 2 t ha ⁻¹	0.94	0.66	0.70	0.35	0.68	2.09	2.15	1.95	1.64	1.98
WB @ 4 t ha ⁻¹	0.89	0.67	0.69	0.56	0.67	2.19	2.16	2.04	1.76	1.97
WB @ 8 t ha ⁻¹	0.85	0.70	0.68	0.64	0.65	2.05	2.07	1.86	1.83	1.94
WB @ 16 t ha ⁻¹	0.84	0.56	0.71	0.59	0.76	1.90	1.92	1.73	1.69	1.83
BB @ 2 t ha ⁻¹	0.95	0.72	0.76	0.47	0.70	2.11	2.15	1.95	1.89	2.07
BB @ 4 t ha ⁻¹	0.85	0.61	0.76	0.71	0.79	1.98	2.35	1.81	1.86	2.08
BB @ 8 t ha ⁻¹	0.95	0.64	0.70	0.59	0.80	2.05	2.21	1.83	1.76	2.11
BB @ 16 t ha ⁻¹	0.84	0.73	0.70	0.68	0.77	2.01	2.09	1.79	2.00	2.04
RHB @ 2 t ha ⁻¹	0.94	0.67	0.59	0.53	0.72	1.96	2.13	1.97	1.98	2.09
RHB @ 4 t ha ⁻¹	0.87	0.66	0.69	0.61	0.77	2.15	2.11	1.82	2.05	2.05
RHB @ 8 t ha ⁻¹	0.86	0.65	0.81	0.66	0.71	1.97	2.14	1.86	2.25	2.08
RHB @ 16 t ha ⁻¹	0.89	0.71	0.80	0.62	0.76	1.94	2.09	1.79	1.95	2.04
SEm±	0.02	0.03	0.02	0.04	0.02	0.08	0.04	0.03	0.09	0.04
CD at 0.05	0.06	0.08	0.07	NS	0.06	NS	0.13	0.09	NS	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 17: Effect of different sources and levels of biochar application on DTPA extractable Zn and Cu content in alkaline soil at different intervals

	Zn (mg kg ⁻¹)					Cu (mg kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	0.56	0.23	0.28	0.19	0.22	1.11	1.04	1.04	0.94	1.04
BB	0.54	0.26	0.24	0.16	0.20	1.10	1.08	1.05	0.94	1.04
RHB	0.64	0.31	0.26	0.18	0.23	1.18	1.01	1.06	0.93	1.04
SEm±	0.01	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.01
CD at 0.05	0.03	0.01	0.01	0.01	0.01	NS	0.02	NS	NS	NS
Levels of biochar										
2 t ha ⁻¹	0.62	0.29	0.27	0.18	0.24	1.12	1.06	1.04	0.94	1.04
4 t ha ⁻¹	0.61	0.27	0.27	0.17	0.21	1.13	1.04	1.05	0.93	1.04
8 t ha ⁻¹	0.55	0.25	0.26	0.15	0.21	1.12	1.05	1.07	0.94	1.04
16 t ha ⁻¹	0.55	0.26	0.26	0.20	0.21	1.15	1.02	1.03	0.93	1.03
SEm±	0.01	0.01	0.01	0.00	0.00	0.03	0.01	0.01	0.01	0.01
CD at 0.05	0.03	0.02	NS	0.01	0.01	NS	0.03	NS	NS	NS
Interaction										
Control	0.76	0.43	0.27	0.29	0.28	1.13	0.96	1.05	0.94	1.02
WB @ 2 t ha ⁻¹	0.61	0.27	0.28	0.19	0.24	1.14	1.04	1.01	0.94	1.04
WB @ 4 t ha ⁻¹	0.59	0.21	0.31	0.19	0.22	1.12	1.04	1.06	0.92	1.04
WB @ 8 t ha ⁻¹	0.50	0.23	0.26	0.19	0.21	1.05	1.06	1.02	0.95	1.04
WB @ 16 t ha ⁻¹	0.55	0.22	0.28	0.19	0.19	1.15	1.02	1.07	0.94	1.03
BB @ 2 t ha ⁻¹	0.56	0.29	0.25	0.14	0.25	1.10	1.09	1.03	0.96	1.03
BB @ 4 t ha ⁻¹	0.53	0.26	0.25	0.19	0.16	1.09	1.07	1.04	0.92	1.04
BB @ 8 t ha ⁻¹	0.63	0.24	0.24	0.11	0.19	1.12	1.11	1.09	0.94	1.05
BB @ 16 t ha ⁻¹	0.43	0.26	0.23	0.19	0.20	1.10	1.06	1.04	0.93	1.05
RHB @ 2 t ha ⁻¹	0.68	0.32	0.26	0.21	0.23	1.12	1.05	1.08	0.91	1.06
RHB @ 4 t ha ⁻¹	0.70	0.35	0.25	0.13	0.25	1.18	1.02	1.06	0.95	1.04
RHB @ 8 t ha ⁻¹	0.53	0.29	0.27	0.16	0.22	1.19	0.99	1.09	0.94	1.05
RHB @ 16 t ha ⁻¹	0.66	0.30	0.26	0.21	0.22	1.22	0.98	0.99	0.92	1.03
SEm±	0.02	0.01	0.01	0.01	0.01	0.05	0.02	0.01	0.02	0.01
CD at 0.05	0.05	0.03	0.03	0.02	0.02	NS	0.05	0.04	NS	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

content as influenced by application of different types and levels of biochar ranged from 2.74 mg kg⁻¹ (BB @ 16 t ha⁻¹ at 60 DAI) to 4.08 mg kg⁻¹ (BB @ 2 t ha⁻¹ at 15 DAI).

In neutral soil, application of WB and application rate of 16 t ha⁻¹ recorded significantly lower DTPA extractable Cu content at all intervals (Table 16). Higher Cu content was observed at 30 DAI (1.92 to 2.35 mg kg⁻¹) and lower at 90 DAI (1.64 to 2.25 mg kg⁻¹) over a period of incubation. Interaction between sources of biochar and levels of application was found to be significant at 30 and 60 DAI. Among all treatment combinations, application of WB @ 16 t ha⁻¹ recorded significantly lowest Cu content and ranged from 1.69 to 1.92 mg kg⁻¹ at all intervals.

Application of different sources and levels of biochar application recorded a non significant effect on DTPA extractable Cu content at all intervals except 30 DAI. During study period, higher Cu content was observed at 15 DAI and lower at 90 DAI. Over a period of incubation, numerically higher Cu content (1.22 mg kg⁻¹) was recorded with application of RHB @ 16 t ha⁻¹ at 15 DAI and lower (0.91 mg kg⁻¹) with RHB @ 2 t ha⁻¹ at 90 DAI.

4.2.10 Effect of different sources and levels of biochar application on DTPA extractable iron (Fe) content (mg kg⁻¹) in different soils

Significant effect of various types of biochar and application rates on DTPA extractable Fe content was recorded in all the studied soils at different intervals (Tables 18-20). In general, application of WB recorded lower Fe content in both acidic and neutral soils while application of RHB recorded significantly lower Fe content in alkaline soil.

DTPA extractable Fe content differed significantly with application of different rates of biochar in acidic soil at all intervals (Table 18). However, interaction effect of source and levels remained significant at 30 and 60 DAI. A decreasing trend of Fe content was noticed from 15 to 30 DAI and there after an increasing trend was observed till the end of study period peaking at 120 DAI. Over a period of incubation, application of BB @ 2 t ha⁻¹ recorded the highest (85.10 mg kg⁻¹) Fe content at 120 DAI and WB @ 16 t ha⁻¹ recorded lowest Fe content (48.76 mg kg⁻¹) at 30 DAI.

In neutral soil, a significant effect of source of biochar on Fe content was observed at 60, 90 and 120 DAI (Table 19). However levels of application of showed significant effect at all intervals except 15 DAI. Higher Fe contents were observed at 120 DAI and lower at 90 DAI. Among different treatments, application of WB @ 16 t ha⁻¹ recorded significantly lower Fe content at all intervals (25.12 to 36.01 mg kg⁻¹).

Application of different sources and levels of biochar recorded a significant effect on DTPA extractable Fe content at all intervals in alkaline soil (Table 20). A definite trend of decreasing Fe content with increased rate of biochar application was noticed. Application of RHB @ 16 t ha⁻¹ recorded significantly lower Fe content at all intervals (2.16 to 0.11 mg kg⁻¹). Application of BB @ 2 t ha⁻¹ (3.71 mg kg⁻¹), WB @ 8 t ha⁻¹ (2.98 mg kg⁻¹), WB @ 16 t ha⁻¹ (2.36 mg kg⁻¹), BB @ 4 t ha⁻¹ (3.31 mg kg⁻¹) WB @ 4 t ha⁻¹

Table 18: Effect of different sources and levels of biochar application on DTPA extractable Fe and Mn content in acidic soil at different intervals

Sources* of biochar	Fe (mg kg ⁻¹)					Mn (mg kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	73.48	50.81	53.04	56.10	73.46	35.43	39.76	41.66	33.92	36.30
BB	75.30	51.34	53.18	62.27	79.23	38.65	40.85	41.28	40.47	42.49
RHB	73.60	52.32	55.79	65.92	77.11	39.62	42.21	44.04	46.09	43.32
SEm±	1.42	0.41	0.37	0.59	1.12	0.48	0.34	0.28	0.83	0.38
CD at 0.05	NS	1.20	1.09	1.71	3.25	1.40	0.99	0.83	2.40	1.09
Levels of biochar										
2 t ha ⁻¹	77.72	51.68	54.62	61.27	80.33	39.17	40.94	43.31	40.12	42.97
4 t ha ⁻¹	74.83	52.00	53.96	60.66	77.83	38.07	41.52	42.70	38.95	42.04
8 t ha ⁻¹	72.84	52.02	54.55	64.12	76.57	38.34	41.37	42.10	41.31	38.95
16 t ha ⁻¹	71.12	50.26	52.89	59.68	71.67	36.02	39.94	41.18	40.26	38.86
SEm±	1.64	0.48	0.43	0.68	1.29	0.56	0.40	0.33	0.95	0.44
CD at 0.05	4.75	1.38	1.25	1.98	3.75	1.61	1.15	0.95	NS	1.26
Interaction										
Control	76.38	51.40	54.84	62.29	83.95	38.62	40.50	43.56	42.29	45.35
WB @ 2 t ha ⁻¹	76.66	51.75	54.22	59.76	79.13	38.96	40.35	43.13	37.36	40.26
WB @ 4 t ha ⁻¹	73.95	51.23	53.21	58.10	74.24	34.57	40.93	42.52	35.84	38.20
WB @ 8 t ha ⁻¹	73.37	51.48	54.54	57.15	74.67	36.61	39.85	42.15	33.91	34.97
WB @ 16 t ha ⁻¹	69.93	48.76	50.17	49.41	65.80	31.57	37.93	38.85	28.57	31.79
BB @ 2 t ha ⁻¹	82.01	51.82	54.31	60.86	85.10	38.96	41.27	42.73	38.39	44.82
BB @ 4 t ha ⁻¹	75.41	50.67	54.55	60.19	81.78	38.68	40.18	43.38	38.56	45.99
BB @ 8 t ha ⁻¹	70.54	51.65	52.41	66.04	77.06	37.66	41.58	39.63	45.10	37.70
BB @ 16 t ha ⁻¹	73.25	51.22	51.44	62.01	72.96	39.31	40.37	39.39	39.83	41.45
RHB @ 2 t ha ⁻¹	74.48	51.46	55.32	63.20	76.74	39.59	41.19	44.08	44.59	43.82
RHB @ 4 t ha ⁻¹	75.13	54.10	54.10	63.68	77.46	40.95	43.46	42.21	42.45	41.94
RHB @ 8 t ha ⁻¹	74.62	52.94	56.68	69.17	77.97	40.75	42.67	44.54	44.92	44.18
RHB @ 16 t ha ⁻¹	70.18	50.79	57.05	67.63	76.27	37.19	41.51	45.30	52.38	43.35
SEm±	2.84	0.83	0.75	1.18	2.24	0.96	0.68	0.57	1.65	0.75
CD at 0.05	NS	NS	2.17	3.42	NS	2.79	NS	1.65	4.79	2.19

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 19: Effect of different sources and levels of biochar application on DTPA extractable Fe and Mn content in neutral soil at different intervals

Sources* of biochar	Fe (mg kg ⁻¹)					Mn (mg kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	29.14	41.58	38.10	28.06	39.84	84.01	169.55	165.33	174.83	182.07
BB	28.47	42.06	36.34	29.37	43.40	85.47	188.76	180.67	204.92	214.58
RHB	29.31	41.78	40.06	31.03	44.13	104.38	199.65	191.63	202.03	215.63
SEm±	1.57	0.67	0.52	0.14	0.61	3.26	2.16	2.84	1.71	2.23
CD at 0.05	NS	NS	1.52	0.41	1.77	9.44	6.27	8.22	4.96	6.47
Levels of biochar										
2 t ha ⁻¹	29.97	39.94	40.77	29.69	43.34	83.01	200.98	197.57	212.99	222.02
4 t ha ⁻¹	30.51	44.62	39.55	29.86	42.37	98.36	196.56	176.15	203.48	214.16
8 t ha ⁻¹	29.42	43.63	38.54	30.59	43.38	95.05	190.23	177.52	181.01	201.48
16 t ha ⁻¹	25.98	39.05	33.81	27.80	40.76	88.73	156.18	165.60	178.22	178.70
SEm±	1.81	0.78	0.61	0.16	0.70	3.76	2.50	3.28	1.97	2.58
CD at 0.05	NS	2.25	1.76	0.47	2.04	10.90	7.24	9.50	5.72	7.48
Interaction										
Control	37.34	38.95	42.05	30.70	39.97	96.80	210.33	202.63	214.11	235.57
WB @ 2 t ha ⁻¹	31.21	43.32	39.04	28.98	40.52	81.24	186.90	197.84	199.21	216.60
WB @ 4 t ha ⁻¹	34.33	45.79	43.27	28.59	41.68	94.16	183.50	168.12	190.05	194.50
WB @ 8 t ha ⁻¹	28.40	44.65	38.40	29.56	41.16	93.63	173.03	160.77	162.18	178.52
WB @ 16 t ha ⁻¹	22.60	32.57	31.68	25.12	36.01	67.02	134.78	134.59	147.86	138.65
BB @ 2 t ha ⁻¹	31.54	40.02	41.20	28.83	44.44	88.37	212.92	182.82	221.39	224.68
BB @ 4 t ha ⁻¹	23.06	44.98	34.19	28.70	41.37	72.93	199.69	189.68	209.24	220.93
BB @ 8 t ha ⁻¹	30.80	44.14	36.06	29.47	45.01	92.65	197.94	176.29	191.87	211.67
BB @ 16 t ha ⁻¹	28.47	39.12	33.90	30.48	42.80	87.91	144.48	173.90	197.17	201.03
RHB @ 2 t ha ⁻¹	27.15	36.48	42.07	31.27	45.06	79.43	203.13	212.06	218.36	224.78
RHB @ 4 t ha ⁻¹	34.13	43.10	41.18	32.28	44.05	127.99	206.48	170.66	211.16	227.06
RHB @ 8 t ha ⁻¹	29.07	42.10	41.15	32.73	43.96	98.88	199.73	195.49	188.96	214.26
RHB @ 16 t ha ⁻¹	26.88	45.45	35.85	27.81	43.46	111.25	189.27	188.32	189.63	196.43
SEm±	3.13	1.34	1.05	0.28	1.22	6.51	4.33	5.67	3.42	4.47
CD at 0.05	NS	3.89	3.04	0.81	NS	18.88	12.55	16.45	9.92	12.95

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 20: Effect of different sources and levels of biochar application on DTPA extractable Fe and Mn content in alkaline soil at different intervals

	Fe (mg kg ⁻¹)					Mn (mg kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	3.37	2.86	2.18	3.05	4.26	4.88	8.56	7.36	3.16	4.49
BB	3.47	2.81	2.09	3.19	4.09	4.95	8.34	6.48	3.01	4.43
RHB	2.64	1.18	0.84	2.01	2.91	4.89	6.96	5.41	2.90	3.75
SEm±	0.09	0.03	0.02	0.03	0.02	0.11	0.06	0.11	0.06	0.06
CD at 0.05	0.25	0.09	0.07	0.08	0.05	NS	0.19	0.32	0.16	0.18
Levels of biochar										
2 t ha ⁻¹	3.45	2.63	1.89	3.00	4.01	4.93	8.31	6.50	3.19	4.40
4 t ha ⁻¹	3.18	2.28	1.82	2.83	3.84	4.87	7.80	6.78	2.91	4.34
8 t ha ⁻¹	3.00	2.22	1.59	2.67	3.69	4.92	8.08	6.24	3.03	4.06
16 t ha ⁻¹	3.01	2.01	1.54	2.51	3.48	4.91	7.62	6.15	2.96	4.09
SEm±	0.10	0.04	0.03	0.03	0.02	0.12	0.07	0.13	0.06	0.07
CD at 0.05	0.29	0.11	0.08	0.09	0.06	NS	0.22	0.37	0.19	0.21
Interaction										
Control	3.40	2.45	2.31	3.11	4.04	5.03	7.75	7.57	3.64	4.50
WB @ 2 t ha ⁻¹	3.41	2.81	2.09	3.11	4.20	4.98	8.41	7.08	3.47	4.63
WB @ 4 t ha ⁻¹	3.42	2.81	2.23	3.01	4.31	4.85	8.67	7.69	3.00	4.50
WB @ 8 t ha ⁻¹	3.26	2.98	2.06	3.11	4.30	4.66	8.58	7.21	3.16	4.40
WB @ 16 t ha ⁻¹	3.36	2.85	2.36	2.96	4.23	5.01	8.59	7.47	3.01	4.42
BB @ 2 t ha ⁻¹	3.71	2.97	2.01	3.27	4.23	4.95	8.34	6.59	3.13	4.53
BB @ 4 t ha ⁻¹	3.35	2.63	1.90	3.31	4.16	4.92	8.44	6.98	2.86	4.56
BB @ 8 t ha ⁻¹	3.30	2.78	2.31	3.13	4.07	4.97	8.68	6.20	2.93	4.34
BB @ 16 t ha ⁻¹	3.52	2.84	2.14	3.07	3.92	4.95	7.88	6.14	3.11	4.30
RHB @ 2 t ha ⁻¹	3.21	2.10	1.58	2.61	3.61	4.84	8.18	5.83	2.98	4.04
RHB @ 4 t ha ⁻¹	2.77	1.39	1.32	2.16	3.06	4.85	6.30	5.66	2.86	3.97
RHB @ 8 t ha ⁻¹	2.42	0.90	0.38	1.77	2.69	5.11	6.97	5.31	2.99	3.45
RHB @ 16 t ha ⁻¹	2.16	0.33	0.11	1.50	2.29	4.78	6.38	4.83	2.77	3.54
SEm±	0.18	0.06	0.05	0.05	0.04	0.21	0.13	0.22	0.11	0.13
CD at 0.05	NS	0.19	0.13	0.16	0.11	NS	0.37	NS	NS	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

(4.31 mg kg⁻¹) recorded highest Fe content at 15, 30, 60, 90 and 120 DAI respectively. A decreasing trend was noticed with incubation time from 15 to 60 DAI and there after increasing trend was observed from 90 to 120 DAI recording highest at 120 DAI (2.29 to 4.31 mg kg⁻¹).

4.2.11 Effect of different sources and levels of biochar application on DTPA extractable manganese (Mn) content (ppm) in different soils

Different sources of biochar application varied DTPA extractable Mn content significantly in acidic, neutral and alkaline soil at all intervals (Tables 18-20). In general, lower Mn content was observed with application of WB in acidic and neutral soils while application of RHB recorded lower values in alkaline soil.

In acidic soil, application level of 16 t ha⁻¹ recorded lower DTPA extractable Mn content at all intervals (36.02 to 41.18 mg kg⁻¹) (Table 18). Application of RHB increased Mn content from 15 to 90 DAI. While, application of WB and BB recorded an increasing trend of Mn content from 15 DAI to 60 DAI and decreased at 90 DAI and again a slight increase was observed at 120 DAI. Higher Mn content of 40.95, 43.46, 45.30, 52.38, and 45.99 mg kg⁻¹ was recorded with application of RHB @ 4 t ha⁻¹ at 15 and 30 DAI, RHB @ 16 t ha⁻¹ at 60 and 90 DAI and BB @ 4 t ha⁻¹ respectively. Application of WB @ 16 t ha⁻¹ recorded significantly lower Mn content at all intervals (28.57 to 38.85 mg kg⁻¹).

In neutral soil, application of various types of biochar at different levels recorded significant effect on available Mn content at all intervals (Table 19). Independent of biochar application, an increase in Mn content was observed with incubation time. Higher Mn content was observed at 120 DAI and lower at 15 DAI. In different treatments, the Mn content varied from 67.02 mg kg⁻¹ (WB @ 16 t ha⁻¹ at 15 DAI) to 235.57 mg kg⁻¹ (control at 120 DAI). Application of WB @ 16 t ha⁻¹ recorded significantly lower Mn content at all incubation period (67.02 to 147.86 mg kg⁻¹).

The Mn content differed significantly in alkaline soil (Table 20) with the application of different sources and levels of biochar at all intervals except 15 DAI. However, interaction effect appeared to be significant only at 30 DAI. Among different treatment combinations, application of WB and BB at different rates recorded significantly higher Mn content (7.88 to 8.68 mg kg⁻¹) over control while RHB at different levels recorded significantly lower Mn content (6.30 to 6.97 mg kg⁻¹) except 2 t ha⁻¹ at 30 DAI. Highest Mn content was recorded in treatment BB @ 8 t ha⁻¹ (8.68 mg kg⁻¹) and lowest in RHB @ 4 t ha⁻¹ (6.30 mg kg⁻¹) at 30 DAI.

4.2.12. Effect of different sources and levels of biochar application on CaCl₂ - Si (ppm) in different soils

CaCl₂ - Si content as influenced by biochar application in different soils are presented in Table 21- 23.

Perusal of data showed a significant effect of sources and levels of biochar and their interaction on CaCl₂ - Si content at all intervals and in all studied soils. In general,

Table 21: Effect of different sources and levels of biochar application on CaCl₂ - Si and exchangeable Na content in acidic soil at different intervals

	CaCl ₂ - Si (ppm)					Na (cmol (p ⁺) kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	45.51	41.59	49.21	49.49	53.93	0.28	0.28	0.18	0.19	0.21
BB	45.12	40.91	47.83	51.67	54.66	0.24	0.24	0.18	0.19	0.21
RHB	44.97	44.15	49.82	53.15	56.07	0.24	0.25	0.17	0.21	0.23
SEm±	0.36	0.30	0.49	0.37	0.64	0.01	0.00	0.00	0.00	0.00
CD at 0.05	1.04	0.88	1.42	1.08	1.85	0.01	0.01	0.01	0.01	0.01
Levels of biochar										
2 t ha ⁻¹	44.68	40.54	47.39	49.52	53.38	0.25	0.25	0.17	0.19	0.21
4 t ha ⁻¹	44.24	42.39	47.98	49.53	54.99	0.25	0.26	0.18	0.19	0.22
8 t ha ⁻¹	45.34	41.23	51.20	54.26	55.69	0.27	0.27	0.17	0.21	0.21
16 t ha ⁻¹	46.54	44.71	49.23	52.44	55.48	0.25	0.26	0.18	0.20	0.23
SEm±	0.42	0.35	0.56	0.43	0.74	0.01	0.01	0.00	0.00	0.00
CD at 0.05	1.21	1.01	1.63	1.24	2.13	NS	NS	NS	0.01	0.01
Interaction										
Control	59.94	40.96	48.33	46.21	45.26	0.30	0.29	0.15	0.18	0.22
WB @ 2 t ha ⁻¹	46.52	40.80	48.15	50.19	53.52	0.27	0.26	0.17	0.18	0.20
WB @ 4 t ha ⁻¹	43.69	42.84	48.06	48.12	52.62	0.30	0.30	0.17	0.18	0.21
WB @ 8 t ha ⁻¹	44.32	41.54	55.16	49.51	54.79	0.31	0.32	0.18	0.20	0.21
WB @ 16 t ha ⁻¹	47.50	41.20	45.48	50.15	54.78	0.25	0.26	0.19	0.21	0.23
BB @ 2 t ha ⁻¹	44.53	40.70	47.64	50.23	52.31	0.23	0.22	0.17	0.20	0.20
BB @ 4 t ha ⁻¹	44.55	40.91	47.64	50.25	56.28	0.24	0.24	0.20	0.18	0.21
BB @ 8 t ha ⁻¹	46.81	39.87	48.44	55.64	56.50	0.26	0.25	0.18	0.20	0.20
BB @ 16 t ha ⁻¹	44.59	42.16	47.58	50.55	53.54	0.24	0.25	0.18	0.18	0.23
RHB @ 2 t ha ⁻¹	42.98	40.13	46.38	48.13	54.31	0.27	0.26	0.18	0.19	0.23
RHB @ 4 t ha ⁻¹	44.46	43.42	48.25	50.21	56.07	0.22	0.24	0.17	0.21	0.22
RHB @ 8 t ha ⁻¹	44.88	42.28	50.01	57.65	55.76	0.24	0.23	0.16	0.22	0.22
RHB @ 16 t ha ⁻¹	47.53	50.78	54.64	56.61	58.11	0.25	0.26	0.16	0.22	0.23
SEm±	0.72	0.60	0.98	0.74	1.27	0.01	0.01	0.01	0.01	0.00
CD at 0.05	2.09	1.75	2.83	2.15	3.70	0.03	0.03	0.02	0.02	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 22: Effect of different sources and levels of biochar application on CaCl_2 - Si and exchangeable sodium content in neutral soil at different intervals

Sources* of biochar	CaCl_2 - Si (ppm)					Exchangeable sodium ($\text{cmol (p}^+) \text{ kg}^{-1}$)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
WB	86.38	85.70	88.97	85.25	87.70	1.47	1.43	1.75	1.32	1.63
BB	96.07	98.62	89.47	86.72	94.98	1.69	1.70	1.52	1.39	1.73
RHB	103.88	97.59	96.92	89.31	90.94	1.78	1.64	1.61	1.40	1.74
SEm\pm	0.47	0.87	1.31	0.50	0.73	0.02	0.02	0.03	0.01	0.02
CD at 0.05	1.35	2.52	3.79	1.45	2.10	0.06	0.05	0.07	0.04	0.05
Levels of biochar										
2 t ha ⁻¹	89.27	91.47	89.61	85.66	88.87	1.71	1.61	1.75	1.35	1.66
4 t ha ⁻¹	91.55	97.18	91.99	88.14	90.77	1.57	1.51	1.58	1.35	1.71
8 t ha ⁻¹	102.11	96.72	92.90	86.64	91.68	1.63	1.63	1.57	1.40	1.67
16 t ha ⁻¹	98.85	90.51	92.66	87.93	93.51	1.68	1.61	1.62	1.38	1.76
SEm\pm	0.54	1.00	1.51	0.58	0.84	0.02	0.02	0.03	0.02	0.02
CD at 0.05	1.56	2.91	NS	1.67	2.43	0.07	0.05	0.09	NS	0.06
Interaction										
Control	95.64	91.03	83.29	82.61	80.77	1.78	1.70	1.52	1.16	1.52
WB @ 2 t ha ⁻¹	90.31	85.59	87.24	84.10	80.87	1.37	1.27	1.93	1.25	1.54
WB @ 4 t ha ⁻¹	88.92	86.35	87.53	86.23	87.16	1.38	1.34	1.87	1.30	1.68
WB @ 8 t ha ⁻¹	84.35	86.20	89.48	86.86	92.24	1.57	1.56	1.64	1.34	1.62
WB @ 16 t ha ⁻¹	81.96	84.66	91.63	83.83	90.52	1.56	1.55	1.56	1.38	1.70
BB @ 2 t ha ⁻¹	88.11	93.82	91.14	88.87	97.06	1.75	1.83	1.52	1.39	1.74
BB @ 4 t ha ⁻¹	87.07	102.62	91.51	91.78	96.35	1.62	1.64	1.48	1.39	1.75
BB @ 8 t ha ⁻¹	107.10	109.86	88.03	80.38	94.37	1.58	1.59	1.51	1.41	1.65
BB @ 16 t ha ⁻¹	102.00	88.18	87.20	85.83	92.14	1.82	1.72	1.57	1.36	1.78
RHB @ 2 t ha ⁻¹	89.39	94.99	90.44	84.02	88.68	2.00	1.74	1.79	1.39	1.69
RHB @ 4 t ha ⁻¹	98.68	102.59	96.92	86.42	88.80	1.71	1.54	1.39	1.36	1.70
RHB @ 8 t ha ⁻¹	114.88	94.11	101.18	92.68	88.41	1.72	1.73	1.54	1.45	1.76
RHB @ 16 t ha ⁻¹	112.59	98.68	99.15	94.13	97.88	1.67	1.57	1.73	1.40	1.80
SEm\pm	0.93	1.74	2.61	1.00	1.45	0.04	0.03	0.05	0.03	0.04
CD at 0.05	2.70	5.04	NS	2.90	4.21	0.12	0.09	0.15	0.08	0.10

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 23: Effect of different sources and levels of biochar application on CaCl₂ - Si and exchangeable sodium in alkaline soil at different intervals

	CaCl ₂ - Si (ppm)					Exchangeable sodium (cmol (p ⁺) kg ⁻¹)				
	Days after incubation					Days after incubation				
	15	30	60	90	120	15	30	60	90	120
Sources* of biochar										
WB	43.53	38.68	37.63	41.82	39.88	6.10	5.79	5.28	5.16	5.87
BB	43.42	40.96	42.86	41.49	41.38	6.02	6.13	5.39	5.14	5.73
RHB	95.67	91.79	100.06	80.79	90.84	5.94	6.41	5.74	5.29	5.86
SEm±	0.63	0.57	1.12	0.59	0.56	0.04	0.03	0.04	0.03	0.06
CD at 0.05	1.83	1.65	3.24	1.72	1.61	0.11	0.09	0.13	0.08	NS
Levels of biochar										
2 t ha ⁻¹	47.63	42.72	44.03	47.45	45.03	5.94	6.03	5.36	5.11	5.83
4 t ha ⁻¹	53.66	48.91	48.91	45.37	51.08	5.89	6.05	5.59	5.22	5.82
8 t ha ⁻¹	59.12	54.55	61.55	51.88	61.65	6.21	6.21	5.57	5.36	5.91
16 t ha ⁻¹	83.07	82.40	86.25	74.12	71.70	6.04	6.15	5.35	5.10	5.72
SEm±	0.73	0.66	1.29	0.69	0.64	0.04	0.04	0.05	0.03	0.06
CD at 0.05	2.11	1.91	3.74	1.99	1.86	0.13	0.10	0.14	0.10	NS
Interaction										
Control	41.21	41.82	36.28	37.40	40.98	6.06	6.32	4.96	4.94	5.45
WB @ 2 t ha ⁻¹	44.88	35.95	37.61	43.93	37.77	6.01	5.80	5.10	4.80	5.89
WB @ 4 t ha ⁻¹	46.20	43.83	38.12	41.00	39.83	5.85	5.77	5.49	5.28	5.92
WB @ 8 t ha ⁻¹	42.02	35.14	38.05	42.90	42.70	6.22	5.80	5.15	5.36	5.98
WB @ 16 t ha ⁻¹	41.02	39.82	36.76	39.46	39.20	6.34	5.78	5.40	5.20	5.68
BB @ 2 t ha ⁻¹	42.42	40.98	39.74	42.69	42.79	5.97	6.06	5.28	5.21	5.67
BB @ 4 t ha ⁻¹	42.80	39.75	40.57	41.72	41.40	5.94	6.15	5.53	5.05	5.50
BB @ 8 t ha ⁻¹	44.90	40.58	45.54	40.39	41.56	6.47	6.10	5.50	5.26	5.84
BB @ 16 t ha ⁻¹	43.54	42.53	45.59	41.18	39.76	5.72	6.20	5.24	5.05	5.89
RHB @ 2 t ha ⁻¹	55.59	51.24	54.73	55.73	54.54	5.84	6.24	5.70	5.33	5.94
RHB @ 4 t ha ⁻¹	71.99	63.15	68.04	53.38	72.01	5.89	6.21	5.76	5.34	6.03
RHB @ 8 t ha ⁻¹	90.45	87.92	101.07	72.34	100.69	5.96	6.73	6.08	5.44	5.91
RHB @ 16 t ha ⁻¹	164.64	164.86	176.41	141.73	136.13	6.07	6.46	5.43	5.05	5.57
SEm±	1.26	1.14	2.24	1.19	1.11	0.08	0.06	0.09	0.06	0.11
CD at 0.05	3.65	3.31	6.48	3.45	3.23	0.23	0.18	0.25	0.17	0.32

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

WB recorded significantly lower CaCl_2 - Si content in neutral and alkaline soil, but found to be on par with BB and RHB in acidic soil. RHB recorded higher CaCl_2 - Si content in all the soils. Increased rate of biochar application increased Si content in all the soils.

In acidic soil, CaCl_2 - Si content ranged from 41.59 to 53.93, 40.91 to 54.66 and 44.15 to 56.07 ppm with the application of WB, BB and RHB respectively, at different intervals of incubation (Table 21). Independent of types and levels of biochar application, there was a decrease in CaCl_2 - Si content from 15 to 30 DAI and then gradual increase in CaCl_2 - Si content was observed till 120 DAI. Different treatments such as control (59.94 ppm), RHB @ 16 t ha⁻¹ (50.78 ppm), WB @ 8 t ha⁻¹ (55.16 ppm), RHB @ 8 t ha⁻¹ (57.65 ppm) and RHB @ 16 t ha⁻¹ (58.11 ppm) recorded correspondingly higher CaCl_2 - Si content at 15, 30, 60, 90 and 120 DAI.

In neutral soil, among the different sources and levels, application of RHB and application rate of 8 t ha⁻¹ recorded higher CaCl_2 - Si content at all intervals except 120 DAI (Table 22). Though CaCl_2 - Si content varied with time of incubation no definite pattern was observed. Application of RHB @ 8 t ha⁻¹ (114.88 ppm), BB @ 8 t ha⁻¹ (109.86 ppm), RHB @ 8 t ha⁻¹ (101.18 ppm), RHB @ 16 t ha⁻¹ (94.13 ppm) and RHB @ 16 t ha⁻¹ (97.88 ppm) recorded significantly higher CaCl_2 - Si content at 15, 30, 60, 90 and 120 DAI respectively, over control. Application of biochar at different rates and interaction effect remained non significant at 60 DAI.

CaCl_2 - Si content differed significantly in alkaline soil with application of different sources and levels of biochar at all intervals (Table 23). Among the different sources and application rates, application of RHB (80.79 to 100.06 ppm) and application rate of 16 t ha⁻¹ (71.70 to 86.25 ppm) recorded higher CaCl_2 - Si content. Of all the treatments, over a period of incubation higher CaCl_2 - Si content were recorded with application of RHB @ 16 t ha⁻¹ (176.41 ppm) at 60 DAI and lower with WB @ 8 t ha⁻¹ (35.14 ppm) at 30 DAI.

4.3 To study the effect of graded levels of biochar on growth and yield of aerobic rice

4.3.1 Effect of different sources and levels of biochar application on growth attributes of rice in acidic, neutral and alkaline soils

The data on growth components viz., plant height, number of tillers and chlorophyll content as influenced by application of different sources and levels of biochar application are presented in Tables 24- 27.

4.3.1.1 Plant height (cm)

The influences of different sources and levels of biochar on plant height at different growth stages in acidic, neutral and alkaline soils are presented in Tables 24, 25 and 26 respectively.

In acidic soil, with application different sources of biochar significant differences on plant height were observed at all growth stages except 90 DAS and at harvest;

Table 24: Effect of different sources and levels of biochar application on plant height and number of tillers of rice in acidic soil

	Plant height (cm)					Number of tillers plant ⁻¹			
	30 DAS	45 DAS	60 DAS	90 DAS	At harvest	45 DAS	60 DAS	90 DAS	At harvest
Sources* of biochar									
WB	36.07	81.16	99.89	101.82	107.08	7.42	9.25	9.67	9.67
BB	38.23	77.80	101.40	102.18	106.57	7.17	9.17	9.50	9.50
RHB	35.66	78.47	102.25	103.24	106.88	8.67	10.75	10.75	10.75
SEm±	0.34	0.29	0.37	0.49	1.17	0.23	0.16	0.18	0.18
CD at 0.05	0.99	0.83	1.09	NS	NS	0.67	0.46	0.54	0.54
Levels of biochar									
2 t ha ⁻¹	38.43	78.56	98.64	99.27	105.21	6.78	9.11	9.33	9.33
4 t ha ⁻¹	36.03	79.90	101.06	102.80	107.87	7.44	9.56	9.78	9.78
8 t ha ⁻¹	36.01	79.74	103.22	104.52	107.96	8.44	10.22	10.56	10.56
16 t ha ⁻¹	36.12	78.37	101.80	103.07	106.33	8.33	10.00	10.22	10.22
SEm±	0.40	0.33	0.43	0.56	1.35	0.27	0.18	0.21	0.21
CD at 0.05	1.15	0.96	1.25	1.63	NS	0.77	0.54	0.62	0.62
Interaction									
Control	34.73	69.93	93.37	96.87	100.30	4.67	7.00	7.33	7.33
WB @ 2 t ha ⁻¹	38.60	81.63	97.67	97.90	106.57	6.33	8.67	9.00	9.00
WB @ 4 t ha ⁻¹	35.73	83.67	100.00	103.50	107.17	7.00	9.33	9.67	9.67
WB @ 8 t ha ⁻¹	36.07	79.83	104.33	106.37	110.23	8.67	10.00	10.67	10.67
WB @ 16 t ha ⁻¹	33.87	79.50	97.57	99.50	104.33	7.67	9.00	9.33	9.33
BB @ 2 t ha ⁻¹	39.83	77.80	100.17	100.37	102.17	7.33	9.33	9.67	9.67
BB @ 4 t ha ⁻¹	38.50	78.30	102.27	103.00	110.93	7.00	9.33	9.67	9.67
BB @ 8 t ha ⁻¹	33.90	77.97	101.33	103.07	108.63	7.33	9.33	9.67	9.67
BB @ 16 t ha ⁻¹	40.67	77.13	101.83	102.30	104.53	7.00	8.67	9.00	9.00
RHB @ 2 t ha ⁻¹	36.87	76.23	98.10	99.53	106.90	6.67	9.33	9.33	9.33
RHB @ 4 t ha ⁻¹	33.87	77.73	100.90	101.90	105.50	8.33	10.00	10.00	10.00
RHB @ 8 t ha ⁻¹	38.07	81.43	104.00	104.13	105.00	9.33	11.33	11.33	11.33
RHB @ 16 t ha ⁻¹	33.83	78.49	106.00	107.40	110.13	10.33	12.33	12.33	12.33
SEm±	0.69	0.58	0.75	0.98	2.34	0.46	0.32	0.37	0.37
CD at 0.05	1.99	1.67	2.17	2.83	6.80	1.34	0.93	1.07	1.07

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 25: Effect of different sources and levels of biochar application on plant height and number of tillers in neutral soil

Sources* of biochar	Plant height (cm)					Number of tillers plant ⁻¹			
	30 DAI	45 DAI	60 DAI	90 DAI	At harvest	45 DAI	60 DAI	90 DAI	At harvest
WB	27.29	42.03	61.98	73.25	75.09	5.33	7.83	8.33	8.33
BB	27.40	40.54	60.80	70.82	74.09	4.75	7.75	8.25	8.25
RHB	32.13	46.85	67.62	74.63	75.54	5.58	8.08	8.75	8.75
SEm±	0.43	0.44	0.61	0.57	0.59	0.17	0.18	0.15	0.15
CD at 0.05	1.24	1.26	1.77	1.65	NS	0.48	NS	NS	NS
Levels of biochar									
2 t ha ⁻¹	27.80	39.20	59.92	71.13	74.12	4.78	7.89	8.33	8.33
4 t ha ⁻¹	28.39	44.03	67.22	75.42	77.03	5.11	8.44	9.00	9.00
8 t ha ⁻¹	29.90	44.96	62.90	72.76	74.42	5.78	7.78	8.22	8.22
16 t ha ⁻¹	29.67	44.38	63.81	72.29	74.06	5.22	7.44	8.22	8.22
SEm±	0.49	0.50	0.71	0.66	0.68	0.19	0.21	0.18	0.18
CD at 0.05	1.43	1.46	2.05	1.90	1.97	0.56	0.60	0.51	0.51
Interaction									
Control	32.20	41.10	67.67	71.80	75.33	5.00	6.67	7.67	7.67
WB @ 2 t ha ⁻¹	26.67	37.57	60.13	70.97	74.17	5.33	7.67	8.00	8.00
WB @ 4 t ha ⁻¹	27.35	45.53	68.87	78.00	78.60	5.33	8.33	9.00	9.00
WB @ 8 t ha ⁻¹	28.60	46.43	63.50	77.27	76.10	5.67	8.00	8.33	8.33
WB @ 16 t ha ⁻¹	26.53	38.60	55.40	66.77	71.50	5.00	7.33	8.00	8.00
BB @ 2 t ha ⁻¹	23.73	32.37	56.77	68.40	74.20	4.33	7.67	8.33	8.33
BB @ 4 t ha ⁻¹	25.17	40.70	64.30	74.23	76.67	4.67	8.33	8.67	8.67
BB @ 8 t ha ⁻¹	29.82	43.37	58.00	64.30	69.83	5.33	7.67	8.00	8.00
BB @ 16 t ha ⁻¹	30.89	45.73	64.13	76.33	75.67	4.67	7.33	8.00	8.00
RHB @ 2 t ha ⁻¹	33.00	47.67	62.87	74.03	74.00	4.67	8.33	8.67	8.67
RHB @ 4 t ha ⁻¹	32.67	45.87	68.50	74.03	75.83	5.33	8.67	9.33	9.33
RHB @ 8 t ha ⁻¹	31.27	45.07	67.20	76.70	77.33	6.33	7.67	8.33	8.33
RHB @ 16 t ha ⁻¹	31.60	48.80	71.90	73.77	75.00	6.00	7.67	8.67	8.67
SEm±	0.86	0.87	1.22	1.14	1.18	0.33	0.36	0.31	0.31
CD at 0.05	2.48	2.53	3.55	3.30	3.41	NS	1.04	0.89	0.89

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 26: Effect of different sources and levels of biochar application on plant height and number of tillers of rice in alkaline soils

	Plant height (cm)					Number of tillers plant ⁻¹			
	30 DAI	45 DAI	60 DAI	90 DAI	At harvest	45 DAI	60 DAI	90 DAI	At harvest
Sources* of biochar									
WB	19.78	34.29	52.98	62.77	70.52	1.00	1.17	1.83	2.42
BB	19.16	30.21	45.40	59.08	69.93	1.00	1.00	1.50	2.33
RHB	17.46	22.64	41.77	52.07	59.63	1.08	1.25	1.33	2.25
SEm±	0.24	0.98	0.83	0.62	0.58	0.05	0.09	0.15	0.12
CD at 0.05	0.71	2.84	2.39	1.81	1.68	NS	NS	NS	NS
Levels of biochar									
2 t ha ⁻¹	19.74	34.08	52.44	58.83	69.06	1.00	1.22	2.22	2.67
4 t ha ⁻¹	18.76	28.66	47.28	58.41	67.24	1.00	1.00	1.11	2.56
8 t ha ⁻¹	20.09	29.38	43.89	56.37	69.00	1.11	1.11	1.44	2.11
16 t ha ⁻¹	16.61	24.08	43.26	58.27	61.47	1.00	1.22	1.44	2.00
SEm±	0.28	1.13	0.95	0.72	0.67	0.05	0.11	0.17	0.14
CD at 0.05	0.82	3.28	2.76	2.09	1.94	NS	NS	0.49	0.41
Interaction									
Control	18.00	40.00	63.92	67.67	70.33	1.00	1.67	1.67	2.33
WB @ 2 t ha ⁻¹	20.97	39.63	58.03	65.50	70.50	1.00	1.67	3.00	3.00
WB @ 4 t ha ⁻¹	19.30	32.50	46.63	56.77	65.07	1.00	1.00	1.00	2.67
WB @ 8 t ha ⁻¹	22.50	35.93	55.92	64.87	75.33	1.00	1.00	2.00	2.00
WB @ 16 t ha ⁻¹	16.35	29.10	51.35	63.93	71.17	1.00	1.00	1.33	2.00
BB @ 2 t ha ⁻¹	19.50	32.87	52.50	61.00	73.13	1.00	1.00	2.67	2.67
BB @ 4 t ha ⁻¹	18.33	25.67	44.63	57.27	68.60	1.00	1.00	1.00	2.67
BB @ 8 t ha ⁻¹	19.27	33.33	40.15	55.17	72.67	1.00	1.00	1.00	2.00
BB @ 16 t ha ⁻¹	19.53	28.97	44.33	62.87	65.33	1.00	1.00	1.33	2.00
RHB @ 2 t ha ⁻¹	18.75	29.73	46.80	50.00	63.53	1.00	1.00	1.00	2.33
RHB @ 4 t ha ⁻¹	18.65	27.80	50.58	61.20	68.07	1.00	1.00	1.33	2.33
RHB @ 8 t ha ⁻¹	18.50	18.87	35.60	49.07	59.00	1.33	1.33	1.33	2.33
RHB @ 16 t ha ⁻¹	13.95	14.17	34.08	48.00	47.90	1.00	1.67	1.67	2.00
SEm±	0.49	1.96	1.65	1.25	1.16	0.09	0.18	0.29	0.25
CD at 0.05	1.41	5.69	4.79	3.61	3.35	NS	0.54	0.85	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

whereas levels of application were found to be non significant only at harvest (Table 24). Application of all sources and levels of biochar increased the plant height significantly over control at all growth stages. At harvest, the maximum plant height (110.93 cm) was recorded by the treatment receiving BB @ 4 t ha⁻¹ and minimum (100.30 cm) by control treatment.

Plant height recorded at 30, 45, 60, 90 and at harvest differed significantly with the application of different sources and levels of biochar in neutral soil (Table 25). But the source of biochar application remained non significant at harvest. Overall, application of RHB (75.54 cm) and at the level of 4 t ha⁻¹ (77.03 cm) recorded higher plant height than other sources and levels at harvest. The plant height ranged from 69.83 to 78.60 cm in different treatment combinations at harvest, recording highest with WB @ 4 t ha⁻¹ and lowest with BB @ 8 t ha⁻¹.

In case of alkaline soil, application of different sources and levels of biochar recorded a significant effect on plant height at all growth stages (Table 26). Application of WB recorded significantly higher plant height of 19.78, 34.29, 52.98, 62.77 and 70.52 cm at 30, 45, 60, 90 and at harvest respectively, than other sources. Application level of 2 t ha⁻¹ recorded higher plant height of 19.74, 34.08, 52.44, 58.83 and 69.06 cm at 30, 45, 60, 90 and at harvest respectively, than other levels. Among the different treatment combinations, application of WB @ 8 t ha⁻¹ recorded maximum plant height (75.33 cm) and found to be on par with treatment BB @ 2 t ha⁻¹ (73.13 cm) and minimum (47.90 cm) was recorded with application of RHB @ 16 t ha⁻¹ treatment.

4.3.1.2 Number of tillers plant⁻¹

The number of tillers plant⁻¹ differed significantly with the application of different sources and levels of biochar in acidic, neutral and alkaline soil (Table 24-26).

Significant positive effect of biochar application on number of tillers plant⁻¹ was observed in acidic soil at all growth stages (Table 24). Among the different sources and levels of biochar application, RHB and application rate @ 8 t ha⁻¹ recorded higher number of tillers plant⁻¹ at all growth stages. Independent of sources and levels, application of biochar significantly increased the number of tillers plant⁻¹ over control at all growth stages. Treatment receiving RHB @ 16 t ha⁻¹ recorded significantly higher number of tillers plant⁻¹ (12.33) over control (7.33).

Application of different sources of biochar had a non significant effect on number of tiller plant⁻¹ at all growth stages except 45 DAS in neutral soil (Table 24). However, different levels of application recorded significant effect on number of tillers plant⁻¹ at all growth stages. Application of all types and levels of biochar significantly increased the number tillers plant⁻¹ over control at all growth stages except 45 DAS. At harvest, number of tillers plant⁻¹ ranged from 7.67 to 9.33 recording highest number of tillers in treatment RHB @ 4 t ha⁻¹ and lowest number in control.

Though application of different sources of biochar showed a non significant effect on number of tillers plant⁻¹, levels (90 DAS and at harvest) and interaction (60 and 90

Table 27: Effect of different sources and levels of biochar application on SPAD reading (chlorophyll content) of rice in acidic, neutral and alkaline soils at different growth stages

	Acidic soil			Neutral soil			Alkaline soil		
	45 DAS	60 DAS	90 DAS	45 DAI	60 DAI	90 DAI	45 DAS	60 DAS	90 DAS
Sources* of biochar									
WB	40.45	43.26	43.28	35.84	40.55	39.72	30.19	35.90	39.96
BB	40.53	44.03	43.80	37.13	40.90	39.43	31.18	34.21	38.57
RHB	40.73	44.91	44.21	39.33	41.88	40.33	28.37	30.99	35.72
SEm±	0.20	0.22	0.24	0.39	0.29	0.26	0.53	0.56	0.40
CD at 0.05	NS	0.63	0.69	1.14	0.83	NS	1.54	1.61	1.15
Levels of biochar									
2 t ha ⁻¹	40.37	42.98	44.07	37.63	41.03	39.82	33.66	35.94	38.60
4 t ha ⁻¹	40.82	44.93	43.79	38.51	41.44	39.86	32.26	33.84	38.40
8 t ha ⁻¹	40.73	44.80	43.83	38.23	39.92	40.36	30.26	33.62	37.34
16 t ha ⁻¹	40.37	43.56	43.37	35.36	42.06	39.27	23.48	31.39	37.98
SEm±	0.23	0.25	0.28	0.45	0.33	0.30	0.61	0.64	0.46
CD at 0.05	NS	0.73	NS	1.32	0.96	NS	1.77	1.86	NS
Interaction									
Control	38.63	41.37	41.97	39.73	40.10	39.20	33.70	35.03	37.70
WB @ 2 t ha ⁻¹	41.53	42.90	43.10	38.30	41.43	39.17	36.90	38.03	40.50
WB @ 4 t ha ⁻¹	40.87	44.13	43.70	37.93	41.55	40.47	31.93	35.43	39.00
WB @ 8 t ha ⁻¹	40.03	42.70	43.53	37.45	39.47	41.27	31.63	33.83	40.53
WB @ 16 t ha ⁻¹	39.37	43.30	42.80	29.68	39.77	37.97	20.30	36.30	39.80
BB @ 2 t ha ⁻¹	39.63	43.37	45.13	36.08	40.20	40.47	31.10	36.33	39.93
BB @ 4 t ha ⁻¹	40.63	46.47	43.33	36.30	40.70	39.00	32.23	32.60	37.37
BB @ 8 t ha ⁻¹	41.20	45.20	44.00	38.67	39.27	38.73	34.13	34.57	38.30
BB @ 16 t ha ⁻¹	40.67	41.10	42.73	37.47	43.43	39.53	27.23	33.33	38.67
RHB @ 2 t ha ⁻¹	39.93	42.67	43.97	38.50	41.44	39.83	32.97	33.47	35.37
RHB @ 4 t ha ⁻¹	40.97	44.20	44.33	41.30	42.07	40.10	32.60	33.50	38.83
RHB @ 8 t ha ⁻¹	40.97	46.50	43.97	38.57	41.03	41.07	25.00	32.47	33.20
RHB @ 16 t ha ⁻¹	41.07	46.27	44.57	38.93	42.99	40.30	22.90	24.53	35.47
SEm±	0.39	0.44	0.48	0.79	0.57	0.52	1.06	1.11	0.79
CD at 0.05	1.14	1.27	1.38	2.28	1.66	1.51	3.07	3.23	2.30

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

DAS) showed a significant effect on number of tillers plant⁻¹ in alkaline soil (Table 25). The number of tillers plant⁻¹ in different treatments ranged from 2 to 3 at harvest, recording maximum number of tillers with application of WB @ 2 t ha⁻¹.

4.3.1.3 SPAD reading (chlorophyll content)

The data presented in Table 27, revealed significant interaction effect of sources and levels of biochar on chlorophyll content at different growth stages in all studied soils.

In acidic soil, application of different sources of biochar had a significant effect on SPAD reading at 60 and 90 DAS. While, levels of application recorded a significant effect only at 60 DAS. Application of different sources and levels of biochar increased SPAD reading over control at all growth stages. At 90 DAS, highest SPAD reading was noticed with application of RHB @ 16 t ha⁻¹ (44.57) and lower in control (41.97).

A significant effect of different sources and levels of biochar application on SPAD reading was observed at 45 and 60 DAS in neutral soil. At 90 DAS, SPAD reading ranged from 37.97 to 41.27 in different treatments. Highest SPAD reading was observed with application of WB @ 8 t ha⁻¹ and lowest in treatment WB @ 16 t ha⁻¹.

In alkaline soil, application WB recorded higher SPAD reading than other two sources at all growth stages. However application at different rates showed significant effect only at 45 and 60 DAS, recording higher with 2 t ha⁻¹ application rate. SPAD reading as influenced by different sources and levels of biochar ranged from 33.20 to 40.53 at 90 DAS. With application of WB @ 8 t ha⁻¹ higher SPAD reading was observed and lower with RHB @ 8 t ha⁻¹ at 90 DAS.

4.3.2 Effect of different sources and levels of biochar on yield attributes of rice in acidic, neutral and alkaline soil

4.3.2.1 Number of panicles plant⁻¹

Results in Table 28 revealed the significant effect of application of different types and rates of biochar on number of panicles plant⁻¹ in acidic, neutral and alkaline soils at harvest.

In acidic soil, number of panicles plant⁻¹ differed significantly with application of different sources and levels of biochar. Among the different sources and levels, application of RHB (11.75) and application rate @ 8 t ha⁻¹ (11.67) recorded higher number of panicles plant⁻¹. Independent of types and levels, application of biochar significantly increased the number of panicles plant⁻¹ over control. The maximum number of panicles plant⁻¹ (12.67) was recorded with application of RHB @ 16 t ha⁻¹ and lower (6.67) was observed in control.

Application of different sources of biochar was found to have a non significant effect on number of panicles plant⁻¹ in neutral soil. Application rate and interaction recorded a significant influence on number of panicles plant⁻¹ in neutral soil. Among different levels, application at 4 t ha⁻¹ recorded higher number (8.44) of panicles plant⁻¹.

Table 28: Effect of different sources and levels of biochar application on yield attributes of rice in acidic, neutral and alkaline soils

	Acidic soil		Neutral soil		Alkaline soil	
	Panicles pot ⁻¹	Panicle length (cm)	Panicles pot ⁻¹	Panicle length (cm)	Panicles pot ⁻¹	Panicle length (cm)
Sources* of biochar						
WB	10.08	19.12	7.83	17.17	1.33	14.63
BB	10.25	19.02	7.75	17.12	1.42	14.18
RHB	11.75	19.51	8.17	17.14	1.00	12.76
SEm±	0.15	0.24	0.17	0.34	0.09	0.16
CD at 0.05	0.44	NS	NS	NS	0.27	0.47
Levels of biochar						
2 t ha ⁻¹	9.56	19.04	7.89	16.99	1.44	16.26
4 t ha ⁻¹	10.33	19.39	8.44	17.59	1.56	16.04
8 t ha ⁻¹	11.67	19.38	7.89	16.94	1.00	12.88
16 t ha ⁻¹	11.22	19.07	7.44	17.06	1.00	10.24
SEm±	0.18	0.28	0.20	0.40	0.11	0.19
CD at 0.05	0.51	NS	0.58	NS	0.31	0.55
Interaction						
Control	6.67	17.41	6.67	16.26	1.33	15.03
WB @ 2 t ha ⁻¹	8.67	18.74	7.67	17.39	1.67	16.27
WB @ 4 t ha ⁻¹	9.33	19.62	8.33	16.18	1.67	16.40
WB @ 8 t ha ⁻¹	11.67	19.56	8.00	17.38	1.00	15.20
WB @ 16 t ha ⁻¹	10.67	18.57	7.33	17.75	1.00	10.67
BB @ 2 t ha ⁻¹	9.33	18.99	7.67	15.82	1.67	17.33
BB @ 4 t ha ⁻¹	10.00	19.06	8.33	17.92	2.00	16.40
BB @ 8 t ha ⁻¹	11.33	19.19	7.67	17.08	1.00	12.33
BB @ 16 t ha ⁻¹	10.33	18.86	7.33	17.67	1.00	10.63
RHB @ 2 t ha ⁻¹	10.67	19.38	8.33	17.75	1.00	15.17
RHB @ 4 t ha ⁻¹	11.67	19.49	8.67	18.67	1.00	15.33
RHB @ 8 t ha ⁻¹	12.00	19.40	8.00	16.38	1.00	11.10
RHB @ 16 t ha ⁻¹	12.67	19.79	7.67	15.75	1.00	9.43
SEm±	0.31	0.48	0.35	0.69	0.18	0.33
CD at 0.05	0.89	1.38	1.00	2.00	NS	0.95

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Although, a there was a significant differences in number of panicles plant⁻¹ with application of different sources and levels of biochar when compared to control, the maximum number of panicles plant⁻¹ were recorded with application of RHB @ 4 t ha⁻¹ (8.67) and lower in control (6.67).

Significant effect of sources and levels of biochar application on number of panicles plant⁻¹ were noticed in alkaline soil. However, interaction effect was found to be non significant. Among the different sources and levels, higher number of panicles plant⁻¹ were observed with application of BB (1.42) and application rate at 4 t ha⁻¹ (1.56). Among different treatment combinations, BB @ 4 t ha⁻¹ recorded higher number of panicles plant⁻¹ (2.00).

4.3.2.2 Panicle length

The effect of different sources and levels of biochar application on panicle length in acidic, neutral and alkaline soils are presented in Table 28.

Perusal of data shows a non significant effect of sources and levels of biochar application on panicle length in acidic and neutral soil; while, a significant interaction effect was observed.

In acidic soil, panicle length in different treatments ranged from 17.41 to 19.79 cm. Independent of sources and levels, application of biochar significantly increased panicle length over control. Higher panicle length was attained with application of RHB @ 16 t ha⁻¹ and lower in control.

In neutral soil, variation in panicle length due to interaction effect ranged from 15.75 to 18.67 cm. The treatment receiving RHB @ 4 t ha⁻¹ recorded higher length of panicle while application of RHB @ 16 t ha⁻¹ recorded lower panicle length.

Application of different sources and levels of biochar showed a significant effect on panicle length in alkaline soil. Among the different sources and levels, application of WB (14.63 cm) and application rate of 2 t ha⁻¹ (16.26 cm) recorded higher length of panicle. Panicle length in different treatments ranged from 9.43 to 17.33 cm. The higher panicle length was observed with application of BB @ 2 t ha⁻¹ and lower in RHB @ 16 t ha⁻¹.

4.3.3 Effect of application of different sources and levels of biochar application on Straw and grain yield in different soils

4.3.3.1 Straw yield

The results of application of different types and levels of biochar on straw and grain yield of rice in different soils are presented in Table 29.

Significantly higher straw yield was obtained in acidic soil with application of RHB (18.91 g pot⁻¹) followed by WB (18.09 g pot⁻¹) and BB (17.67 g pot⁻¹). Independent of biochar type, application @ rate of 8 t ha⁻¹ recorded higher straw yield (19.06 g pot⁻¹)

Table 29: Effect of different sources and levels of biochar application on straw and grain yield of rice in acidic, neutral and alkaline soils

	Acidic soil		Neutral soil		Alkaline soil	
	Straw ← (g pot ⁻¹) →	Grain	Straw ← (g pot ⁻¹) →	Grain	Straw ← (g pot ⁻¹) →	Grain
Sources* of biochar						
WB	18.09	11.46	15.92	10.60	3.76	1.24
BB	17.67	11.28	15.21	10.42	3.68	1.13
RHB	18.91	12.51	17.42	10.81	2.53	0.74
SEm±	0.17	0.18	0.12	0.08	0.04	0.02
CD at 0.05	0.48	0.52	0.36	0.22	0.11	0.06
Levels of biochar						
2 t ha ⁻¹	17.39	10.72	15.93	10.84	3.62	1.16
4 t ha ⁻¹	18.23	11.47	17.27	11.32	3.99	1.21
8 t ha ⁻¹	19.06	12.88	15.87	10.29	3.18	0.91
16 t ha ⁻¹	18.21	11.94	15.66	9.99	2.50	0.85
SEm±	0.19	0.21	0.14	0.09	0.05	0.02
CD at 0.05	0.56	0.61	0.41	0.25	0.13	0.07
Interaction						
Control	15.74	9.47	14.18	8.86	3.10	1.33
WB @ 2 t ha ⁻¹	17.14	10.34	16.09	10.91	4.43	1.50
WB @ 4 t ha ⁻¹	18.82	11.49	17.31	11.54	4.83	1.44
WB @ 8 t ha ⁻¹	19.06	13.07	15.26	10.20	3.13	1.04
WB @ 16 t ha ⁻¹	17.33	10.95	15.00	9.73	2.63	1.00
BB @ 2 t ha ⁻¹	17.29	10.43	15.55	10.65	3.97	1.23
BB @ 4 t ha ⁻¹	17.72	11.24	16.39	11.00	4.17	1.35
BB @ 8 t ha ⁻¹	18.66	12.48	14.67	10.09	3.70	1.02
BB @ 16 t ha ⁻¹	17.02	10.98	14.23	9.97	2.90	0.91
RHB @ 2 t ha ⁻¹	17.75	11.38	16.14	10.95	2.47	0.76
RHB @ 4 t ha ⁻¹	18.14	11.68	18.10	11.42	2.97	0.85
RHB @ 8 t ha ⁻¹	19.45	13.09	17.68	10.58	2.70	0.68
RHB @ 16 t ha ⁻¹	20.28	13.89	17.74	10.28	1.97	0.65
SEm±	0.33	0.36	0.25	0.15	0.08	0.04
CD at 0.05	0.96	1.05	0.71	0.44	0.23	0.12

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

than other rates. Although application of biochar of different kinds and levels increased the straw yield significantly, treatment receiving RHB @ 16 t ha⁻¹ recorded significantly higher straw yield (20.28 g pot⁻¹) and found to be on par with RHB @ 8 t ha⁻¹ (19.45 g pot⁻¹). The lowest straw yield (15.74 g pot⁻¹) was recorded in control treatment.

In neutral soil, straw yield of 15.92, 15.21 and 17.42 g pot⁻¹ were observed with application of WB, BB and RHB respectively. Highest straw yield was noticed at the application rate of 4 t ha⁻¹ than other rates. Application of RHB at all rates of 4 (18.10 g pot⁻¹), 8 (17.68 g pot⁻¹) and 16 (17.74 g pot⁻¹) t ha⁻¹ recorded significantly higher straw yield than other treatments and lowest in control (14.18 g pot⁻¹).

Application of different biochar in alkaline soil varied the straw yield significantly and followed an order of WB (3.76 g pot⁻¹) > BB (3.68 g pot⁻¹) > RHB (2.53 g pot⁻¹). Independent of type of biochar, application level of 4 t ha⁻¹ recorded significantly higher straw yield (3.99 g pot⁻¹) than other levels of application. Significantly higher straw yield was observed in the treatment receiving WB @ 4 t ha⁻¹ (4.83 g pot⁻¹) and followed by WB @ 2 t ha⁻¹ (4.43 g pot⁻¹) in comparison to all other treatments. Significantly lower straw yield (1.97 g pot⁻¹) was noticed in the treatment receiving RHB @ 16 t ha⁻¹.

4.3.3.2 Grain yield

Application of different biochars at different levels and their interaction influenced significantly grain yield of rice in all the studied soils (Table 29).

Application of RHB recorded significantly higher grain yield (12.51 g pot⁻¹) in acidic soil than BB (11.28 g pot⁻¹) and RHB (11.46 g pot⁻¹). Application levels differed grain yield significantly following an order of 2 (10.72 g pot⁻¹) < 4 (11.47 g pot⁻¹) = 16 (11.94 g pot⁻¹) > 8 (12.88 g pot⁻¹) t ha⁻¹. Significantly higher grain yield of 13.89, 13.09 and 13.07 g pot⁻¹ were recorded with application of RHB @ 16 t ha⁻¹, RHB @ 8 t ha⁻¹ and WB @ 8 t ha⁻¹ respectively in comparison to other treatments. Lowest grain yield (9.47 g pot⁻¹) was observed in control treatment.

In neutral soil, grain yield of 10.60, 10.42 and 10.81 g pot⁻¹ was noticed with application of WB, BB and RHB respectively. Independent of type of biochar, application level of 4 t ha⁻¹ recorded significantly highest grain yield (11.32 g pot⁻¹). The treatment receiving WB @ 4 t ha⁻¹ and control recorded highest (11.54 g pot⁻¹) and lowest (11.42 g pot⁻¹) grain yield, respectively.

Application of different biochar varied grain yield significantly and followed an order of WB (1.24 g pot⁻¹) > BB (1.13 g pot⁻¹) > RHB (0.74 g pot⁻¹). Significant reduction in grain yield was observed with application rate of 8 (0.91 g pot⁻¹) and 16 t ha⁻¹ (0.85 g pot⁻¹) irrespective of type of biochar applied. Application of WB @ 2 t ha⁻¹ recorded significantly highest grain yield (1.50 g pot⁻¹) and was found to be on par with WB @ 4 t ha⁻¹ (1.44 g pot⁻¹).

4.3.4 Effect of different sources and levels of biochar application on content and uptake of nutrients in straw in different soils

4.3.4.1 Nitrogen content and uptake

The data pertaining to content and uptake of N in straw in different soils are presented in Table 30 and 31 respectively.

In acidic soil, among different types of biochar, RHB recorded significantly higher N content (0.98 %) and uptake (186.12 mg pot⁻¹) in straw than other sources. Irrespective of sources of biochar, application @ 4 t ha⁻¹ recorded significantly higher straw N content (1.00 %) than other levels. Among different treatment combinations N content in straw ranged from 0.83 to 1.04 per cent. Applications of RHB @ 4 t ha⁻¹ recorded significantly higher N content over control. N Uptake in straw ranged from 137.00 to 201.51 mg pot⁻¹ with the application of different types and levels of biochar. Significantly higher N uptake was observed with the application of RHB @ 16 t ha⁻¹ (201.51 mg pot⁻¹) which was found to be on par with RHB @ 8 t ha⁻¹ (192.27 mg pot⁻¹) compared to control (137.00 mg pot⁻¹).

Higher N content of 0.91 per cent in straw was recorded in neutral soil with application of RHB than WB and BB. Application level of 4 t ha⁻¹ recorded higher N content (0.90 %) in straw than other levels. The N content as influenced by different sources and levels of biochar application ranged from 0.83 to 0.93 per cent. Higher N content in straw was observed with application of RHB @ 4 t ha⁻¹ and lower with WB @ 16 t ha⁻¹. Of different types and rates, significantly higher N uptake by straw was observed with RHB (158.20 mg pot⁻¹) and application rate of 4 t ha⁻¹ (156.26 mg pot⁻¹). The treatment RHB @ 4 t ha⁻¹ (168.51 mg pot⁻¹) and control (118.51 mg pot⁻¹) recorded correspondingly higher and lower N uptake.

There was a significant effect on N content of straw with the application of different sources of biochar in alkaline soil. Application of RHB recorded lower N content (0.79 %) in straw than other two sources. Of all the treatment combinations, application of both BB and RHB @ 4 t ha⁻¹ recorded the highest straw N content (0.85 %) and the lowest with RHB @ 16 t ha⁻¹ (0.72 %). Among different sources and levels, higher N uptake by straw was recorded with the application of WB (30.9 mg pot⁻¹) and @ 4 t ha⁻¹ (33.64 mg pot⁻¹) compared to other sources and levels. Significantly higher N uptake by straw was noticed with application of WB @ 4 t ha⁻¹ (40.43 mg pot⁻¹) compared to other treatment combinations.

In general, application of higher rates (16 t ha⁻¹) of both WB and BB reduced N content and uptake in straw in all the studied soils.

4.3.4.2 Phosphorus content and uptake

Data pertaining to effect of various types and rates of biochar application in different soils on phosphorus content and uptake by straw are presented in Table 30 and 31 respectively.

Table 30: Effect of different sources and levels of biochar application on N, P and K content (%) in rice straw in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	N	P	K	N	P	K	N	P	K
Sources* of biochar									
WB	0.91	0.14	1.08	0.85	0.21	1.07	0.82	0.19	0.71
BB	0.91	0.15	1.08	0.90	0.19	1.04	0.83	0.19	0.67
RHB	0.98	0.15	1.05	0.91	0.23	1.06	0.79	0.20	0.68
SEm±	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
CD at 0.05	0.03	0.01	NS	0.01	0.01	0.02	0.01	NS	0.03
Levels of biochar									
2 t ha ⁻¹	0.93	0.13	1.04	0.89	0.21	1.03	0.83	0.20	0.64
4 t ha ⁻¹	1.00	0.15	1.07	0.90	0.21	1.04	0.84	0.20	0.65
8 t ha ⁻¹	0.94	0.15	1.01	0.88	0.21	1.08	0.81	0.18	0.67
16 t ha ⁻¹	0.89	0.15	1.15	0.87	0.22	1.07	0.76	0.19	0.78
SEm±	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01
CD at 0.05	0.03	0.01	0.03	0.02	NS	0.02	0.02	0.01	0.04
Interaction									
Control	0.87	0.13	0.91	0.84	0.22	1.03	0.79	0.19	0.67
WB @ 2 t ha ⁻¹	0.95	0.13	1.07	0.86	0.22	1.06	0.82	0.21	0.63
WB @ 4 t ha ⁻¹	0.95	0.14	1.09	0.87	0.22	1.06	0.84	0.19	0.67
WB @ 8 t ha ⁻¹	0.93	0.15	0.99	0.85	0.20	1.11	0.84	0.18	0.70
WB @ 16 t ha ⁻¹	0.83	0.13	1.15	0.83	0.20	1.05	0.77	0.19	0.84
BB @ 2 t ha ⁻¹	0.91	0.13	1.02	0.90	0.18	1.06	0.83	0.18	0.67
BB @ 4 t ha ⁻¹	1.01	0.15	1.10	0.91	0.19	1.01	0.85	0.20	0.65
BB @ 8 t ha ⁻¹	0.90	0.15	1.05	0.90	0.20	1.04	0.83	0.20	0.64
BB @ 16 t ha ⁻¹	0.84	0.16	1.13	0.88	0.20	1.05	0.79	0.19	0.72
RHB @ 2 t ha ⁻¹	0.92	0.13	1.04	0.92	0.24	0.99	0.84	0.21	0.62
RHB @ 4 t ha ⁻¹	1.04	0.15	1.00	0.93	0.23	1.06	0.85	0.21	0.64
RHB @ 8 t ha ⁻¹	0.99	0.15	1.00	0.89	0.21	1.09	0.76	0.18	0.67
RHB @ 16 t ha ⁻¹	0.99	0.16	1.16	0.89	0.25	1.11	0.72	0.19	0.79
SEm±	0.02	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.02
CD at 0.05	0.06	0.01	0.06	0.03	0.02	0.04	0.03	0.02	NS

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 31: Effect of different sources and levels of biochar application on N, P, K uptake (mg pot⁻¹) by rice straw in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	N	P	K	N	P	K	N	P	K
Sources* of biochar									
WB	165.59	24.62	194.34	135.99	33.40	170.01	30.91	7.28	26.13
BB	161.68	26.58	190.47	136.36	29.26	157.76	30.54	7.01	24.52
RHB	186.12	28.43	199.09	158.20	40.65	185.28	20.13	4.96	17.00
SEm±	2.36	0.53	1.93	1.43	0.47	1.77	0.36	0.12	0.46
CD at 0.05	6.84	1.53	5.60	4.14	1.36	5.12	1.05	0.35	1.34
Levels of biochar									
2 t ha ⁻¹	161.22	22.97	181.40	141.87	33.99	164.63	30.05	7.12	23.28
4 t ha ⁻¹	181.80	26.64	194.45	156.26	36.59	180.05	33.64	7.89	26.14
8 t ha ⁻¹	178.82	28.89	192.96	140.01	32.83	171.69	25.90	5.86	21.26
16 t ha ⁻¹	162.69	27.66	209.74	135.92	34.34	167.70	19.17	4.80	19.52
SEm±	2.73	0.61	2.23	1.65	0.54	2.04	0.42	0.14	0.53
CD at 0.05	7.90	1.77	6.47	4.78	1.58	5.92	1.21	0.40	1.55
Interaction									
Control	137.00	20.62	142.98	118.51	31.17	145.65	24.51	6.00	20.66
WB @ 2 t ha ⁻¹	163.33	22.68	182.78	137.70	34.72	169.86	36.50	9.17	28.09
WB @ 4 t ha ⁻¹	178.66	25.68	206.07	151.16	37.75	182.68	40.43	9.37	32.36
WB @ 8 t ha ⁻¹	176.40	27.70	188.70	130.25	31.17	169.69	26.40	5.52	21.87
WB @ 16 t ha ⁻¹	143.98	22.42	199.82	124.84	29.96	157.82	20.32	5.07	22.21
BB @ 2 t ha ⁻¹	157.68	23.33	176.49	139.44	28.20	164.78	33.03	6.96	26.52
BB @ 4 t ha ⁻¹	178.68	26.62	195.75	149.11	30.97	164.98	35.28	8.20	27.00
BB @ 8 t ha ⁻¹	167.79	28.88	196.55	131.84	29.42	152.03	30.83	7.28	23.76
BB @ 16 t ha ⁻¹	142.59	27.48	193.11	125.05	28.45	149.24	23.01	5.59	20.80
RHB @ 2 t ha ⁻¹	162.66	22.91	184.52	148.47	39.07	159.25	20.64	5.24	15.22
RHB @ 4 t ha ⁻¹	188.05	27.62	181.52	168.51	41.07	192.50	25.22	6.09	19.06
RHB @ 8 t ha ⁻¹	192.27	30.10	193.63	157.94	37.88	193.34	20.47	4.77	18.16
RHB @ 16 t ha ⁻¹	201.51	33.10	236.29	157.86	44.60	196.04	14.18	3.73	15.55
SEm±	4.72	1.06	3.87	2.85	0.94	3.54	0.72	0.24	0.92
CD at 0.05	13.68	3.07	11.21	8.28	2.73	10.25	2.10	0.69	2.68

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

In acidic soil, P content of 0.14, 0.15 and 0.15 per cent in straw were recorded with application of WB, BB and RHB respectively. Application rate of 2 t ha⁻¹ recorded significantly lower P content (0.13 %) than other levels of application. Addition of various types and levels of biochar recorded significantly higher P content in straw than control (0.13 %). Higher P content of 0.16 per cent in straw was observed with application of both BB and RHB applied @ 16 t ha⁻¹. Significantly higher straw P uptake (28.43 mg pot⁻¹) was recorded with the application of RHB than other two sources. Application of RHB @ 16 t ha⁻¹ recorded the highest P uptake by straw (33.10 mg pot⁻¹) and the lowest in control (20.62 mg pot⁻¹).

Significantly higher P content of 0.23 per cent in straw was noticed in neutral soil with application of RHB in neutral soil. But application of different levels of biochar did not vary the P content in straw significantly. The P content of straw with the application of various types and levels of biochar ranged from 0.18 to 0.25 per cent. Application of RHB @ 16 t ha⁻¹ recorded higher P content (0.25 %) and application of BB @ 2 t ha⁻¹ recorded lower P content (0.18 %) in straw. Significantly higher P uptake by straw was observed with application of RHB (40.65 mg pot⁻¹) and application level of 4 t ha⁻¹ (36.59 mg pot⁻¹) than other sources and levels. Application of different sources and levels of biochar varied the P uptake by straw from 28.20 to 44.60 mg pot⁻¹. Higher P uptake was noticed in treatment receiving RHB @ 16 t ha⁻¹ and lower in BB @ 2 t ha⁻¹.

Application of different sources of biochar in alkaline soil recorded a non significant effect on P content in straw. However different rates of biochar application had a significant effect on P content in straw. The P content in straw ranged from 0.18 to 0.21 per cent in different treatments. Among different biochar types used, higher P uptake of 7.28 mg pot⁻¹ was observed with application of WB. Among the different treatment combinations, application of WB @ 4 t ha⁻¹ recorded significantly higher straw P uptake (9.37 mg pot⁻¹) and found to be on par with treatment WB @ 2 t ha⁻¹ (9.17 mg pot⁻¹).

4.3.4.3 Potassium content and uptake

Results of effect of different sources and levels of biochar application on K content and uptake by straw in different soils are presented in Table 30 and 31 respectively.

In acidic soil, application of different sources of biochar had a non significant effect on K content of straw. However, significant differences were observed at different rates of application. Significantly higher K content (1.15 %) in straw was noticed at application rate of 16 t ha⁻¹. Independent of type and level, biochar application significantly increased K content in straw over control (0.91 %). Significantly higher K content (1.16 %) in straw was noticed with application of RHB @ 16 t ha⁻¹. The K uptake of 194.34, 190.47 and 199.09 mg pot⁻¹ by straw was recorded with application of WB, BB and RHB respectively. K uptake by straw increased with increased level of biochar application. Application rate of 16 t ha⁻¹ recorded significantly higher K uptake by straw (209.74 mg pot⁻¹). Among the different treatments, application of RHB @ 16 t

ha⁻¹ (236.29 mg pot⁻¹) recorded significantly highest K uptake followed by WB @ 4 t ha⁻¹ (206.07 mg pot⁻¹) and least in control (142.98 mg pot⁻¹).

The K content and uptake by straw in neutral soil differed significantly with application of different sources and levels of biochar. Among different sources, WB recorded significantly higher K content in straw (1.07 %). Irrespective of type of biochar, application rate of 8 t ha⁻¹ recorded higher K content in straw (1.08 %). Significantly higher K content of 1.11 % was observed with application of both WB @ 8 t ha⁻¹ and RHB @ 16 t ha⁻¹ in comparison to control (1.03 %). K uptake by straw followed decreasing order of RHB (185.28 mg pot⁻¹) > WB (170 mg pot⁻¹) > BB (157.76 mg pot⁻¹). Application level of 4 t ha⁻¹ (180.05 mg pot⁻¹) recorded significantly higher K uptake by straw than other levels. Application of all biochar and at all levels significantly increased K uptake by straw over control (145.65 mg pot⁻¹) and higher K uptake (196.04 mg pot⁻¹) by straw was recorded with the application of RHB @ 16 t ha⁻¹.

In alkaline soil, application of WB, BB and RHB recorded K content of 0.71, 0.67 and 0.68 per cent in straw respectively. Independent of type of biochar, K content of straw increased with increased level of biochar application. Significantly higher K content in straw was observed with an application rate of 16 t ha⁻¹ (0.78 %). Though application of different types and levels of biochar recorded a non significant effect on K content in straw, the highest K content in straw was noticed in treatment WB @ 16 t ha⁻¹ (0.84 %) and lowest in RHB @ 2 t ha⁻¹ (0.62 %). Among different sources and levels, WB (26.13 mg pot⁻¹) and @ 4 t ha⁻¹ (26.14 mg pot⁻¹) recorded significantly higher K uptake by straw than other sources and levels. The changes in K uptake by straw as influenced by different sources and levels of biochar application varied from 15.55 to 32.36 mg pot⁻¹. Application of WB @ 4 t ha⁻¹ and RHB @ 16 t ha⁻¹ recorded significantly highest and lowest K uptake by straw respectively.

4.3.4.4 Calcium content and uptake

Perusal of data presented in Table 32 and 33 revealed significant effect of sources and levels of biochar application on Ca content and uptake respectively in different soils.

Application of BB (0.55 %) recorded significantly lower Ca content in straw in acidic soil than WB (0.57 %) and RHB (0.57 %). Irrespective of type of biochar, increased rate of application increased Ca content in straw. Application of different combination of sources and levels of biochar significantly increased the Ca content in straw over control (0.42 %). Significantly higher Ca content of 0.63 % in straw was observed with application of both WB @ 8 and 16 t ha⁻¹. Application of different biochar influenced Ca uptake by straw following a decreasing order of RHB (106.69 mg pot⁻¹) > WB (103.71 mg pot⁻¹) > BB (97.64 mg pot⁻¹). Among the different rates of application, 8 t ha⁻¹ recorded significantly higher Ca uptake (110.34 mg pot⁻¹) by straw. Differences in Ca uptake by straw as result of addition of different sources and levels of biochar ranged from 65.31 to 120.42 mg pot⁻¹ recording significantly highest uptake in treatment WB @ 8 t ha⁻¹ (120.42 mg pot⁻¹) and significantly lowest in control (65.31 mg pot⁻¹).

Table 32: Effect of different sources and levels of biochar application on Ca, Mg and S content (%) of rice straw in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
Sources* of biochar									
WB	0.57	0.34	0.13	0.59	0.36	0.14	0.76	0.40	0.14
BB	0.55	0.34	0.14	0.59	0.39	0.12	0.71	0.34	0.17
RHB	0.57	0.34	0.14	0.60	0.42	0.17	0.65	0.37	0.16
SEm±	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00
CD at 0.05	0.01	NS	0.01	0.01	0.01	0.01	0.03	0.01	0.01
Levels of biochar									
2 t ha ⁻¹	0.54	0.32	0.13	0.57	0.42	0.15	0.73	0.41	0.15
4 t ha ⁻¹	0.55	0.36	0.14	0.60	0.40	0.15	0.70	0.37	0.17
8 t ha ⁻¹	0.58	0.35	0.14	0.58	0.38	0.14	0.71	0.35	0.17
16 t ha ⁻¹	0.58	0.32	0.14	0.61	0.37	0.15	0.69	0.34	0.14
SEm±	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00
CD at 0.05	0.01	0.02	0.01	0.02	0.01	0.01	NS	0.02	0.01
Interaction									
Control	0.42	0.40	0.10	0.50	0.33	0.14	0.73	0.46	0.13
WB @ 2 t ha ⁻¹	0.49	0.35	0.14	0.59	0.41	0.14	0.72	0.49	0.15
WB @ 4 t ha ⁻¹	0.54	0.35	0.14	0.58	0.38	0.14	0.71	0.42	0.17
WB @ 8 t ha ⁻¹	0.63	0.32	0.13	0.56	0.32	0.13	0.82	0.37	0.13
WB @ 16 t ha ⁻¹	0.63	0.32	0.13	0.61	0.34	0.14	0.79	0.32	0.12
BB @ 2 t ha ⁻¹	0.55	0.31	0.12	0.58	0.42	0.14	0.75	0.33	0.17
BB @ 4 t ha ⁻¹	0.54	0.37	0.15	0.58	0.40	0.13	0.74	0.35	0.18
BB @ 8 t ha ⁻¹	0.54	0.38	0.15	0.58	0.41	0.10	0.73	0.33	0.20
BB @ 16 t ha ⁻¹	0.58	0.30	0.14	0.63	0.33	0.12	0.64	0.33	0.14
RHB @ 2 t ha ⁻¹	0.58	0.32	0.13	0.54	0.43	0.17	0.72	0.41	0.13
RHB @ 4 t ha ⁻¹	0.58	0.35	0.15	0.64	0.41	0.17	0.66	0.36	0.17
RHB @ 8 t ha ⁻¹	0.56	0.35	0.15	0.61	0.39	0.18	0.59	0.35	0.17
RHB @ 16 t ha ⁻¹	0.54	0.34	0.15	0.60	0.43	0.19	0.65	0.36	0.17
SEm±	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.01	0.01
CD at 0.05	0.03	0.04	0.01	0.03	0.02	0.01	0.06	0.03	0.02

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 33: Effect of different sources and levels of biochar application on Ca, Mg and S uptake (mg pot⁻¹) by rice straw in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
Sources* of biochar									
WB	103.71	60.83	24.18	93.14	57.91	21.68	28.15	15.53	5.51
BB	97.64	60.14	24.61	89.70	59.94	18.71	26.52	12.37	6.36
RHB	106.69	63.89	27.26	104.45	72.23	30.41	16.52	9.26	3.98
SEm±	1.10	1.17	0.44	1.13	0.65	0.37	0.41	0.21	0.11
CD at 0.05	3.18	NS	1.29	3.27	1.88	1.08	1.20	0.60	0.31
Levels of biochar									
2 t ha ⁻¹	93.91	56.52	22.70	91.08	67.29	23.33	26.43	14.94	5.59
4 t ha ⁻¹	100.46	65.00	26.33	103.64	68.61	25.66	28.24	15.07	6.74
8 t ha ⁻¹	110.34	66.27	27.47	92.15	59.62	21.89	22.89	11.10	5.33
16 t ha ⁻¹	106.01	58.69	24.88	96.19	57.91	23.53	17.36	8.43	3.49
SEm±	1.27	1.35	0.51	1.30	0.75	0.43	0.48	0.24	0.12
CD at 0.05	3.67	3.91	1.48	3.77	2.17	1.24	1.38	0.69	0.35
Interaction									
Control	65.31	62.75	16.38	70.74	47.29	19.30	22.67	14.38	4.18
WB @ 2 t ha ⁻¹	83.47	60.30	23.33	95.08	66.77	21.77	32.00	21.84	6.80
WB @ 4 t ha ⁻¹	101.25	66.53	26.05	100.88	65.68	24.49	34.18	20.23	7.98
WB @ 8 t ha ⁻¹	120.42	61.03	25.57	84.78	48.26	19.84	25.66	11.58	4.10
WB @ 16 t ha ⁻¹	109.69	55.45	21.75	91.84	50.93	20.62	20.75	8.49	3.17
BB @ 2 t ha ⁻¹	95.51	53.06	21.08	90.30	65.75	21.27	29.59	12.99	6.69
BB @ 4 t ha ⁻¹	95.58	65.50	26.20	94.56	65.75	21.92	30.86	14.42	7.29
BB @ 8 t ha ⁻¹	101.10	70.27	27.95	84.57	60.86	14.77	27.10	12.36	7.44
BB @ 16 t ha ⁻¹	98.37	51.74	23.20	89.38	47.41	16.89	18.54	9.69	4.01
RHB @ 2 t ha ⁻¹	102.73	56.19	23.69	87.85	69.35	26.95	17.69	10.00	3.27
RHB @ 4 t ha ⁻¹	104.54	62.96	26.74	115.50	74.41	30.57	19.67	10.56	4.95
RHB @ 8 t ha ⁻¹	109.50	67.51	28.91	107.10	69.75	31.04	15.92	9.36	4.45
RHB @ 16 t ha ⁻¹	109.97	68.90	29.68	107.35	75.40	33.07	12.79	7.11	3.27
SEm±	2.19	2.34	0.89	2.25	1.30	0.74	0.82	0.41	0.21
CD at 0.05	6.35	6.77	2.57	6.53	3.76	2.15	2.39	1.20	0.61

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

In neutral soil, irrespective of levels of biochar, RHB recorded higher Ca (0.60 %) content and uptake ($104.45 \text{ mg pot}^{-1}$) in straw. Among different levels, application of 16 t ha^{-1} recorded higher Ca content (0.61 %). Independent of sources and levels, Ca content in straw significantly increased with application of biochar over control (0.50 %). Highest Ca content in straw was observed with application of RHB @ 4 t ha^{-1} (0.64 %). Among different rates of application, significantly higher Ca uptake ($103.64 \text{ mg pot}^{-1}$) by straw was observed @ 4 t ha^{-1} . The highest Ca uptake by straw was observed in treatment receiving RHB @ 4 t ha^{-1} ($115.50 \text{ mg pot}^{-1}$) and lowest in control ($70.74 \text{ mg pot}^{-1}$).

In alkaline soil, significantly higher Ca content in straw was recorded by WB (0.76 %) application than BB (0.71%) and RHB (0.65%). However, application levels had a non significant effect on Ca content in straw. Among the different treatment combinations, highest Ca content in straw was recorded with application of WB @ 8 t ha^{-1} (0.82 %) and lowest with RHB @ 8 t ha^{-1} (0.59 %). Different sources of biochar addition significantly varied straw Ca uptake and followed an order of RHB ($16.52 \text{ mg pot}^{-1}$) < BB ($26.52 \text{ mg pot}^{-1}$) < WB ($28.15 \text{ mg pot}^{-1}$). Application level of 4 t ha^{-1} recorded significantly higher Ca uptake ($28.24 \text{ mg pot}^{-1}$) by straw than other levels. Of all treatment combinations, highest Ca uptake by straw was observed with application of WB @ 4 t ha^{-1} ($34.18 \text{ mg pot}^{-1}$) and lowest with RHB @ 16 t ha^{-1} ($12.79 \text{ mg pot}^{-1}$).

4.3.4.5 Magnesium content and uptake

Effect of different sources and levels of biochar application in different soils on Mg content and uptake by straw are presented in Table 32 and 33 respectively.

In acidic soil, application of various types of biochar had a non significant effect on Mg content and uptake by straw. However application level had a significant effect on Mg content in straw. Application level of 4 t ha^{-1} recorded highest Mg content (0.36 %) in straw than other levels. Addition of biochar reduced the Mg content in straw when compared to control treatment. Mg content of straw varied from 0.30 to 0.40 per cent in different treatments. Highest Mg content in straw was observed in control and lower in BB @ 16 t ha^{-1} . Application rate of 8 t ha^{-1} ($66.27 \text{ mg pot}^{-1}$) recorded significantly higher Mg uptake than other rates. Among different treatment combinations, treatment receiving BB @ 8 t ha^{-1} ($70.27 \text{ mg pot}^{-1}$) recorded higher Mg uptake by straw and lower with BB @ 16 t ha^{-1} ($51.74 \text{ mg pot}^{-1}$).

The Mg content in straw differed significantly in neutral soil with the application of different sources and levels of biochar. Mg content in straw as influenced by different types of biochar followed an increasing order of WB (0.36 %) < BB (0.39 %) < RHB (0.42 %). Irrespective of type of biochar, increased rate of application significantly decreased Mg content and uptake by straw. The Mg content in straw ranged from 0.32 to 0.43 per cent in different treatments. Highest Mg content in straw was observed with application of both RHB @ 2 and 16 t ha^{-1} and lowest with WB @ 8 t ha^{-1} . Among different sources, significantly higher Mg uptake by straw was noticed with application of RHB ($72.23 \text{ mg pot}^{-1}$) in comparison to BB ($59.94 \text{ mg pot}^{-1}$) and WB ($57.91 \text{ mg pot}^{-1}$). Treatment receiving RHB @ 16 t ha^{-1} recorded significantly higher Mg uptake ($75.40 \text{ mg pot}^{-1}$) by straw over control ($47.29 \text{ mg pot}^{-1}$).

Application of WB recorded significantly higher Mg content (0.40 %) and uptake (15.53 mg pot⁻¹) by straw in alkaline soil. Irrespective of type of biochar, increased level of biochar application decreased the Mg content and uptake by straw. Application of WB @ 2 t ha⁻¹ (0.49 %) and WB @ 16 t ha⁻¹ (0.32 %) recorded significantly highest and lowest Mg content in straw respectively. The straw Mg uptake varied from 7.11 to 21.84 mg pot⁻¹ in different treatments recording higher uptake in WB @ 2 t ha⁻¹ and lower in RHB @ 16 t ha⁻¹.

Among different rates of biochar, 16 t ha⁻¹ application rate decreased Mg content and uptake by straw in all studied soil.

4.3.4.6 Sulphur content and uptake

Perusal of data presented in Table 32 and 33 revealed significant effect of different sources and levels of biochar application on sulphur content and uptake in straw respectively in different soils.

Application of RHB in acidic soil recorded the highest S content (0.14 %) and uptake (27.26 mg pot⁻¹) by straw than other sources of biochar. Application level of 2 t ha⁻¹ recorded significantly lower S content (0.13 %) and uptake (22.70 mg pot⁻¹) by straw than other levels. Application of all sources and levels of biochar significantly increased S content in straw over control (0.10 %). In different treatments, S content in straw varied from 0.10 to 0.15 per cent. Application of RHB @ 16 t ha⁻¹ (29.68 mg pot⁻¹) recorded significantly higher S uptake by straw and lower in control (16.38 mg pot⁻¹).

In neutral soil, S content in straw differed significantly with the application of different source of biochar and followed an increasing order of BB (0.12 %) < WB (0.14 %) < RHB (0.17 %). The S content in straw varied from 0.10 to 0.19 per cent as influenced by different types and levels of biochar application. Significantly highest S content in straw was observed in the treatment receiving RHB @ 16 t ha⁻¹ (0.19 %) and was found to be on par with treatment RHB @ 8 t ha⁻¹ (0.18 %) and lowest in BB @ 8 t ha⁻¹ (0.10 %). Among different sources and levels, significantly highest S uptake by straw was noticed with application of RHB (30.41 mg pot⁻¹) and @ rate of 4 t ha⁻¹ (25.66 mg pot⁻¹). S uptake by straw in different treatments differed significantly, recording highest uptake with application of RHB @ 16 t ha⁻¹ (33.07 mg pot⁻¹) and lowest with BB @ 8 t ha⁻¹ (14.77 mg pot⁻¹).

In case of alkaline soil, the S content in straw with the application of different types of biochar followed a decreasing order of BB (0.17 %) < RHB (0.16 %) < WB (0.14 %). Though graded level of biochar application varied S content significantly no definite pattern was observed with application rates. Addition of different kinds and rates of biochar varied the S content in straw from 0.12 to 0.20 per cent. Of all the treatment combinations, application of BB @ 8 t ha⁻¹ and WB @ 16 t ha⁻¹ correspondingly recorded highest and lowest S content in straw. Among the different sources, significantly higher S uptake by straw was observed with application of BB (6.36 mg pot⁻¹) and significantly lower with RHB (3.98 mg pot⁻¹). Significantly higher S uptake by straw was noticed at application rate of 4 t ha⁻¹ (6.74 mg pot⁻¹) than other levels. Highest uptake of S by straw

was observed with application of WB @ 4 t ha⁻¹ (7.98 mg pot⁻¹) and lowest with WB @ 16 t ha⁻¹ (4.10 mg pot⁻¹).

4.3.4.7 Zinc content and uptake

Influence of different sources and levels of biochar application on Zn content and uptake by straw in different soils are presented in Table 34 and 35 respectively.

In acidic soil, with application of different sources of biochar the Zn content of straw followed a descending order of BB (93.69 mg kg⁻¹) > WB (90.94 mg kg⁻¹) > RHB (85.72 mg kg⁻¹). Among different rates, application of 16 t ha⁻¹ recorded significantly lower Zn content (86.56 mg kg⁻¹) in straw. The highest Zn content in straw was observed with application of WB @ 2 t ha⁻¹ (99.78 mg kg⁻¹) and lowest with WB @ 16 t ha⁻¹ (81.56 mg kg⁻¹). Application of different sources of biochar had a non significant effect on Zn uptake by straw. Whereas graded levels of biochar application differed Zn uptake by straw significantly. Higher Zn uptake by straw was observed at application rate of 8 t ha⁻¹ (1.72 mg pot⁻¹) and lower at 16 t ha⁻¹ (1.57 mg pot⁻¹). The highest Zn uptake (1.75 mg pot⁻¹) by straw was noticed with the application of both WB and BB @ 8 t ha⁻¹ and lowest with control (1.40 mg pot⁻¹).

Significantly lower Zn content (49.83 mg kg⁻¹) and uptake (0.80 mg pot⁻¹) in straw was recorded with application WB in neutral soil. Irrespective of types of biochar, increased level of application decreased the Zn content and uptake by straw. The lowest Zn (39.78 mg kg⁻¹) content of straw was observed with application of WB @ 16 t ha⁻¹ and the highest (62.89 mg kg⁻¹) with application of BB @ 4 t ha⁻¹. The change in Zn uptake by straw varied from 0.60 to 1.11 mg pot⁻¹ in different treatments. Highest Zn uptake in straw was observed in the treatment RHB @ 16 t ha⁻¹ and lowest in WB @ 16 t ha⁻¹.

In alkaline soil, application of RHB recorded significantly lowest Zn content (13.29 mg kg⁻¹) in straw and uptake (0.03 mg pot⁻¹). Significantly higher Zn content of 18.44 mg kg⁻¹ in straw was observed with application of both WB and BB @ 4 t ha⁻¹. Application of RHB @ 16 t ha⁻¹ recorded significantly lower straw Zn content (12.11 mg kg⁻¹). Application of different sources and levels of biochar varied straw Zn uptake from 0.02 to 0.09 mg pot⁻¹. Higher Zn uptake by straw was noticed in the treatment receiving WB @ 4 t ha⁻¹ and lower in RHB @ 16 t ha⁻¹.

4.3.4.8 Iron content and uptake

Effect of different sources and levels of biochar application on iron content and uptake in different soils are presented in Table 34 and 35 respectively.

In acidic soil, independent of types and levels, biochar application reduced Fe content in straw in comparison to control (330.78 mg kg⁻¹). Different treatments recorded Fe content in straw ranging from 220.00 to 330.78 mg kg⁻¹. Lowest Fe content in straw was recorded with application of WB @ 4 t ha⁻¹. Irrespective of types of biochar, increased application rate increased Fe uptake by straw recoding significantly highest at application rate of 16 t ha⁻¹ (5.10 mg pot⁻¹). Among different treatments, application of

Table 34: Effect of different sources and levels of biochar application on Zn, Fe, Mn and Cu content (mg pot⁻¹) in rice straw in acidic, neutral and alkaline soils

	Acidic soil				Neutral soil				Alkaline soil			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
Sources* of biochar												
WB	90.94	265.89	553.06	19.11	49.83	97.69	1317.64	27.72	16.42	93.97	179.64	25.89
BB	93.69	270.75	755.25	26.25	56.00	101.58	1413.64	27.78	16.50	63.69	182.25	28.28
RHB	85.72	262.83	863.75	27.03	56.22	73.17	1480.50	29.83	13.29	71.81	162.81	23.86
SEm±	0.95	4.48	10.11	0.41	0.82	1.13	16.29	0.63	0.19	1.15	1.69	0.35
CD at 0.05	2.74	NS	29.30	1.19	2.38	3.29	47.22	1.81	0.55	3.35	4.90	1.01
Levels of biochar												
2 t ha ⁻¹	90.70	283.74	831.11	22.37	56.70	77.89	1462.70	28.93	15.67	87.22	171.96	27.00
4 t ha ⁻¹	93.00	249.41	819.19	23.85	56.19	108.04	1467.04	28.22	16.48	89.63	170.85	26.07
8 t ha ⁻¹	90.22	249.48	694.26	24.63	52.44	99.22	1484.26	28.63	15.54	76.67	184.11	26.04
16 t ha ⁻¹	86.56	283.33	551.52	25.67	50.74	78.11	1201.89	28.00	13.93	52.44	172.67	24.93
SEm±	1.09	5.18	11.67	0.47	0.95	1.31	18.81	0.72	0.22	1.33	1.95	0.40
CD at 0.05	3.17	15.00	33.83	1.38	2.75	3.80	54.52	NS	0.64	3.86	5.65	1.16
Interaction												
Control	89.11	330.78	1255.67	23.11	57.33	58.33	1517.33	27.44	14.89	92.11	170.33	29.67
WB @ 2 t ha ⁻¹	99.78	285.00	781.67	19.44	60.78	82.33	1443.11	28.67	16.11	104.67	150.00	28.33
WB @ 4 t ha ⁻¹	90.67	220.00	717.33	20.67	56.00	109.33	1412.89	27.67	18.44	110.00	172.89	27.78
WB @ 8 t ha ⁻¹	91.78	250.78	523.22	19.78	42.78	101.67	1473.33	27.11	15.89	100.00	215.22	23.78
WB @ 16 t ha ⁻¹	81.56	307.78	190.00	16.56	39.78	97.44	941.78	27.44	15.22	61.22	180.44	23.67
BB @ 2 t ha ⁻¹	89.22	274.44	843.33	22.11	58.44	89.89	1511.67	26.67	15.78	80.22	191.56	26.67
BB @ 4 t ha ⁻¹	95.78	249.56	781.22	24.22	62.89	122.11	1412.33	28.22	18.44	73.56	161.22	27.44
BB @ 8 t ha ⁻¹	93.78	238.78	730.44	27.67	52.67	108.89	1504.22	28.44	17.33	56.78	187.33	31.00
BB @ 16 t ha ⁻¹	96.00	320.22	666.00	31.00	50.00	85.44	1226.33	27.78	14.44	44.22	188.89	28.00
RHB @ 2 t ha ⁻¹	83.11	291.78	868.33	25.56	50.89	61.44	1433.33	31.44	15.11	76.78	174.33	26.00
RHB @ 4 t ha ⁻¹	92.56	278.67	959.00	26.67	49.67	92.67	1575.89	28.78	12.56	85.33	178.44	23.00
RHB @ 8 t ha ⁻¹	85.11	258.89	829.11	26.44	61.89	87.11	1475.22	30.33	13.39	73.22	149.78	23.33
RHB @ 16 t ha ⁻¹	82.11	222.00	798.56	29.44	62.44	51.44	1437.56	28.78	12.11	51.89	148.67	23.11
SEm±	1.89	8.96	20.21	0.82	1.64	2.27	32.57	1.25	0.38	2.31	3.38	0.69
CD at 0.05	5.49	25.99	58.60	2.38	4.77	6.58	94.43	NS	1.11	6.69	9.79	2.01

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 35: Effect of different sources and levels of biochar application on Zn, Fe, Mn and Cu uptake (mg pot⁻¹) by rice straw in acidic, neutral and alkaline soil

Sources* of biochar	Acidic soil				Neutral soil				Alkaline soil			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
WB	1.65	4.64	10.05	0.35	0.80	1.56	22.34	0.44	0.063	0.367	0.663	0.099
BB	1.66	4.77	13.34	0.46	0.86	1.55	21.55	0.42	0.061	0.241	0.668	0.104
RHB	1.62	4.95	16.29	0.51	0.98	1.28	25.81	0.52	0.034	0.186	0.414	0.060
SEm±	0.02	0.11	0.25	0.01	0.02	0.02	0.35	0.01	0.001	0.005	0.009	0.002
CD at 0.05	NS	NS	0.72	0.03	0.05	0.05	1.02	0.03	0.002	0.014	0.025	0.005
Levels of biochar												
2 t ha ⁻¹	1.58	4.75	14.46	0.39	0.90	1.24	24.98	0.46	0.057	0.324	0.618	0.099
4 t ha ⁻¹	1.69	4.54	14.92	0.43	0.97	1.86	25.37	0.49	0.068	0.364	0.679	0.106
8 t ha ⁻¹	1.72	4.76	13.24	0.47	0.84	1.56	23.56	0.46	0.050	0.240	0.590	0.084
16 t ha ⁻¹	1.57	5.10	10.28	0.47	0.81	1.20	19.02	0.44	0.035	0.131	0.439	0.063
SEm±	0.02	0.13	0.29	0.01	0.02	0.02	0.41	0.01	0.001	0.006	0.010	0.002
CD at 0.05	0.07	0.38	0.83	0.03	0.05	0.06	1.17	NS	0.003	0.016	0.029	0.006
Interaction												
Control	1.40	5.21	19.76	0.36	0.81	0.83	21.51	0.39	0.046	0.286	0.528	0.092
WB @ 2 t ha ⁻¹	1.71	4.30	13.40	0.33	0.98	1.32	28.32	0.46	0.071	0.464	0.665	0.126
WB @ 4 t ha ⁻¹	1.71	4.14	13.53	0.39	0.97	1.89	24.45	0.48	0.089	0.532	0.835	0.134
WB @ 8 t ha ⁻¹	1.75	4.78	9.97	0.38	0.65	1.55	22.48	0.41	0.050	0.313	0.674	0.075
WB @ 16 t ha ⁻¹	1.41	5.33	3.30	0.29	0.60	1.46	14.12	0.41	0.040	0.161	0.476	0.062
BB @ 2 t ha ⁻¹	1.54	4.75	14.58	0.38	0.91	1.40	23.50	0.42	0.063	0.318	0.760	0.106
BB @ 4 t ha ⁻¹	1.70	4.41	13.83	0.43	1.03	2.00	23.15	0.46	0.077	0.306	0.672	0.114
BB @ 8 t ha ⁻¹	1.75	4.45	13.63	0.52	0.77	1.60	22.10	0.42	0.064	0.210	0.693	0.115
BB @ 16 t ha ⁻¹	1.63	5.45	11.34	0.53	0.71	1.22	17.45	0.40	0.042	0.128	0.548	0.081
RHB @ 2 t ha ⁻¹	1.48	5.18	15.42	0.45	0.82	0.99	23.13	0.51	0.037	0.189	0.430	0.064
RHB @ 4 t ha ⁻¹	1.68	5.06	17.41	0.48	0.90	1.68	28.52	0.52	0.037	0.253	0.529	0.068
RHB @ 8 t ha ⁻¹	1.65	5.04	16.13	0.51	1.09	1.54	26.09	0.54	0.036	0.198	0.404	0.063
RHB @ 16 t ha ⁻¹	1.67	4.50	16.19	0.60	1.11	0.91	25.50	0.51	0.024	0.102	0.293	0.045
SEm±	0.04	0.23	0.50	0.02	0.03	0.04	0.70	0.02	0.002	0.010	0.017	0.003
CD at 0.05	0.13	0.66	1.44	0.05	0.09	0.11	2.04	0.06	0.005	0.028	0.050	0.010

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

BB @ 16 t ha⁻¹ recorded higher Fe uptake (5.45 mg pot⁻¹) by straw and lower (4.14 mg pot⁻¹) with WB @ 4 t ha⁻¹.

Application of RHB recorded significantly lower Fe content (73.17 mg kg⁻¹) and uptake (1.28 mg pot⁻¹) by straw in neutral soil. Application of WB, BB and RHB recorded Fe content of 97.69, 101.58 and 73.17 mg kg⁻¹ in straw respectively. Significantly higher Fe content (122.11 mg kg⁻¹) in straw was observed with application of BB @ 4 t ha⁻¹ and significantly lower (51.44 mg kg⁻¹) with RHB @ 16 t ha⁻¹. Among different levels, significantly higher Fe uptake by straw was observed @ 4 t ha⁻¹. Treatment receiving BB @ 4 t ha⁻¹ (2.00 mg pot⁻¹) recorded highest Fe uptake by straw and lowest with control (0.83 mg pot⁻¹).

Significantly lower Fe content (63.69 mg kg⁻¹) of straw was recorded with application of BB in alkaline soil. Irrespective of different types of biochar, increase in rate of application reduced Fe content in straw. Of all the treatment combinations, highest Fe content (110.00 mg kg⁻¹) in straw was noticed in WB @ 4 t ha⁻¹ and lower (51.89 mg kg⁻¹) with RHB @ 16 t ha⁻¹. Among different sources RHB recorded significantly lower Fe uptake by straw. Independent of type of biochar, significantly higher Fe uptake by straw was observed at 4 t ha⁻¹. Although, there was significant differences between treatments, application of WB @ 4 t ha⁻¹ (0.53 mg pot⁻¹) recorded significantly higher Fe uptake by straw and lower with of RHB @ 16 t ha⁻¹ (0.10 mg pot⁻¹).

Application of different sources of biochar recorded a significant effect on straw Fe content and uptake in neutral and alkaline soil only. In general, treatment receiving RHB recorded significantly lower straw Fe content than other two sources in all studied soil.

4.3.4.9 Manganese content and uptake

The data pertaining to the effect of different sources and levels of biochar application on straw Mn content and uptake in different soils are presented in Table 34 and 35 respectively.

A significant effect of biochar application on Mn content of straw was observed in acidic soil. Mn content of 553.06, 755.25 and 863.75 mg kg⁻¹ in straw was observed with application of WB, BB and RHB, respectively. Independent of biochar type, increased rate of biochar application reduced Mn content and uptake by straw. Control treatment (1255.67 mg kg⁻¹) recorded significantly higher straw Mn content and application of WB @ 16 t ha⁻¹ (190.00 mg kg⁻¹) recorded significantly lower Mn content. Among the different types of biochar, significantly higher Mn uptake by straw was observed with RHB application. Of all the treatment combinations, application of WB @ 16 t ha⁻¹ (3.30 mg pot⁻¹) recorded significantly lower Mn uptake and control (19.76 mg pot⁻¹) recorded significantly higher Mn uptake.

In neutral soil, a significant variation was recorded in Mn content of straw due to application of different sources and levels of biochar. Of different types of biochar, application of WB recorded significantly lower Mn content (1317.64 mg kg⁻¹) and uptake

(22.34 mg pot⁻¹) by straw. Independent of biochar types, application @ 16 t ha⁻¹ recorded significantly lower Mn content (1201.89 mg kg⁻¹) and uptake (19.02 mg pot⁻¹) by straw. Higher straw Mn content (1575.89 mg kg⁻¹) was observed with application of RHB @ 2 t ha⁻¹ and lower with (941.78 mg kg⁻¹) WB @ 16 t ha⁻¹. Application of RHB @ 4 t ha⁻¹ recorded higher Mn uptake (28.52 mg pot⁻¹) and lower (14.12 mg pot⁻¹) with WB @ 16 t ha⁻¹.

In alkaline soil, the Mn content of straw as influenced by application of different biochar followed a decreasing order of BB (182.25 mg kg⁻¹) > WB (179.64 mg kg⁻¹) > RHB (162.81 mg kg⁻¹). Application of different sources and levels of biochar varied the Mn content in straw from 148.67 to 215.22 mg kg⁻¹ recording highest in treatment WB @ 8 t ha⁻¹ and lowest in RHB @ 16 t ha⁻¹. The Mn uptake by straw ranged from 0.29 to 0.84 mg pot⁻¹ recording lowest with application of RHB @ 16 t ha⁻¹ and highest with WB @ 4 t ha⁻¹.

4.3.4.10. Copper content and uptake

Effect of different sources and levels of biochar application on Cu content and uptake by straw in different soils are presented in Table 34 and 35 respectively.

Significant differences in Cu content of straw were observed in acidic soil as result of application of different types and rates of biochar. Among different sources, application of RHB recorded higher Cu content (27.03 mg kg⁻¹) and uptake (0.51 mg pot⁻¹) by straw. Irrespective of types of biochar, increased rate of application increased Cu content and uptake by straw. Application of BB @ 16 t ha⁻¹ recorded highest (31.00 mg kg⁻¹) Cu content in straw and lower with WB @ 16 t ha⁻¹ (16.56 mg kg⁻¹). Higher Cu uptake by straw were recorded with the application of RHB @ 16 t ha⁻¹ (0.60 mg pot⁻¹) and lower with WB @ 16 t ha⁻¹ (0.29 mg pot⁻¹).

In neutral soil, the Cu content in straw varied significantly with the application of different sources of biochar only. Application of RHB recorded significantly higher Cu content (29.83 mg kg⁻¹) and uptake (0.52 mg pot⁻¹) by straw than other two sources. Though there was no significant interaction effect on Cu content in straw, numerically highest Cu content in straw was observed in treatment RHB @ 2 t ha⁻¹ (31.44 mg kg⁻¹) and lower in BB @ 2 t ha⁻¹ (26.67 mg kg⁻¹). The Cu uptake by straw was found to be higher in treatment RHB @ 8 t ha⁻¹ (0.54 mg pot⁻¹) and lower in control treatment (0.39 mg pot⁻¹).

A significant effect of sources and levels of biochar application on Cu content and uptake by straw was noticed in alkaline soil. The Cu content of 25.89, 28.28 and 23.86 mg kg⁻¹ in straw was recorded with application of WB, BB and RHB respectively. Irrespective of source of biochar, Cu content in straw decreased with increased rate of biochar application. The Cu content in straw in different treatments ranged from 23.11 to 31.00 mg kg⁻¹. The highest Cu content in straw was noticed with the application of BB @ 8 t ha⁻¹ and lowest in RHB @ 16 t ha⁻¹. Application of RHB (0.06 mg pot⁻¹) recorded significantly lower Cu uptake by straw than WB (0.10 mg pot⁻¹) and BB (0.10 mg pot⁻¹).

Of all treatment combinations, treatment receiving WB both @ 2 and 4 t ha⁻¹ recorded highest (0.13 mg pot⁻¹) Cu uptake and lowest (0.05 mg pot⁻¹) with RHB @ 16 t ha⁻¹.

4.3.4.11 Silicon content and uptake

Perusal of data presented in Table 36 revealed the significant effect of sources of biochar, levels and their interaction on Si content and uptake by straw.

In acidic soil, Si content of straw differed significantly with application of different sources of biochar. Si content in straw followed a decreasing order of RHB (7.50 %) > BB (6.73 %) > WB (6.55 %). Application level of 8 t ha⁻¹ (6.87 %) recorded lower Si content than other levels of application. The changes in Si content of straw as influenced by application of different sources and levels of biochar application ranged from 5.76 to 7.74. Higher Si content in straw was noticed with application of RHB @ 4 t ha⁻¹ and found to be on par with treatments RHB @ 8 t ha⁻¹ (7.67 %) and RHB @ 16 t ha⁻¹ (7.55 %). Significantly lower Si content was observed in control (5.76 %). Significantly higher Si uptake was observed with application of RHB (1.42 g pot⁻¹) than WB (1.19 g pot⁻¹) and BB (1.19 g pot⁻¹). Among different application rates, 8 t ha⁻¹ recorded higher (1.31 g pot⁻¹) uptake of Si by straw. Higher Si uptake by straw was recorded in the treatment RHB @ 16 t ha⁻¹ (1.53 g pot⁻¹) which was found to be on par with RHB @ 8 t ha⁻¹ (1.49 g pot⁻¹). Lower Si uptake by straw was noticed in control (0.91 g pot⁻¹).

Significantly higher Si content in straw was observed with application of BB in neutral soil than other sources of biochar. The Si content in straw followed a decreasing order of BB (6.17 %) > RHB (5.78 %) > WB (5.66 %). Significantly higher Si content was observed at application rate of 8 t ha⁻¹ (6.30 %) than other levels. Application of different sources and levels of biochar significantly increased straw Si content over control (4.93 %). Higher Si content of 6.74 per cent in straw was observed with application of BB @ 16 t ha⁻¹ and found to be on par with BB @ 8 t ha⁻¹ (6.64 %). Among different sources and levels of application, application of RHB and application rate of 8 t ha⁻¹ recorded higher Si uptake by straw. Of all treatment combinations, application of RHB @ 8 t ha⁻¹ (0.75 g pot⁻¹) recorded higher Si uptake by straw and lower with control (0.54 g pot⁻¹).

In alkaline soil, the Si content in straw followed a decreasing trend of RHB (6.28 %) > BB (4.79 %) > WB (4.60 %). Irrespective of source of biochar, the Si content in straw increased with increased rate of application. Application of different sources and levels of biochar varied Si content in straw from 3.85 to 7.21 %. Significantly higher Si content in straw was observed with treatment RHB @ 16 t ha⁻¹ (7.21 %) followed by RHB @ 8 t ha⁻¹ (6.75 %). Significantly lower Si content in straw was noticed in control (3.85 %). Among different sources and levels of biochar, significantly lower Si uptake by straw was noticed with application of RHB and application rate of 16 t ha⁻¹ than other sources and levels of application. Application of WB @ 16 t ha⁻¹ (0.23 g pot⁻¹) recorded significantly higher Si uptake followed by WB @ 2 t ha⁻¹ (0.19 g pot⁻¹) and BB @ 4 t ha⁻¹ (0.19 g pot⁻¹). Significantly lower Si uptake of 0.12 g pot⁻¹ was noticed in treatment WB @ 16 t ha⁻¹ and control treatment.

Table 36: Effect of different sources and levels of biochar application on content and uptake of Si by rice straw in acidic, neutral and alkaline soils

	Si Content (%)			Si Uptake (g pot ⁻¹)		
	Acidic	Neutral	Alkaline	Acidic	Neutral	Alkaline
Sources of biochar						
WB	6.55	5.66	4.60	1.19	0.63	0.17
BB	6.73	6.17	4.79	1.19	0.62	0.18
RHB	7.50	5.78	6.28	1.42	0.70	0.16
SEm±	0.06	0.07	0.03	0.02	0.01	0.00
CD at 0.05	0.18	0.22	0.10	0.05	0.03	0.01
Levels of biochar						
2 t ha ⁻¹	7.00	5.59	4.70	1.22	0.64	0.17
4 t ha ⁻¹	6.95	5.63	5.15	1.27	0.68	0.20
8 t ha ⁻¹	6.87	6.30	5.41	1.31	0.68	0.17
16 t ha ⁻¹	6.90	5.97	5.62	1.26	0.59	0.14
SEm±	0.07	0.09	0.04	0.02	0.01	0.00
CD at 0.05	0.21	0.25	0.11	0.05	0.04	0.01
Interaction						
Control	5.76	4.93	3.85	0.91	0.54	0.12
WB @ 2 t ha ⁻¹	6.60	5.53	4.35	1.13	0.69	0.19
WB @ 4 t ha ⁻¹	6.66	5.40	4.79	1.25	0.72	0.23
WB @ 8 t ha ⁻¹	6.53	6.27	4.70	1.24	0.62	0.15
WB @ 16 t ha ⁻¹	6.42	5.45	4.55	1.11	0.50	0.12
BB @ 2 t ha ⁻¹	7.35	5.72	4.61	1.27	0.59	0.18
BB @ 4 t ha ⁻¹	6.44	5.57	4.67	1.14	0.60	0.19
BB @ 8 t ha ⁻¹	6.41	6.64	4.79	1.20	0.66	0.18
BB @ 16 t ha ⁻¹	6.73	6.74	5.11	1.15	0.63	0.15
RHB @ 2 t ha ⁻¹	7.04	5.51	5.15	1.25	0.65	0.13
RHB @ 4 t ha ⁻¹	7.74	5.91	6.00	1.40	0.73	0.18
RHB @ 8 t ha ⁻¹	7.67	5.99	6.75	1.49	0.75	0.18
RHB @ 16 t ha ⁻¹	7.55	5.73	7.21	1.53	0.65	0.14
SEm±	0.12	0.15	0.07	0.03	0.02	0.01
CD at 0.05	0.36	0.43	0.20	0.09	0.06	0.02

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

4.3.5 Effect of different sources and levels of biochar application on nutrient content and uptake of grain in different soils

4.3.5.1 Nitrogen content and uptake

Influence of different sources and levels of biochar application on N content and uptake in grain in different soils are presented in Table 37 and 38 respectively.

In acidic soil, significant differences of N content and uptake by grain were observed with application of different biochar. The N content in grain as influenced by different sources followed an order of RHB (1.57 %) > WB (1.48) > BB (1.43 %). Among different levels of application, application rate of 4 t ha⁻¹ (1.52 %) recorded higher N content in grain. The changes in N content of grain as influenced by application of different types and levels of biochar varied from 1.36 to 1.60 per cent. The treatment receiving RHB @ 16 t ha⁻¹ recorded highest N content in grain and lowest with BB @ 16 t ha⁻¹. N uptake of 169.63, 161.56 and 196.68 mg pot⁻¹ by grain were respectively recorded with the application of WB, BB and RHB. Among the different levels of biochar application, application rate of 8 t ha⁻¹ recorded significantly highest N uptake by grain. A wide variation in N uptake by grain was notice ranging from 148.44 to 221.64 mg pot⁻¹. Significantly highest N uptake by grain was recorded with the application of RHB @ 16 t ha⁻¹ and least in control.

A significant variation in N content of grain was observed in neutral soil as result of application of biochar of different kinds and levels. Application of WB (1.39 %) and BB (1.40 %) recorded significantly higher N content in grain than RHB (1.34 %). Independent of type of biochar applied, increased rate of application decreased N content in grain. Highest N content in grain was observed with application of RHB @ 4 t ha⁻¹ (1.58 %) and found to be on par with WB @ 2 t ha⁻¹ (1.54 %), WB @ 4 t ha⁻¹ (1.55 %), BB @ 2 t ha⁻¹ (1.57 %) and BB @ 4 t ha⁻¹ (1.51 %). While treatment receiving WB 16 t ha⁻¹ (1.18 %), BB @ 16 t ha⁻¹ (1.17 %), RHB @ 8 t ha⁻¹ (1.13 %) and RHB @ 16 t ha⁻¹ (1.14 %) recorded significantly lower grain N content over other treatments. A non significant difference in N uptake by grain was noticed with application of different sources of biochar. Independent of source of biochar, decreased N uptake by grain with increased level of biochar application was observed, recording significantly lowest (116.23 mg pot⁻¹) N uptake at 16 t ha⁻¹. Highest (180.83 mg pot⁻¹) N uptake by grain was observed with application of RHB @ 4 t ha⁻¹ and lower (114.85 mg pot⁻¹) with WB @ 16 t ha⁻¹.

In case of alkaline soil, significantly higher N content in grain was observed with the application of WB (1.40 %) and BB (1.40 %) than RHB (1.31 %). Independent of source of biochar applied, increased level of biochar application decreased N content in grain recording higher grain N content at rate of 2 t ha⁻¹ (1.54 %). N content of Grain in different treatments ranged from 1.04 to 1.58 per cent. Application of RHB @ 4 t ha⁻¹ recorded highest N content in grain and lowest with RHB @ 16 t ha⁻¹. N uptake by grain 17.77, 15.97 and 9.82 mg pot⁻¹ was observed with application of WB, BB and RHB respectively. Application of WB @ 2 t ha⁻¹ (23.11 mg per pot⁻¹) and WB @ 4 t ha⁻¹ (22.31 mg pot⁻¹) recorded significantly highest N uptake by grain than other treatments. Treatment receiving RHB @ 16 t ha⁻¹ (6.77 mg pot⁻¹) recorded lowest grain N uptake.

Table 37: Effect of different sources and levels of biochar application on N, P and K content (%) in rice grain in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	N	P	K	N	P	K	N	P	K
Sources* of biochar									
WB	1.48	0.28	0.26	1.39	0.28	0.26	1.40	0.25	0.25
BB	1.43	0.28	0.26	1.40	0.27	0.28	1.40	0.25	0.25
RHB	1.57	0.28	0.26	1.34	0.27	0.28	1.31	0.24	0.23
SEm±	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
CD at 0.05	0.02	NS	0.00	0.04	0.01	0.01	0.04	0.01	0.00
Levels of biochar									
2 t ha ⁻¹	1.50	0.28	0.25	1.54	0.28	0.28	1.54	0.25	0.25
4 t ha ⁻¹	1.52	0.28	0.26	1.55	0.27	0.29	1.55	0.26	0.24
8 t ha ⁻¹	1.49	0.27	0.26	1.26	0.26	0.28	1.26	0.24	0.24
16 t ha ⁻¹	1.48	0.29	0.26	1.16	0.27	0.27	1.14	0.24	0.24
SEm±	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00
CD at 0.05	0.02	0.01	0.01	0.05	0.01	0.01	0.05	0.01	0.01
Interaction									
Control	1.57	0.26	0.26	1.42	0.26	0.25	1.42	0.25	0.26
WB @ 2 t ha ⁻¹	1.52	0.28	0.25	1.54	0.29	0.25	1.54	0.26	0.25
WB @ 4 t ha ⁻¹	1.52	0.28	0.26	1.55	0.28	0.28	1.55	0.27	0.25
WB @ 8 t ha ⁻¹	1.42	0.29	0.26	1.30	0.27	0.26	1.30	0.24	0.24
WB @ 16 t ha ⁻¹	1.47	0.29	0.25	1.18	0.27	0.27	1.21	0.24	0.26
BB @ 2 t ha ⁻¹	1.45	0.28	0.26	1.57	0.27	0.28	1.57	0.25	0.25
BB @ 4 t ha ⁻¹	1.43	0.28	0.27	1.51	0.26	0.30	1.51	0.27	0.24
BB @ 8 t ha ⁻¹	1.48	0.25	0.27	1.34	0.26	0.29	1.34	0.26	0.25
BB @ 16 t ha ⁻¹	1.36	0.29	0.25	1.17	0.27	0.27	1.17	0.24	0.25
RHB @ 2 t ha ⁻¹	1.52	0.27	0.25	1.49	0.27	0.30	1.49	0.26	0.25
RHB @ 4 t ha ⁻¹	1.59	0.28	0.26	1.58	0.28	0.29	1.58	0.25	0.22
RHB @ 8 t ha ⁻¹	1.57	0.27	0.26	1.13	0.25	0.28	1.13	0.24	0.22
RHB @ 16 t ha ⁻¹	1.60	0.29	0.26	1.14	0.27	0.26	1.04	0.22	0.23
SEm±	0.01	0.01	0.00	0.03	0.00	0.00	0.03	0.00	0.00
CD at 0.05	0.03	NS	0.01	0.08	0.01	0.01	0.08	0.01	0.01

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 38: Effect of different sources and levels of biochar application on N, P and K uptake (mg pot⁻¹) by rice grain in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	N	P	K	N	P	K	N	P	K
Sources* of biochar									
WB	169.63	32.53	29.40	148.71	29.24	28.08	17.77	3.16	3.13
BB	161.56	30.94	29.61	146.35	27.76	29.57	15.97	2.86	2.80
RHB	196.68	34.87	32.18	145.43	28.80	30.71	9.82	1.79	1.69
SEm±	2.74	0.59	0.56	2.03	0.33	0.34	0.30	0.06	0.05
CD at 0.05	7.96	1.71	1.61	NS	0.97	0.99	0.87	0.18	0.15
Levels of biochar									
2 t ha ⁻¹	160.37	29.63	27.04	166.63	29.87	30.02	17.94	2.95	2.92
4 t ha ⁻¹	174.01	32.45	30.08	175.12	30.88	32.62	18.70	3.21	2.95
8 t ha ⁻¹	192.14	34.76	33.93	129.33	26.82	28.38	11.61	2.24	2.19
16 t ha ⁻¹	177.30	34.28	30.53	116.23	26.82	26.78	9.84	2.03	2.09
SEm±	3.17	0.68	0.64	2.34	0.39	0.40	0.35	0.07	0.06
CD at 0.05	9.19	1.98	1.86	6.79	1.12	1.15	1.01	0.20	0.18
Interaction									
Control	148.44	24.32	24.67	126.15	23.03	21.98	18.98	3.36	3.42
WB @ 2 t ha ⁻¹	156.96	28.65	25.69	168.55	31.34	27.49	23.11	3.85	3.74
WB @ 4 t ha ⁻¹	175.03	32.59	29.66	178.54	31.96	31.88	22.31	3.89	3.66
WB @ 8 t ha ⁻¹	185.42	37.63	34.45	132.90	27.53	26.56	13.52	2.48	2.53
WB @ 16 t ha ⁻¹	161.10	31.25	27.79	114.85	26.12	26.36	12.14	2.44	2.58
BB @ 2 t ha ⁻¹	150.94	29.07	27.24	167.57	29.18	29.65	19.28	3.02	3.10
BB @ 4 t ha ⁻¹	161.17	31.67	30.46	165.99	28.89	32.92	20.38	3.60	3.30
BB @ 8 t ha ⁻¹	184.96	31.36	33.39	135.34	26.06	28.88	13.63	2.62	2.56
BB @ 16 t ha ⁻¹	149.15	31.65	27.34	116.48	26.90	26.83	10.61	2.21	2.24
RHB @ 2 t ha ⁻¹	173.21	31.16	28.19	163.76	29.09	32.92	11.42	1.99	1.91
RHB @ 4 t ha ⁻¹	185.83	33.10	30.12	180.83	31.79	33.04	13.40	2.15	1.89
RHB @ 8 t ha ⁻¹	206.05	35.29	33.95	119.75	26.88	29.71	7.69	1.60	1.47
RHB @ 16 t ha ⁻¹	221.64	39.93	36.45	117.37	27.44	27.15	6.77	1.42	1.47
SEm±	5.49	1.18	1.11	4.06	0.67	0.68	0.60	0.12	0.11
CD at 0.05	15.91	3.42	3.23	11.76	1.94	1.98	1.74	0.35	0.31

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

4.3.5.2 Phosphorus content and uptake

Data presented in Table 37 and 38 revealed the effect of different sources and levels of biochar application on P content and uptake by grain respectively in different soils.

Application of different sources and interaction effect of sources and levels of biochar had a non significant effect on P content of grain in acidic soil. However significant differences were observed with different rates of biochar application. Higher P content (0.29 %) in grain was noticed at rate of 16 t ha⁻¹. Though there was non significant interaction effect on P content of grain, P content in different treatments ranged from 0.25 to 0.27 per cent. P uptake varied significantly with the application of different sources of biochar. Among different sources, significantly higher P content was observed with RHB (34.87 mg pot⁻¹). Irrespective of biochar type, increased rate of biochar application increased P uptake by grain recording higher (34.76 mg pot⁻¹) at rate of 8 t ha⁻¹. Among the different treatment combinations, treatment receiving RHB @ 16 t ha⁻¹ recorded significantly higher P uptake (39.93 mg pot⁻¹) by grain and found to be on par with treatment WB @ 8 t ha⁻¹ (37.63 mg pot⁻¹) and least in control (24.32 mg pot⁻¹).

Significantly higher P uptake by grain was observed in neutral soil, with the application of WB (0.28 %) than other two sources. Though there were significant differences with varied levels of biochar application, no definite trend was observed with application rates. Significantly higher P content in grain was observed at 2 t ha⁻¹ (0.28 %). Application of WB @ 2 t ha⁻¹ (0.29 %), WB @ 4 t ha⁻¹ (0.28 %) and RHB @ 4 t ha⁻¹ (0.28 %) recorded higher grain P content and treatment RHB @ 8 t ha⁻¹ recorded lowest P content (0.25 %) in grain. Among different sources and levels of biochar application, WB (29.24 mg pot⁻¹) and application rate of 4 t ha⁻¹ (30.88 mg pot⁻¹) recorded higher P uptake by grain. Of all treatment combinations, WB @ 2 t ha⁻¹ (31.34 mg pot⁻¹), WB @ 4 t ha⁻¹ (31.96 mg pot⁻¹) and RHB @ 4 t ha⁻¹ (31.79 mg pot⁻¹) recorded significantly higher P uptake by grain and least (23.03 mg pot⁻¹) in control treatment.

In case of alkaline soil, higher P content in grain was observed with application of WB (0.25 %) and BB (0.25 %) than RHB (0.24 %). Application rate of 4 t ha⁻¹ (0.26 %) recorded higher grain P content. Highest grain P content of 0.27 per cent was observed with application of both WB and BB @ 4 t ha⁻¹. Significantly least (0.22 %) P content in grain was noticed in treatment receiving RHB @ 16 t ha⁻¹. Significantly higher P uptake in grain was noticed with, application of WB (3.16 mg pot⁻¹) and at rate of 4 t ha⁻¹ (3.21 mg pot⁻¹) than other sources and levels of biochar application. Among different treatment combinations, highest (3.89 mg pot⁻¹) P uptake by grain was observed in WB @ 4 t ha⁻¹ treatment and lowest (1.42 mg pot⁻¹) with RHB @ 16 t ha⁻¹.

4.3.5.3 Potassium content and uptake

Results of effect of different sources and levels of biochar application in different soils on K content and uptake by grain are presented in Table 37 and 38 respectively.

In case of acidic soil, the K content in grain was found to be higher with application of BB (0.262 %) than WB (0.256 %) and RHB (0.257 %). Independent of

biochar type, increased rate of application increased K content in grain. Application of all biochar and at all levels varied grain K content from 0.25 to 0.27 per cent. Treatment receiving BB @ both 4 and 8 t ha⁻¹ recorded highest K content in grain. Significantly higher K uptake by grain was observed with application of RHB (32.18 mg pot⁻¹) and at level of 8 t ha⁻¹ (33.93 mg pot⁻¹) than other sources and levels of biochar. Application of RHB @ 16 t ha⁻¹ and control treatment recorded correspondingly highest (36.45 mg pot⁻¹) and lowest (24.67 mg pot⁻¹) K uptake by grain in the present study.

In neutral soil, K content of 0.26, 0.28 and 0.28 per cent in grain was observed with application of WB, BB and RHB respectively. Application level of 4 t ha⁻¹ recorded higher (0.29 %) grain K content than other levels of application. Higher K content of 0.30 per cent in grain was observed with application of both BB @ 4 t ha⁻¹ and RHB @ 2 t ha⁻¹. While, control and WB @ 2 t ha⁻¹ treatments recorded lowest (0.25 %) K content in grain. Among various types and levels of biochar applied, addition of RHB and level of 4 t ha⁻¹ recorded higher K uptake by grain. Highest K uptake by grain was noticed in treatment receiving RHB @ 4 t ha⁻¹ (33.04 mg pot⁻¹) and lowest in control (21.98 mg pot⁻¹).

Higher K content of grain in alkaline soil was observed with application of WB (0.25 %) and BB (0.25 %) than RHB (0.23 %). Application rate of 2 t ha⁻¹ (0.25 %) recorded higher K content in grain than other levels of application. WB @ 16 t ha⁻¹ treatment recorded highest K content of 0.26 per cent. While, application of RHB @ 8 and 16 t ha⁻¹ recorded lower (0.22 %) K content in grain. With application of different types of biochar, K uptake by grain followed a decreasing trend of WB (3.13 mg pot⁻¹) > BB (2.80 mg pot⁻¹) > RHB (1.69 mg pot⁻¹). Among the different treatments, significantly highest K uptake by grain was noticed in WB @ 2 t ha⁻¹ (3.74 mg pot⁻¹) and lowest in RHB @ 8 and 16 t ha⁻¹ (1.47 mg pot⁻¹) treatments.

4.3.5.4 Calcium content and uptake

The data on effect of different sources and levels of biochar application on Ca content and uptake in different soils are presented in Table 39 and 40 respectively.

The Ca content differed significantly in acidic soil with the application of different sources of biochar. The Ca content of 0.68, 0.51 and 0.62 per cent in grain were observed with the application of WB, BB and RHB respectively. Independent of biochar type, increased levels of application increased Ca content in grain. Among different treatment combinations, highest Ca content (0.82 %) in grain was recorded with the application of WB @ 16 t ha⁻¹ and lowest (0.49 %) with BB @ 16 t ha⁻¹. Application different type of biochar differed Ca uptake by grain following an order of WB (78.42 mg pot⁻¹) > RHB (77.64 %) > BB (57.12 %). Application of 8 t ha⁻¹ recorded higher (78.63 mg pot⁻¹) Ca uptake in grain than other levels. The Ca uptake by grain in different treatments ranged from 49.87 to 95.75 mg pot⁻¹. Application of WB @ 8 t ha⁻¹ recorded significantly higher Ca uptake by grain and least by control (49.87 mg pot⁻¹)

Application WB (0.42 %), BB (0.42 %) and RHB (0.47 %) differed Ca content of grain significantly in neutral soil. However, application at different rates had a non

Table 39: Effect of different sources and levels of biochar application on Ca, Mg and S content (%) in rice grain in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
Sources* of biochar									
WB	0.68	0.46	0.15	0.42	0.32	0.18	0.48	0.28	0.11
BB	0.51	0.41	0.14	0.42	0.26	0.19	0.47	0.25	0.10
RHB	0.62	0.47	0.14	0.47	0.30	0.17	0.42	0.24	0.08
SEm±	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
CD at 0.05	0.03	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.00
Levels of biochar									
2 t ha ⁻¹	0.58	0.45	0.14	0.46	0.30	0.18	0.48	0.26	0.10
4 t ha ⁻¹	0.60	0.46	0.15	0.44	0.33	0.18	0.45	0.30	0.10
8 t ha ⁻¹	0.61	0.47	0.13	0.40	0.27	0.18	0.45	0.23	0.10
16 t ha ⁻¹	0.63	0.41	0.15	0.45	0.26	0.18	0.44	0.24	0.09
SEm±	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00
CD at 0.05	0.03	0.02	0.01	0.02	0.02	NS	0.02	0.01	0.00
Interaction									
Control	0.53	0.41	0.17	0.54	0.28	0.18	0.40	0.28	0.09
WB @ 2 t ha ⁻¹	0.56	0.45	0.14	0.44	0.33	0.17	0.50	0.25	0.10
WB @ 4 t ha ⁻¹	0.61	0.47	0.17	0.47	0.37	0.18	0.48	0.31	0.10
WB @ 8 t ha ⁻¹	0.73	0.49	0.14	0.35	0.30	0.17	0.46	0.27	0.13
WB @ 16 t ha ⁻¹	0.82	0.42	0.15	0.44	0.28	0.20	0.48	0.29	0.10
BB @ 2 t ha ⁻¹	0.53	0.43	0.13	0.45	0.29	0.20	0.49	0.25	0.11
BB @ 4 t ha ⁻¹	0.51	0.43	0.15	0.43	0.27	0.20	0.46	0.26	0.12
BB @ 8 t ha ⁻¹	0.50	0.42	0.14	0.38	0.24	0.18	0.46	0.24	0.09
BB @ 16 t ha ⁻¹	0.49	0.38	0.14	0.42	0.25	0.18	0.47	0.24	0.08
RHB @ 2 t ha ⁻¹	0.65	0.48	0.14	0.49	0.29	0.18	0.46	0.28	0.09
RHB @ 4 t ha ⁻¹	0.69	0.46	0.12	0.41	0.36	0.17	0.41	0.33	0.09
RHB @ 8 t ha ⁻¹	0.60	0.51	0.11	0.48	0.28	0.17	0.42	0.17	0.07
RHB @ 16 t ha ⁻¹	0.56	0.43	0.18	0.49	0.26	0.16	0.38	0.19	0.08
SEm±	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00
CD at 0.05	0.05	0.03	0.01	0.03	0.04	0.02	0.04	0.02	0.01

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 40: Effect of different sources and levels of biochar application on Ca, Mg and S uptake (mg pot⁻¹) by rice grain in acidic, neutral and alkaline soils

	Acidic soil			Neutral soil			Alkaline soil		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
Sources* of biochar									
WB	78.42	52.52	17.24	45.06	34.11	19.03	5.96	3.48	1.30
BB	57.12	46.73	15.56	43.84	27.49	19.83	5.31	2.82	1.15
RHB	77.64	58.81	17.32	50.18	32.43	18.43	3.10	1.82	0.60
SEm±	1.59	1.18	0.37	0.62	0.48	0.36	0.13	0.07	0.02
CD at 0.05	4.61	3.43	1.07	1.81	1.40	1.05	0.37	0.19	0.07
Levels of biochar									
2 t ha ⁻¹	62.47	48.17	14.60	49.88	33.22	19.65	5.64	2.99	1.18
4 t ha ⁻¹	69.15	52.37	16.83	49.32	37.83	20.85	5.56	3.60	1.24
8 t ha ⁻¹	78.63	61.15	16.85	41.25	27.99	18.03	4.09	2.13	0.89
16 t ha ⁻¹	73.98	49.06	18.54	44.99	26.34	17.86	3.86	2.11	0.76
SEm±	1.84	1.36	0.43	0.72	0.56	0.42	0.15	0.08	0.03
CD at 0.05	5.32	3.96	1.23	2.09	1.62	1.21	0.43	0.22	0.08
Interaction									
Control	49.87	38.77	15.71	47.63	26.71	15.88	5.34	3.73	1.23
WB @ 2 t ha ⁻¹	57.72	46.10	14.71	48.50	36.26	18.32	7.41	3.78	1.50
WB @ 4 t ha ⁻¹	70.13	54.18	19.26	53.91	41.96	20.69	6.96	4.43	1.38
WB @ 8 t ha ⁻¹	95.75	63.77	18.71	35.25	31.06	17.73	4.70	2.83	1.29
WB @ 16 t ha ⁻¹	90.09	46.01	16.27	42.56	27.17	19.38	4.78	2.90	1.01
BB @ 2 t ha ⁻¹	55.64	44.28	13.46	48.05	31.47	20.82	5.97	3.09	1.34
BB @ 4 t ha ⁻¹	56.99	48.78	16.94	47.16	30.39	22.23	6.24	3.56	1.62
BB @ 8 t ha ⁻¹	62.06	52.58	16.92	38.19	23.95	18.63	4.72	2.44	0.88
BB @ 16 t ha ⁻¹	53.77	41.30	14.92	41.98	24.17	17.62	4.31	2.19	0.76
RHB @ 2 t ha ⁻¹	74.06	54.12	15.65	53.08	31.95	19.82	3.54	2.11	0.69
RHB @ 4 t ha ⁻¹	80.32	54.14	14.30	46.90	41.15	19.62	3.50	2.82	0.73
RHB @ 8 t ha ⁻¹	78.08	67.11	14.92	50.31	28.96	17.73	2.86	1.13	0.50
RHB @ 16 t ha ⁻¹	78.09	59.86	24.42	50.43	27.69	16.57	2.49	1.23	0.50
SEm±	3.18	2.36	0.74	1.25	0.97	0.72	0.26	0.13	0.05
CD at 0.05	9.22	6.85	2.14	3.61	2.80	2.10	0.75	0.38	0.13

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

significant effect on Ca content of grain. The changes in Ca content of grain as influenced by different types and levels of biochar application ranged from 0.38 to 0.49 per cent. Treatment receiving RHB @ 16 t ha⁻¹ recorded highest Ca content in grain and lowest with BB @ 8 t ha⁻¹. Among different sources, application of BB recorded significantly lower Ca uptake by grain than other two sources. Application level of 4 t ha⁻¹ recorded higher Ca uptake by grain than other level of application. Treatment receiving WB @ 4 t ha⁻¹ recorded highest Ca uptake (53.91 mg pot⁻¹) and lowest (38.19 mg pot⁻¹) with BB @ 8 t ha⁻¹.

Application of different sources of biochar in alkaline soil varied the Ca content in grain significantly following an order of WB (0.48 %) > BB (0.47 %) > RHB (0.42 %). Higher Ca content (0.48 %) in grain was noticed at application rate of 2 t ha⁻¹. The Ca content in grain ranged from 0.38 to 0.50 per cent in different treatments. The treatment receiving WB @ 2 t ha⁻¹ recorded highest Ca content in grain and lowest with RHB @ 16 t ha⁻¹. Application of WB (5.96 mg pot⁻¹) recorded significantly higher Ca uptake by grain than BB (5.31 mg pot⁻¹) and RHB (3.10 mg pot⁻¹). Independent of biochar type applied, Ca content of grain decreased with increased level of biochar application. Of all the treatment combinations, application of WB @ 2 t ha⁻¹ recorded significantly highest Ca uptake (7.41 mg pot⁻¹) by grain and lowest (2.49 mg pot⁻¹) with RHB @ 16 t ha⁻¹ in comparison to control.

4.3.5.5 Magnesium content and uptake

The results of effect of different sources and levels of biochar application on Mg content and uptake by grain in different soils are presented in Table 39 and 40 respectively.

The Mg content in grain varied significantly with application of different sources and levels of biochar in acidic soil. The Mg content in grain followed a trend of RHB (0.47 %) > WB (0.46 %) > BB (0.41 %) with application of different biochars. Higher Mg content (0.47 %) in grain was observed at the application level of 8 t ha⁻¹. Application of RHB @ 8 t ha⁻¹ (0.51 %) recorded highest Mg content and found to be on par with WB @ 8 t ha⁻¹ (0.49 %) and lowest with BB @ 16 t ha⁻¹ (0.38 %). Application of different biochar differed Mg uptake by grain significantly following an increasing order of BB (46.73 mg pot⁻¹) < WB (52.52 mg pot⁻¹) < RHB (58.81 mg pot⁻¹). Significantly higher Mg uptake (61.15 mg pot⁻¹) by grain was recorded at application rate of 8 t ha⁻¹ in comparison to other levels. Of all the treatment combinations, treatment receiving RHB @ 8 t ha⁻¹ recorded significantly higher Mg uptake (67.11 mg pot⁻¹) by grain and found to be on par with WB @ 8 t ha⁻¹ (63.77 mg pot⁻¹). Lowest Mg uptake (38.77 mg pot⁻¹) by grain was noticed with control treatment.

In neutral soil, application of WB, BB and RHB recorded Mg content of 0.32, 0.26 and 0.30 per cent in grain respectively. Significantly higher Mg content (0.33 %) in grain was observed at application rate of 4 t ha⁻¹ than other rates. Application of various types and levels of biochar application varied Mg content significantly ranging from 0.24 to 0.37 per cent. Highest Mg content (0.37 %) in grain was observed with the application of WB @ 4 t ha⁻¹ which was found to be on par with RHB @ 4 t ha⁻¹ (0.36 %).

Significantly higher Mg uptake by grain was noticed with the application of WB (34.11 mg pot⁻¹) than BB (27.49 mg pot⁻¹) and RHB (32.43 mg pot⁻¹). Among different rates, application at 4 t ha⁻¹ recorded significantly higher Mg uptake (37.83 mg pot⁻¹) by grain. Significantly highest Mg uptake (41.96 mg pot⁻¹) by grain was noticed in the treatment receiving WB @ 4 t ha⁻¹ and lowest (23.95 mg pot⁻¹) with BB @ 8 t ha⁻¹.

Application of different sources of biochar in alkaline soil recorded a significant effect on Mg content and uptake by grain. Application of WB recorded significantly higher Mg content (0.28 %) and uptake (3.48 mg pot⁻¹) by grain than other two sources. Independent of type of biochar, significantly higher Mg content (0.30 %) and uptake (3.60 mg pot⁻¹) was noticed at application rate of 4 t ha⁻¹. Significantly highest Mg content (0.33 %) in grain was noticed with application of RHB @ 4 t ha⁻¹ and found to be on par with WB @ 4 t ha⁻¹ (0.31 %). Significantly lower Mg content (0.17 %) in grain was recorded with application of RHB @ 8 t ha⁻¹. Of all treatment combination, application of WB @ 4 t ha⁻¹ recorded significantly higher Mg uptake (4.43 mg pot⁻¹) by grain and lowest (1.13 mg pot⁻¹) with RHB @ 8 t ha⁻¹.

4.3.5.6 Sulphur content and uptake

Perusal of data presented in Table 39 and 40 revealed the significant effect of different sources, levels and interaction effect of biochar application on S content and uptake by grain in different soils.

In acidic soil, application of WB, BB and RHB recorded S content of 0.15, 0.14 and 0.14 per cent in grain. Though different rates of application had a significant effect on S content of grain no definite pattern was observed. The S content of grain varied from 0.11 to 0.18 per cent. The highest S content of grain was observed with application of RHB @ 16 t ha⁻¹. Highest S uptake (17.32 mg pot⁻¹) by grain was noticed with application of RHB than other two sources. Independent of biochar type increased rate of application increased S uptake by grain. Highest S (24.42 mg pot⁻¹) uptake by grain was observed with application of RHB @ 16 t ha⁻¹ lowest (14.71 mg pot⁻¹) with WB @ 2 t ha⁻¹.

In neutral soil, application of BB (0.19 %) recorded higher S content in grain than WB (0.18 %) and RHB (0.17 %). However, different rates of biochar application had a non significant effect on S content of grain. S content of grain varied from 0.16 to 0.20 per cent in different treatment. Among different sources, application of BB recorded highest S uptake (19.83 mg pot⁻¹) by grain. Among different treatment combinations, BB @ 4 t ha⁻¹ recorded highest S uptake (22.23 mg pot⁻¹) by grain.

In alkaline soil, highest S content (0.11 %) in grain was observed with application of WB than other two sources. Application level of 16 t ha⁻¹ recorded lowest S content (0.08 %) in grain. Among different treatments, highest (0.13 %) and lowest (0.07 %) S contents in grain were observed with application of WB @ 8 t ha⁻¹ and RHB @ 8 t ha⁻¹ respectively. The uptake of S by grain with application of different biochar differed significantly and followed WB (1.30 mg pot⁻¹) > BB (1.15 mg pot⁻¹) > RHB (0.60 mg

pot⁻¹). Of different treatment combinations, application of BB @ 4 t ha⁻¹ recorded higher S uptake (1.62 mg pot⁻¹) by grain.

4.3.5.7 Zinc content and uptake

The data pertaining to effect of different sources and levels of biochar application on grain Zn content and uptake are presented in Table 41 and 42 respectively in acidic, neutral and alkaline soil.

In acidic soil, application of different sources differed grain Zn content significantly following an increasing order of WB (51.14 mg kg⁻¹) < BB (54.75 mg kg⁻¹) < RHB (56.28 mg kg⁻¹). Independent of biochar application, increased rate of application decreased Zn content in grain recording significantly lower at rate of 16 t ha⁻¹ (49.59 mg kg⁻¹). Treatment receiving WB @ 2 t ha⁻¹ (64.22 mg kg⁻¹) and RHB @ 4 t ha⁻¹ (61.56 mg kg⁻¹) recorded significantly higher Zn content over control. Application of WB @ 4 t ha⁻¹ (43.00 mg kg⁻¹) recorded lowest Zn content in grain. Zn uptake of 582.8, 616.9 and 700.1 µg pot⁻¹ by grain were recorded with application of WB, BB and RHB respectively. Application rate of 8 t ha⁻¹ recorded significantly higher (701.4 µg pot⁻¹) Zn uptake by grain than other levels. Application of RHB @ 8 t ha⁻¹ recorded highest (764.5 mg pot⁻¹) Zn uptake by grain and lowest (493.9 mg pot⁻¹) with WB @ 4 t ha⁻¹.

Significant differences in Zn content of grain in neutral soil was observed with different types of biochar application and followed a decreasing trend of BB (62.21 mg kg⁻¹) > WB (57.33 mg kg⁻¹) > RHB (52.38 mg kg⁻¹). Irrespective of type of biochar applied, decreased Zn content in grain was observed with increased rate application recording least at 16 t ha⁻¹ (51.94 mg kg⁻¹). Independent of types and levels, biochar application significantly reduced Zn content in grain compared to control (72.17 mg kg⁻¹). Application of RHB @ 8 t ha⁻¹ (46.67 mg kg⁻¹) recorded significantly lower Zn content in grain. Zn uptake by grain was found to be significantly higher with application of BB and rate of 4 t ha⁻¹ in comparison to other sources and levels of application. The treatment receiving BB @ 4 t ha⁻¹ recorded significantly higher (738.8 µg pot⁻¹) Zn uptake by grain and lower with RHB @ 8 t ha⁻¹ (494.5 µg pot⁻¹).

In alkaline soil, application of different sources of biochar had a non significant effect on Zn content in grain. Among different rates, application at 4 t ha⁻¹ (22.26 mg kg⁻¹) recorded higher Zn content in grain. Of different treatment combinations, treatment receiving BB @ 8 t ha⁻¹ recorded highest (23.67 mg kg⁻¹) Zn content in grain and lowest (18.22 mg kg⁻¹) with RHB @ 16 t ha⁻¹. Application of WB (26.3 µg pot⁻¹) and application rate of 4 t ha⁻¹ (26.9 µg pot⁻¹) recorded significantly higher Zn uptake by grain in comparison to other sources and levels. Significantly highest (32.5 µg pot⁻¹) Zn uptake by grain was noticed with application of WB @ 4 t ha⁻¹ and lowest (11.9 µg pot⁻¹) with RHB @ 16 t ha⁻¹.

4.3.5.8 Iron content and uptake

Perusal of data presented in Table 41 and 42 revealed the significant effect of different sources, levels and interaction effect of biochar application on Fe content and uptake by grain in different soils.

Table 41: Effect of different sources and levels of biochar application on Zn, Fe, Mn and Cu content (%) in rice grain in acidic, neutral and alkaline soils

	Acidic soil				Neutral soil				Alkaline soil			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
Sources* of biochar												
WB	51.14	78.75	92.50	24.42	57.33	127.79	235.56	54.25	21.19	73.08	62.89	23.00
BB	54.75	77.72	98.33	33.06	62.21	161.79	234.67	62.08	21.11	82.56	53.92	32.50
RHB	56.28	91.06	101.53	40.69	52.38	148.63	241.03	69.17	20.86	60.51	56.42	34.47
SEm±	0.74	0.72	1.18	0.45	0.94	2.72	2.10	0.30	0.41	1.06	0.89	0.43
CD at 0.05	2.15	2.09	3.41	1.29	2.72	7.87	NS	0.87	NS	3.09	2.57	1.25
Levels of biochar												
2 t ha ⁻¹	59.52	77.48	99.04	28.96	63.22	150.72	253.74	60.39	20.26	87.04	58.11	27.78
4 t ha ⁻¹	52.63	83.74	107.37	32.81	60.17	139.83	249.56	60.89	22.26	67.49	59.93	30.93
8 t ha ⁻¹	54.48	81.63	99.33	33.85	53.89	140.50	235.81	62.61	21.89	65.37	56.26	29.44
16 t ha ⁻¹	49.59	87.19	84.07	35.26	51.94	153.22	209.22	63.44	19.81	68.30	56.67	31.81
SEm±	0.86	0.83	1.36	0.51	1.08	3.14	2.43	0.35	0.47	1.23	1.02	0.50
CD at 0.05	2.49	2.41	3.94	1.49	3.14	9.09	7.04	1.01	1.37	3.56	NS	1.44
Interaction												
Control	54.78	82.11	138.89	21.22	72.17	148.67	274.78	51.67	19.22	62.44	54.00	14.00
WB @ 2 t ha ⁻¹	64.22	75.78	104.00	21.22	61.83	126.33	243.00	53.33	19.22	84.56	65.89	20.56
WB @ 4 t ha ⁻¹	43.00	85.44	106.67	24.00	62.17	117.67	256.56	53.67	22.56	72.33	64.44	22.11
WB @ 8 t ha ⁻¹	51.78	81.89	85.33	24.78	53.33	123.50	244.00	54.67	22.44	60.56	63.67	22.78
WB @ 16 t ha ⁻¹	45.56	71.89	74.00	27.67	52.00	143.67	198.67	55.33	20.56	74.89	57.56	26.56
BB @ 2 t ha ⁻¹	56.44	78.78	97.11	29.56	64.67	175.50	250.56	60.17	18.89	77.67	54.22	27.67
BB @ 4 t ha ⁻¹	53.33	81.33	106.56	33.11	67.17	147.17	248.67	61.17	21.22	74.56	57.44	32.44
BB @ 8 t ha ⁻¹	53.33	73.78	112.78	35.33	61.67	158.67	241.56	63.33	23.67	93.56	50.67	33.67
BB @ 16 t ha ⁻¹	55.89	77.00	76.89	34.22	55.33	165.83	197.89	63.67	20.67	84.44	53.33	36.22
RHB @ 2 t ha ⁻¹	57.89	77.89	96.00	36.11	63.17	150.33	267.67	67.67	22.67	98.89	54.22	35.11
RHB @ 4 t ha ⁻¹	61.56	84.44	108.89	41.33	51.17	154.67	243.44	67.83	23.00	55.58	57.89	38.22
RHB @ 8 t ha ⁻¹	58.33	89.22	99.89	41.44	46.67	139.33	221.89	69.83	19.56	42.00	54.44	31.89
RHB @ 16 t ha ⁻¹	47.33	112.67	101.33	43.89	48.50	150.17	231.11	71.33	18.22	45.56	59.11	32.67
SEm±	1.49	1.44	2.35	0.89	1.88	5.43	4.21	0.60	0.82	2.13	1.77	0.86
CD at 0.05	4.31	4.18	6.82	2.58	5.44	15.75	12.19	1.74	2.38	6.17	5.14	2.50

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Table 42: Effect of different sources and levels of biochar application on Zn, Fe, Mn and Cu uptake ($\mu\text{g pot}^{-1}$) by rice grain in acidic, neutral and alkaline soils

	Acidic soil				Neutral soil				Alkaline soil			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
Sources* of biochar												
WB	582.8	905.5	1056.6	280.6	610.2	1348.3	2509.0	574.3	26.3	92.4	78.8	28.2
BB	616.9	875.4	1115.8	374.2	650.1	1685.6	2453.2	646.6	23.7	91.9	60.9	36.3
RHB	700.1	1151.8	1270.1	511.5	567.0	1606.8	2609.3	746.9	15.5	45.2	41.4	25.5
SEm\pm	13.0	18.4	24.0	7.7	9.7	29.3	32.8	4.8	0.6	2.3	1.6	0.8
CD at 0.05	37.7	53.4	69.5	22.4	28.0	84.9	95.2	14.0	1.8	6.7	4.6	2.3
Levels of biochar												
2 t ha ⁻¹	637.0	830.6	1059.6	313.1	684.8	1630.3	2750.7	654.5	23.1	99.2	68.8	30.5
4 t ha ⁻¹	604.5	960.4	1232.0	376.7	679.5	1581.0	2825.3	688.7	26.9	84.0	73.3	36.0
8 t ha ⁻¹	701.4	1052.8	1277.2	436.0	553.6	1444.4	2424.6	645.1	20.2	62.3	51.4	26.5
16 t ha ⁻¹	590.1	1066.5	1021.1	429.3	518.6	1531.9	2094.9	635.4	17.0	60.4	48.0	26.9
SEm\pm	15.0	21.3	27.7	8.9	11.2	33.8	37.9	5.6	0.7	2.7	1.8	0.9
CD at 0.05	43.6	61.7	80.3	25.9	32.3	98.0	109.9	16.1	2.1	7.7	5.3	2.7
Interaction												
Control	519.9	777.0	1315.6	201.2	639.7	1318.0	2436.0	458.0	25.7	83.3	72.0	18.6
WB @ 2 t ha ⁻¹	663.7	783.4	1073.8	219.7	674.8	1379.7	2652.9	582.1	28.7	126.8	98.6	30.7
WB @ 4 t ha ⁻¹	493.9	981.2	1226.1	275.6	715.3	1357.0	2959.5	618.8	32.5	104.4	93.3	32.0
WB @ 8 t ha ⁻¹	674.4	1069.2	1115.1	324.3	544.3	1260.0	2489.3	557.7	23.2	63.4	65.8	23.5
WB @ 16 t ha ⁻¹	499.0	788.2	811.4	302.8	506.4	1396.5	1934.6	538.5	20.6	74.9	57.5	26.6
BB @ 2 t ha ⁻¹	589.0	821.7	1012.7	308.6	688.4	1868.5	2667.4	640.5	23.2	95.2	66.4	33.9
BB @ 4 t ha ⁻¹	599.7	914.1	1198.8	372.2	738.8	1619.5	2735.6	672.8	28.7	100.7	77.5	43.8
BB @ 8 t ha ⁻¹	665.2	920.5	1408.4	440.6	622.0	1600.5	2436.0	638.8	24.0	95.1	51.5	34.3
BB @ 16 t ha ⁻¹	613.5	845.3	843.5	375.6	551.3	1653.8	1973.9	634.3	18.7	76.6	48.1	33.0
RHB @ 2 t ha ⁻¹	658.2	886.7	1092.4	410.9	691.1	1642.7	2931.7	740.7	17.3	75.6	41.3	26.8
RHB @ 4 t ha ⁻¹	719.8	986.0	1271.1	482.4	584.3	1766.6	2780.8	774.6	19.5	47.1	49.0	32.4
RHB @ 8 t ha ⁻¹	764.5	1168.5	1308.2	543.0	494.5	1472.8	2348.5	738.9	13.3	28.5	37.0	21.7
RHB @ 16 t ha ⁻¹	657.8	1566.1	1408.5	609.5	498.0	1545.3	2376.3	733.5	11.9	29.6	38.4	21.2
SEm\pm	26.0	36.8	48.0	15.5	19.3	58.5	65.7	9.6	1.2	4.6	3.2	1.6
CD at 0.05	75.5	106.8	139.1	44.9	56.0	169.7	190.4	28.0	3.6	13.3	9.2	4.6

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

Higher Fe content of grain in acidic soil was observed with application of RHB (91.06 mg kg^{-1}) and application rate of 16 t ha^{-1} (87.19 mg kg^{-1}) than other sources and levels. Of all treatment combinations, treatment receiving RHB @ 16 t ha^{-1} recorded significantly highest ($112.67 \text{ mg kg}^{-1}$) Fe content in grain and lowest (71.89 mg kg^{-1}) with WB @ 16 t ha^{-1} . Of different types and levels of biochar applied, RHB ($1151.8 \mu\text{g pot}^{-1}$) and rate of 16 t ha^{-1} ($1066 \mu\text{g pot}^{-1}$) recorded significantly higher Fe uptake by grain. With the application of RHB @ 16 t ha^{-1} significantly higher ($1566.1 \mu\text{g pot}^{-1}$) Fe uptake was observed. While, lower Fe uptake value of $777.0 \mu\text{g pot}^{-1}$ were recorded in control.

Application of different type of biochar in neutral soil, differed Fe content in grain significantly following a decreasing order of BB ($161.79 \text{ mg kg}^{-1}$) > RHB ($148.63 \text{ mg kg}^{-1}$) > WB ($127.70 \text{ mg kg}^{-1}$). Application of biochar at different rates, though had a significant effect, no definite trend of Fe content in grain was observed with application rates. Treatment receiving BB @ 2 t ha^{-1} recorded highest ($175.50 \text{ mg kg}^{-1}$) Fe content in grain and found to be on par with treatment BB @ 16 t ha^{-1} ($165.83 \text{ mg kg}^{-1}$). While, application of WB @ 4 t ha^{-1} recorded lower ($117.67 \text{ mg kg}^{-1}$) Fe content in grain. Fe uptake by grain was significantly reduced with application of WB ($1348.3 \mu\text{g pot}^{-1}$) and application rate of 8 t ha^{-1} ($1444.4 \mu\text{g pot}^{-1}$) in comparison to other sources and levels of application. Among different treatment combinations, application of BB @ 2 t ha^{-1} ($1868.5 \mu\text{g pot}^{-1}$) and WB @ 8 t ha^{-1} ($1260 \mu\text{g pot}^{-1}$) recorded correspondingly highest and lowest Fe uptake by grain.

In alkaline soil, among different sources, significantly higher Fe content in grain was recorded in BB (82.56 mg kg^{-1}) than WB (73.08 mg kg^{-1}) and RHB (60.51 mg kg^{-1}). Application level of 2 t ha^{-1} (87.04 mg kg^{-1}) recorded significantly higher Fe content in grain than other levels. Higher Fe content were recorded in the treatment receiving RHB @ 2 t ha^{-1} (98.89 mg kg^{-1}) which was found to be on par with BB @ 8 t ha^{-1} (93.56 mg kg^{-1}). RHB @ 8 t ha^{-1} (42.00 mg kg^{-1}) and RHB @ 16 t ha^{-1} (45.56 mg kg^{-1}) treatments recorded significantly lower grain Fe content than all other treatments. Significantly higher Fe uptake by grain was noticed with application of WB ($92.4 \mu\text{g pot}^{-1}$) and BB ($91.9 \mu\text{g pot}^{-1}$) than RHB ($45.2 \mu\text{g pot}^{-1}$). Independent of type of biochar applied, increased levels of application decreased Fe uptake by grain, recording highest at 2 t ha^{-1} ($99.2 \mu\text{g pot}^{-1}$) application rate. Among the different treatment combinations, significantly higher ($126.8 \mu\text{g pot}^{-1}$) grain Fe uptake was recorded in WB @ 2 t ha^{-1} and lower in RHB @ 8 t ha^{-1} ($37.0 \mu\text{g pot}^{-1}$).

4.3.5.9 Manganese content and uptake

Mn content and uptake in grain as influenced by application of different sources and levels of biochar in different soils are presented in Table 41 and 42 respectively.

In acidic soil, the Mn content in grain was found to be significantly higher with application of RHB ($101.53 \text{ mg kg}^{-1}$) and application rate of 4 t ha^{-1} ($107.37 \text{ mg kg}^{-1}$) than other types and rates of biochar application. Application of different types and levels of biochar reduced Mn content in grain compared to control ($138.89 \text{ mg kg}^{-1}$). Significantly lower Mn content in grain was observed with application of WB @ 16 t ha^{-1} (74.00 mg kg^{-1}). The Mn uptake of 1056.6 , 1115.8 and $1270.1 \mu\text{g pot}^{-1}$ by grain were

recorded with application of WB, BB and RHB respectively. Of different levels, higher Mn uptake was observed with application level of 8 t ha⁻¹ (1277.2 µg pot⁻¹). The changes in Mn content with application of different sources and levels of biochar ranged from 811.4 to 1408.5 µg pot⁻¹. The treatment receiving RHB @ 16 t ha⁻¹ and WB @ 16 t ha⁻¹ recorded correspondingly highest and lowest Mn uptake.

A non significant effect of source of biochar application was observed for Mn content of grain in neutral soil. Irrespective of type biochar added, increased level of application significantly decreased grain Mn content recording lowest (209.22 mg kg⁻¹) at application rate of 16 t ha⁻¹. Application of biochar reduced grain Mn content significantly compared to control (274.78 mg kg⁻¹). Significantly lower grain Mn content were noticed in treatment receiving WB @ 16 t ha⁻¹ (198.67 mg kg⁻¹) and BB @ 16 t ha⁻¹ (197.89 mg kg⁻¹). Significantly higher Mn uptake by grain was observed with application of RHB (2609.0 µg pot⁻¹) and 4 t ha⁻¹ application level (2825.3 µg pot⁻¹) than other sources and levels of biochar. Among different treatment combination, highest (2952.9 µg pot⁻¹) Mn uptake by grain was noticed with the application of WB @ 4 t ha⁻¹ and lower (1934.6 µg pot⁻¹) with WB @ 16 t ha⁻¹.

In alkaline soil, the Mn content in grain as influenced by different types of biochar followed a decreasing trend of WB (62.89 mg kg⁻¹) > RHB (56.42 mg kg⁻¹) > BB (53.92 mg kg⁻¹). However, graded levels of biochar application had a non significant effect on Mn content of grain. Application of different types and level of biochar application varied Mn content in grain from 50.67 to 65.89 mg kg⁻¹. Treatment receiving WB @ 2 t ha⁻¹ recorded highest Mn content in grain and lowest with BB @ 8 t ha⁻¹. Significantly higher Mn uptake by grain was observed with WB (78.8 µg pot⁻¹) application than BB (60.9 µg pot⁻¹) and RHB (41.4 µg pot⁻¹). Application level of 4 t ha⁻¹ (73.3 µg pot⁻¹) recorded higher Mn uptake than other levels. Significantly highest Mn uptake was noticed in WB @ 2 t ha⁻¹ (98.6 µg pot⁻¹) which was found to be on par with WB @ 4 t ha⁻¹ (93.3 µg pot⁻¹) treatment and least with RHB @ 8 t ha⁻¹ (37.0 µg pot⁻¹).

4.3.5.10 Copper content and uptake

Results of Cu content and uptake by grain as influenced by application of different sources and levels of biochar are presented in Table 41 and 42 respectively.

In acidic soil, Cu content in grain as result of different biochar application followed a decreasing trend of RHB (40.69 mg kg⁻¹) > BB (33.06 mg kg⁻¹) > WB (24.42 mg kg⁻¹). Application level of 16 t ha⁻¹ recorded higher grain Cu content than other levels of application. The difference in Cu content in grain between the treatments ranged from 21.22 to 43.89 mg kg⁻¹. Highest grain Cu content was observed with application of RHB @ 16 t ha⁻¹ and lowest with control. The Cu uptake of 280.6, 374.2 and 511.5 µg pot⁻¹ by grain were recorded with application of WB, BB and RHB respectively. Independent of type of biochar, application level of 8 t ha⁻¹ recorded higher Cu uptake (436.3 µg pot⁻¹) by grain than other levels. Significantly highest Cu uptake was observed with application of RHB @ 16 t ha⁻¹ (609.5 µg pot⁻¹) and lowest in control (201.2 µg pot⁻¹).

Significantly lower Cu content in grain was observed with application of WB (54.25 mg kg⁻¹) in neutral soil than BB (62.08 mg kg⁻¹) and RHB (69.17 mg kg⁻¹). Increased rate of biochar application increased Cu content in grain. Application of RHB @ 16 t ha⁻¹ (71.33 mg kg⁻¹) and control (51.67 mg kg⁻¹) recorded correspondingly highest and lowest Cu content in grain. Among different sources and levels of biochar application, application of RHB (746.9 µg pot⁻¹) and application level of 4 t ha⁻¹ (688.7 µg pot⁻¹) recorded significantly higher Cu uptake by grain. Of all treatment combination, treatment receiving RHB @ 4 t ha⁻¹ recorded highest (774.6 µg pot⁻¹) Cu content and lowest (458.0 µg pot⁻¹) with control.

In alkaline soil, significantly higher Cu content in grain was observed with application of RHB (34.47 mg kg⁻¹) than other sources. Among different rates of application, 16 t ha⁻¹ rate recorded highest (31.81 mg kg⁻¹) Cu content in grain. Grain Cu content varied from 14.00 to 38.22 mg kg⁻¹ in different treatments. Application of RHB @ 4 t ha⁻¹ recorded highest Cu content in grain and lowest with control. Application of BB (36.3 µg pot⁻¹) and level of 4 t ha⁻¹ (36.0 µg pot⁻¹) recorded significantly higher Cu uptake by grain than other sources and levels. Treatment receiving BB @ 4 t ha⁻¹ recorded significantly highest Cu uptake.

Among different biochar RHB recorded significantly higher Cu content in grain and increased level of biochar application increased Cu content in grain irrespective of biochar type in all studied soils.

4.3.5.11 Silicon content and uptake

The results of different sources and levels of biochar application in different soil on Si content and uptake by grain are presented in Table 43.

In acidic soil, significantly higher Si content (1.86 %) and uptake (0.23 g pot⁻¹) by grain was recorded with the application of RHB. Increase in Si content of grain was roughly proportional to application rate and significantly highest (1.78 %) at 16 t ha⁻¹. Significantly higher (2.11 %) and lower (1.32 %) Si content in grain was observed in with application of RHB @ 16 t ha⁻¹ and BB @ 2 t ha⁻¹. Increased level of application increased the Si uptake by grain recording highest (215.59 mg pot⁻¹) at 16 t ha⁻¹ application rate. Application of biochar significantly increased Si uptake by grain and varied from 131.93 to 293.21 mg pot⁻¹. Treatment receiving RHB @ 16 t ha⁻¹ and control recorded highest and lowest Si uptake by grain respectively.

Application RHB recorded significantly higher Si content (1.69 %) and uptake (0.18 g pot⁻¹) in grain of neutral soil. Independent of source of biochar, highest Si content (1.73 %) and uptake (0.17 g pot⁻¹) in grain was observed at the application rate of 16 t ha⁻¹ in comparison to other levels. Although application of different types and levels of biochar increased Si content of grain in comparison to control, highest Si content in grain was noticed with application of BB @ 16 t ha⁻¹ (1.91 %) and lowest in control (1.33 %). Si uptake by grain varied from 118.28 to 190.65 mg pot⁻¹ in different treatments. Lowest and highest Si uptake was observed in control and BB @ 16 t ha⁻¹ treatments.

Table 43: Effect of different sources and levels of biochar application on content and uptake of Si by rice grain in acidic, neutral and alkaline soils)

	Content (%)			Uptake (mg kg ⁻¹)		
	Acidic	Neutral	Alkaline	Acidic	Neutral	Alkaline
Sources* of biochar						
WB	1.50	1.45	1.85	171.54	153.09	23.07
BB	1.46	1.65	1.96	164.31	171.44	22.02
RHB	1.86	1.69	2.08	234.13	182.01	15.20
SEm±	0.01	0.02	0.01	3.14	2.13	0.45
CD at 0.05	0.04	0.04	0.04	9.11	6.17	1.31
Levels of biochar						
2 t ha ⁻¹	1.47	1.47	1.90	157.75	159.28	21.93
4 t ha ⁻¹	1.62	1.50	1.98	186.01	169.54	23.98
8 t ha ⁻¹	1.55	1.68	1.85	200.62	172.95	16.58
16 t ha ⁻¹	1.78	1.73	2.12	215.59	173.62	17.88
SEm±	0.01	0.02	0.01	3.63	2.46	0.52
CD at 0.05	0.04	0.05	0.04	10.51	7.12	1.51
Interaction						
Control	1.39	1.33	1.71	131.93	118.28	22.81
WB @ 2 t ha ⁻¹	1.43	1.35	1.76	147.36	147.33	26.31
WB @ 4 t ha ⁻¹	1.62	1.42	1.98	185.51	163.70	28.60
WB @ 8 t ha ⁻¹	1.41	1.55	1.63	184.16	157.97	16.89
WB @ 16 t ha ⁻¹	1.55	1.47	2.04	169.12	143.36	20.46
BB @ 2 t ha ⁻¹	1.32	1.49	2.04	137.25	158.42	24.99
BB @ 4 t ha ⁻¹	1.38	1.41	1.95	155.46	155.26	26.26
BB @ 8 t ha ⁻¹	1.44	1.80	1.81	180.09	181.42	18.37
BB @ 16 t ha ⁻¹	1.68	1.91	2.04	184.44	190.65	18.46
RHB @ 2 t ha ⁻¹	1.66	1.57	1.90	188.64	172.07	14.50
RHB @ 4 t ha ⁻¹	1.86	1.66	2.02	217.07	189.68	17.10
RHB @ 8 t ha ⁻¹	1.81	1.70	2.13	237.61	179.46	14.48
RHB @ 16 t ha ⁻¹	2.11	1.82	2.27	293.21	186.86	14.72
SEm±	0.03	0.03	0.03	6.28	4.25	0.90
CD at 0.05	0.07	0.09	0.07	18.21	12.33	2.61

* WB - Wood biochar

BB - Bamboo biochar

RHB - Rice husk biochar

In alkaline soil, the Si content of 1.85, 1.96 and 2.08 per cent was recorded with application of WB, BB and RHB respectively. Increased level of application increased Si content of grain. Among different treatment combinations, RHB @ 16 t ha⁻¹ recorded significantly highest Si content (2.27 %) in grain followed by RHB @ 8 t ha⁻¹ (2.13 %) and least (1.63 %) in WB @ 8 t ha⁻¹. Application of WB recorded highest Si uptake (23.07 mg pot⁻¹) by grain than BB (22.02 mg pot⁻¹) and RHB (15.20 mg pot⁻¹). Application of different kinds and levels of biochar varied Si uptake by grain and ranged from 14.48 to 28.60 mg pot⁻¹. Highest Si uptake by grain was observed with application of WB @ 4 t ha⁻¹ and lowest with RHB @ 8 t ha⁻¹.

V DISCUSSION

The results of the investigation on “**Characterization of biochar, nutrient release and its effect on growth and yield of aerobic rice**” are discussed in this chapter under following headings.

5.1 Characterization of biochar for physic-chemical properties

5.2 Studies on release of nutrients and silicon from biochar in acidic, neutral and alkaline soil

5.3 Studies on biochar application on growth and yield of aerobic rice

5.1 Characterization of biochar for physic-chemical properties of biochar

Three different biochars used in the present study were derived from wood, bamboo and rice husk feedstock. The wood and bamboo biochar were pyrolysed at 550 °C and rice husk biochar at 400 °C. The biochars are characterized for different physical (BD, PD, porosity, MWHC, colour and ash content) and chemical (pH, EC, CEC and CCE) properties. There was significant variation in the properties of biochars used in the present study. The observed influence of feedstock type and pyrolysis temperature on physico-chemical properties of biochar was also reported by Gaskin *et al.* (2008) and Singh *et al.* (2010). It was also revealed that feedstock was a better predictor of variation in biochar properties than pyrolysis temperature as the differences in properties of bamboo and wood were noticed though produced at similar temperature.

Lower bulk density (0.31 g cm^{-3}) and particle density (1.32 g cm^{-3}) were recorded in WB (Table 3). Such lower BD values for biochar produced from woody materials were also reported by Pastor-Villegas *et al.* (2006) and Rodriguez-Reinoso (1992). Brewer *et al.* (2014) in a study estimated the BD values of biochars produced from different feedstock and it ranged from 0.25 to 0.6 g cm^{-3} . Oberlin (2002) also reported similar particle density of biochar which ranged from 1.5 to 1.7 g cm^{-3} . Brown *et al.* (2006) also observed lower (1.47 g cm^{-3}) particle density of pine wood biochar collected from natural fire site.

The higher porosity was recorded in WB (73.83 %) and lower in BB (57.27 %). Such variation in porosity can be attributed to feedstock type and pyrolysis temperature. The original structure of most types of materials is imprinted on the biochar product (Laine *et al.*, 1991; Wildman and Derbyshire, 1991; Lua *et al.*, 2004 and Amonette and Joseph, 2009b) and thus had an overwhelming influence on its final physical and structural characteristics. The difference in porosity may be attributed to differences in cell shape and size distribution in woody and herbaceous plants (Sun *et al.*, 2012; Wildman and Derbyshire, 1991). Further increase in porosity with temperature is caused by the progressive removal of volatiles from pores (Troeh and Thompson, 2005 and Chan and Xu, 2009).

Biochar derived from wood feedstock recorded higher MWHC (213.31 %) than other feedstock. Lower BD and higher porosity of WB contributed to higher MWHC.

Many of plant derived materials (e.g. coir pith) also reported to have higher MWHC. Jeyaseeli and Samuel, (2010) while characterizing the coir pith for physical properties concluded that water holding capacity of material depends primarily on number and size distribution of pores and specific surface area of material.

The Highest ash content (39.4 %) was recorded in RHB. Lower ash content of WB and BB can be attributed to lower mineral constituents. Wang *et al.* (2013) reported that ash content of biochars derived from different crop residue ranged from 14.5 to 40.3 percent with an average of 30.9 per cent. While, those produced from bamboo and elm feedstock recorded ash content ranging from 1.10 to 3.10 per cent. The high ash content of crop straw-derived biochars was mainly due to the accumulation of enrichment of various inorganic components (Singh *et al.*, 2010). Bi *et al.* (2008) observed higher ash content of 39 percent for rice straw derived biochar. Such high ash content of rice straw biochar can be ascribed to its high Si content (9 - 18 %) and other metal cations.

All the biochar were alkaline in nature and their pH ranged from 7.39 to 10.50 (Table 4). Such high pH values of biochar were also reported by Gaskin *et al.* (2008) and Singh *et al.* (2010). High pH of biochar can be attributed to hydrolysis of salts of Ca, Mg and K. Singh *et al.* (2010) reported lower pH values for wood biochars than crop and manure derived biochar. In contrary, in the present study WB recorded higher pH than crop residue biochar which can be attributed to higher production temperature and presence of higher exchangeable and soluble salts. Gaskin *et al.* (2008) recorded an increase in pH of biochar produced from pine chip feedstock from 7.55 to 8.30 when pyrolysis temperature was increased from 400 to 500 °C.

The presence of higher soluble salts in the biochars resulted in higher EC value. Wabel *et al.* (2013) observed the EC values of 0.76 and 1.34 dS m⁻¹ respectively for biochar produced at 200 and 400 °C. However, these values sharply increased with the pyrolysis temperature up to 600 and 800 °C and amounted to 9.03 and 10.26 dS m⁻¹, respectively.

The CEC of different biochar used in the present study ranged from 23.43 to 38.63 cmol (p⁺) kg⁻¹ recording highest in RHB. The higher CEC of RHB can be attributed to its lower production temperature. Biochar produced at lower temperature contain ample of functional groups which contributes to CEC. The acidic functional groups present on biochar surfaces contribute to its CEC (Cheng *et al.*, 2008). Decrease in functional group with increase in temperature from 300 °C to 500 °C was reported by Yuan *et al.* (2011). Similarly Gaskin *et al.* (2008) reported that for a same feedstock, CEC of biochar produced at 500°C were significantly lower than that produced at 400 °C.

The carbon content in different biochar ranged from 39.33 to 75.50 recording higher in BB and WB and least in RHB (Table 5). Ash rich RHB contained more minerals especially Si (32.50 %) which decreased C content. RHB recorded higher N, P, Zn and Fe while WB contained higher exchangeable bases, Mn and Cu. The values of different nutrients in biochar are similar to those reported in literature (Gaskin *et al.*, 2008 and Singh *et al.*, 2010).

5.2 Studies on release of nutrients and silicon from biochar in acidic, neutral and alkaline soil

5.2.1 Studies on different sources and levels of biochar application on soil pH and EC in different soils

Perusal of data presented in Table 6-8 and Fig. 1 revealed the significant effect of application of different sources of biochar on soil pH in all studied soils. Application rate recorded significant effect on soil pH at all intervals in acidic soil, only at 30, 90 and 120 DAI in neutral soil and a non significant effect in alkaline soil at all intervals. Among different biochars used, WB increased the pH of soil to a greater extent than other two sources in all studied soils and at all intervals. Application level of 16 t ha⁻¹ recorded significantly higher pH than other levels in acidic and neutral soils at all intervals.

The observed changes in pH of soil incubated 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. Accompanying this reaction, there could be increase in soil solution pH caused by the depletion of the readily hydrolysable monomeric Al and the formation of the more neutral [Al(OH)₃]⁰ species (Novak *et al.*, 2009). The findings of present study is in line with several authors (Chan *et al.*, 2007; Liard *et al.*, 2010b; Yamato *et al.*, 2006) who recorded increase in soil pH by applying different kinds of biochar to soil. Application of wood bark biochar at 37 t ha⁻¹ increased the pH by 1.0 to 1.5 units (Yamato *et al.*, 2006).

The ameliorating effect of biochar is dependent on its pH values, pyrolysis temperature and feed stock materials. The pH of WB, BB and RHB used in the present investigation are 10.50, 10.03 and 7.39 respectively. The ameliorating effects of the biochars increased with increase in pyrolysis temperature, which is consistent with changes in alkalinity of biochars. Yuan and Xu (2011), reported a significant positive linear correlation between biochar-treated soil pH and biochar pH ($r^2 = 0.46$). Gaskin *et al.* (2010) reported lower pH responses with the application of pine chip biochar compared to pea shell biochar due to its lower base cations. Similarly, in the present study, application of WB recorded higher pH increase over control in comparison to other two sources due to high pH and CCE and presence of higher basic cations.

Application of RHB recorded lower pH values than other two sources at all intervals and in all studied soils. This may be due to lower production temperature, lower pH value and lower C:N ratio. McBeath and Smernik (2009) reported faster mineralization with application of low temperature biochars. Similarly, Harris *et al.* (2013) observed that peanut hull biochar respired more carbon than pine chip biochar as it contains three times more ash and approximately 12 g kg⁻¹ more aliphatic compounds than pine chip biochar. In the present study, possible mineralization and subsequent nitrification of RHB might have reduced pH of soil though it contained higher ash content (39.4 %). Similarly, Yuan *et al.* (2011) in an incubation study demonstrated that

increase in soil pH with application of different crop residue was proportional to the ash alkalinity of the plant materials, but inversely to their N content.

Increased rate of application of biochar increased soil pH at all intervals. Biochar application is known to increase pH of acidic soils which are base poor soil. Such observations are in line with Chintala *et al.* (2014); Anteneh *et al.* (2014) and Hass *et al.* (2012). Increased rate of application increased the addition of bases and there by recorded higher pH in the present investigation. These 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. Application of 0 to 12 t ha^{-1} of biochar reduced exchangeable acidity from 0.60 to 0.39 $\text{cmol (p}^+) \text{kg}^{-1}$.

Interestingly, low pH responses were observed with application of biochar to alkaline soil and application rates found to be non significant at all intervals. This may be due to native alkalinity, higher exchangeable bases and buffering capacity of alkaline soil.

Decrease in soil pH of all the soils amended with different biochars at different levels with increased period of incubation in the present investigation may be due to decomposition of organic matter and nitrification. The balance between input of ash alkalinity from biochar and decomposition of organic matter of soil determines the final soil pH of biochar amended soils. Such decrease in pH with incubation time was also noticed by Yuan *et al.* (2011), Hass *et al.* (2012) and Wan *et al.* (2014). Yuan *et al.* (2011) showed that the pH of crop straw derived biochar-amended acidic *Ultisol* decreased with incubation period, eventhough the pH was still higher than that of the control.

Immediate decrease in soil pH of neutral soil at 15 DAI may be due to high native nitrogen content (671 kg of N ha^{-1}) of soil. This high amount of initial N might have undergone nitrification leading to decreased pH (Catherine and David, 1999). The presence high levels of ammonium in soil will support intensive nitrification (Alexander, 1977). This microbial oxidation reaction leads to the formation of HNO_3 , a strong acid that can acidify the soil (Miegroet And Cole, 1984).

Application of various types and levels of biochar varied soil EC to less extent but significant and followed no definite trend with sources, rate and soil type over a period of incubation (Fig. 2). Significant effect of biochar application on EC was observed at 30, 60 and 90 DAI in acidic and neutral and only at 90 DAI in alkaline soil. Significant increase in EC with biochar application was often reported in literature (Chintala *et al.*, 2014; Glaser *et al.*, 2000; Gundale and De luca, 2007 and Chan *et al.*, 2008). Lower EC in some of biochar amended treatments were recorded at different intervals in present investigation compared to control and may be attributed to possible sorption of salts by biochar amended soil. Such low variation in EC of biochar treated soil was also noticed by Thomas *et al.* (2013). Artiola *et al.* (2012) observed the range of variation in EC from 1.1 to 1.2 dS m^{-1} in a pot leachate regardless of treatment of pine waste biochar with no

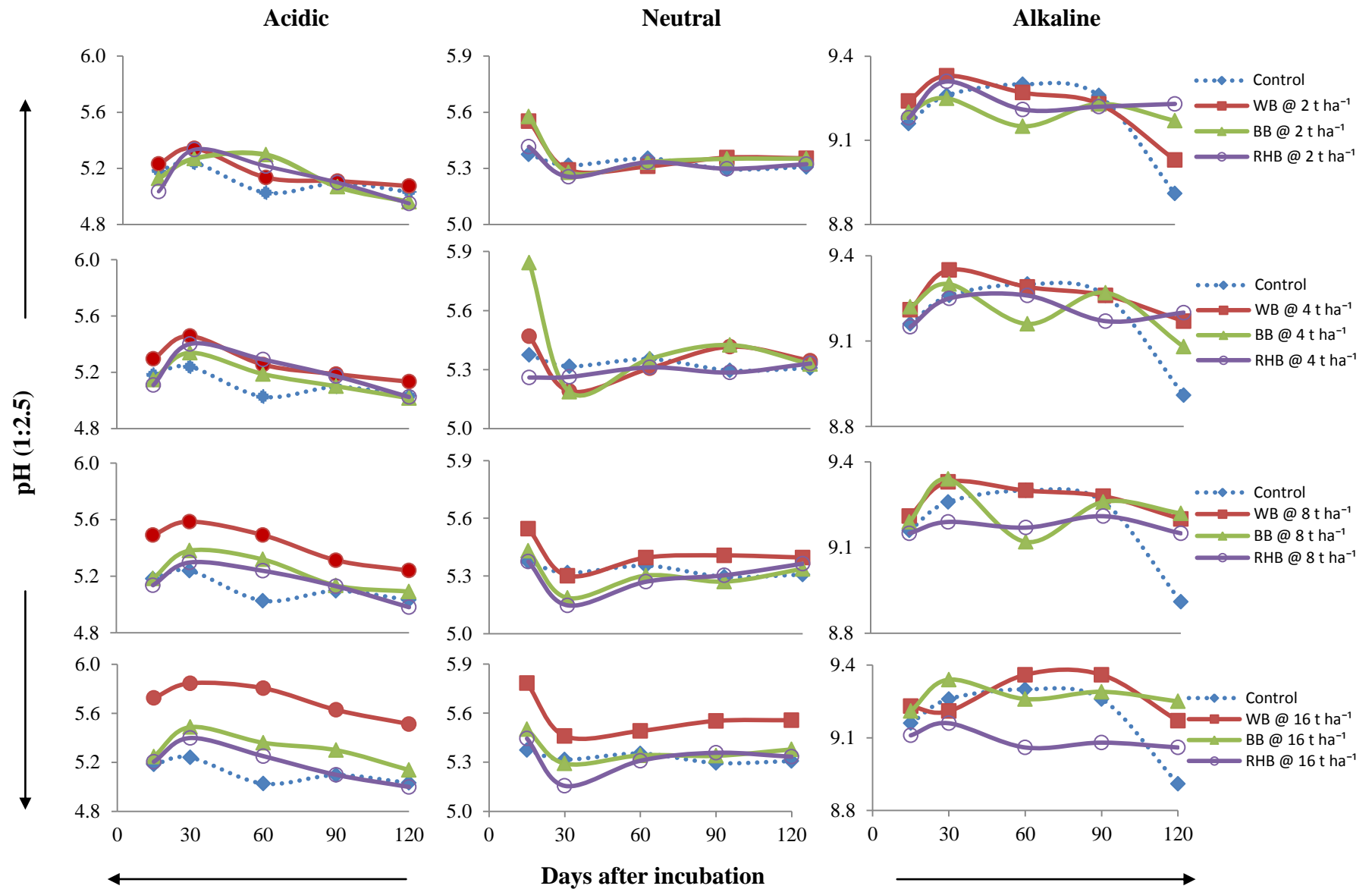


Fig. 1: Effect of different sources and levels of biochar application on soil pH in different soils

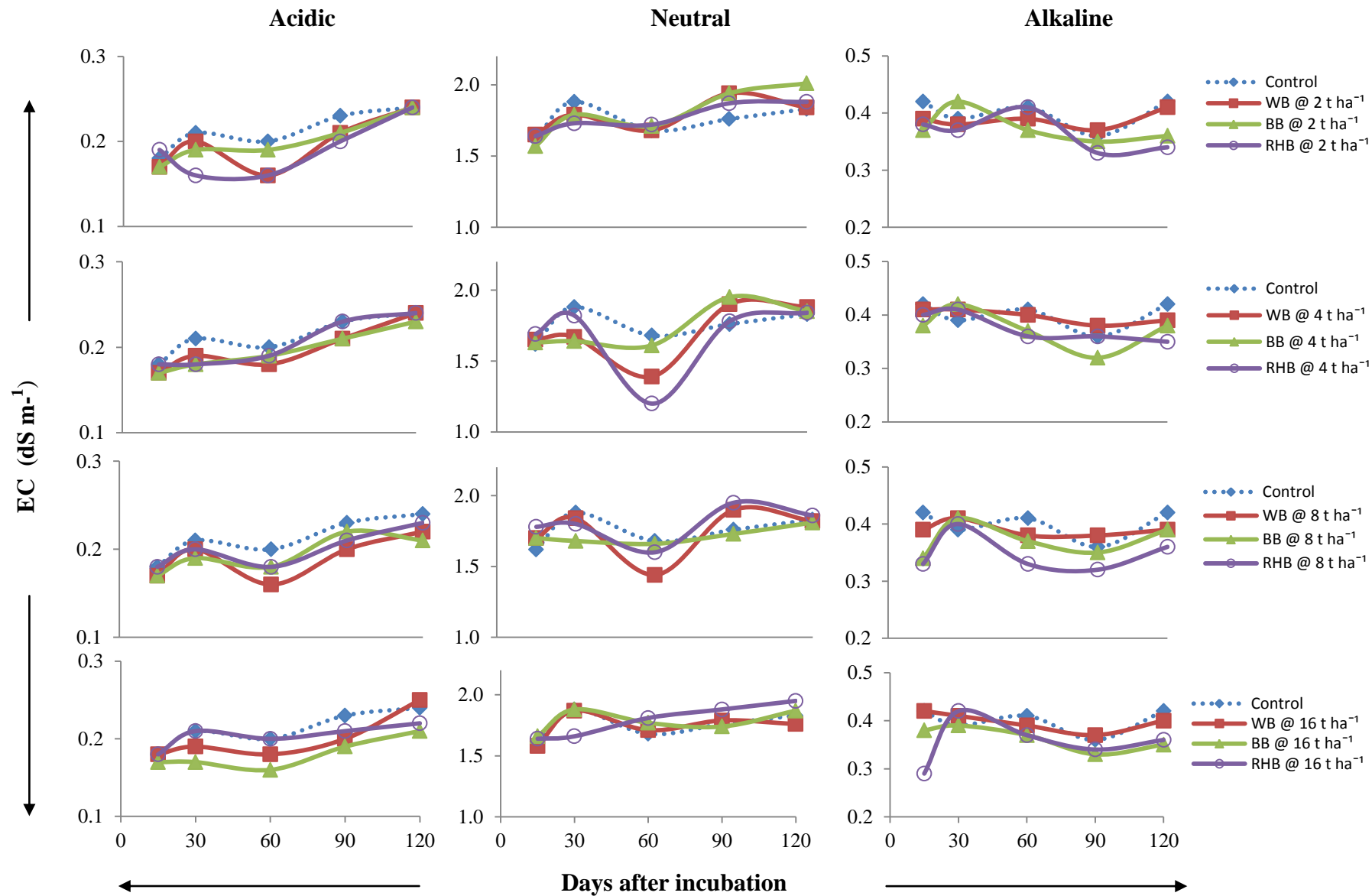


Fig. 2: Effect of different sources and levels of biochar application on EC (dS m⁻¹) of different soils

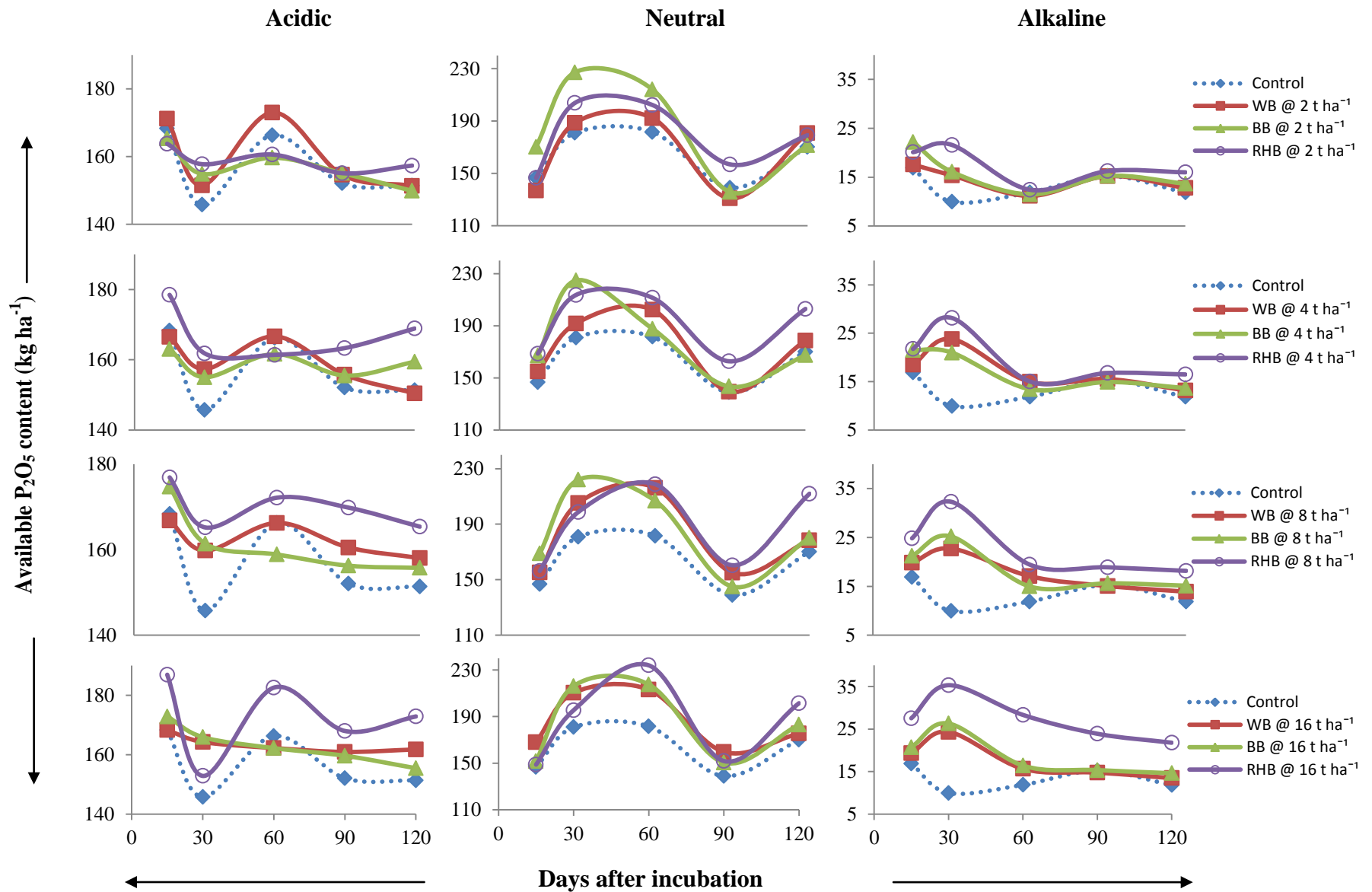


Fig. 3: Effect of different sources and levels of biochar application on available phosphorus content (kg ha⁻¹) of different soils

temporal trend though it contains 2,200 mg kg⁻¹ of water soluble salts. The increase in soil EC was likely temporary and small and was not consistently detected in the biochar-treated soils as noticed in the present study.

5.2.2 Studies on different sources and levels of biochar application on soil available phosphorus in different soils

Perusal of data presented in Table 9 to 11 and Fig. 3 revealed the significant effect of sources of biochar, application rates and their interaction on soil available P₂O₅ content in all studied soils at all intervals.

Independent of types and levels, biochar application increased available P₂O₅ content in all studied soils. The possible mechanism for increased P₂O₅ availability with biochar application in soil can be attributed to a) presence of soluble and exchangeable phosphate in biochar b) modifier of soil pH and ameliorator of P complexing metals (Al³⁺, Fe³⁺) c) promoter of microbial activity and hastening P mineralization. Such increase in available P₂O₅ content with biochar addition was also reported by Laird *et al.* (2010); Novak *et al.* (2009); Parvage *et al.* (2013) and Hass *et al.* (2012).

In present investigation, among the different sources of biochar, application of RHB recorded significantly higher available P₂O₅ than other two sources in all studied soils. Significantly higher available P₂O₅ content of 166.11, 157.98 and 18.11 kg ha⁻¹ was noticed with application of RHB at 120 DAI in acidic, neutral and alkaline soil respectively (Table 9-11 and Fig 3).

The nutrient content of biochars is largely influenced by the type of feedstock and pyrolysis conditions (Singh *et al.*, 2010), whereas the availability of nutrients in biochars is related to the type of bonds associated with the element involved (De Luca *et al.*, 2009 and Yao *et al.*, 2010). Phosphorus is mainly found in the ash fraction, with pH-dependent reactions and presence of chelating substances controlling its solubilisation (De Luca *et al.*, 2009). Further Mukherjee and Zimmerman (2013) in a study observed that, lower temperature fresh biochar (250 °C) released more nutrients than higher temperature biochars (650 °C) and grass biochar released more nutrients than wood biochars. Similarly, in present study higher available P₂O₅ content of RHB amended soil may be due to higher total P content (0.24 %), higher ash content (39.4 %), lower production temperature and being a non wood source.

Higher available P₂O₅ content was observed at 15 DAI, 60 DAI and 30 DAI in acidic, neutral and alkaline soil, respectively. In general, there was decrease in P₂O₅ content over a period of incubation in acidic and alkaline soil. Such observations were similar to those reported by Sample *et al.* (1980) and Sharpley *et al.* (1983). The combination of adsorption and precipitation of P with Fe³⁺, Al³⁺ and Ca²⁺ reduced the available P over a time. Lehmann (2007) reported that biochar can adsorb > 3000 mg kg⁻¹ of phosphates even at low solution concentration of 40 mg L⁻¹. Such adsorption can greatly contribute to reduction of P content in soil solution. Besides adsorption, precipitation of P can be expected with Al and Fe in acidic soil and with Ca in alkaline soil. Xu *et al.* (2013) found that among different fractions of P, Ca-P was greatly

enhanced with biochar application. Decrease in Ca content at 30 DAI in acidic soil can be linked to precipitation of P as Ca - P in the present study. Similar observation was also noticed by Huck *et al.* (2014).

In present study, there was an increasing trend of available P₂O₅ content with incubation time in neutral soil. Similar to pH, there was also decrease in soil available P₂O₅ content till 30 DAI. But over a period of incubation time mineralization might have increased the P₂O₅ content in soil.

5.2.3 Studies on different sources and levels of biochar application on soil exchangeable bases in different soil

There was a significant effect of application of different kinds and levels of biochar on exchangeable bases in acidic, neutral and alkaline soils (Table 9- 14, 21-23 and Fig. 4-7)

Exchangeable bases such as Ca, Mg, K and Na content in soil varied significantly with application of biochar of different kinds and levels. Higher exchangeable Ca content in soil was observed with application of WB than other two sources in both acidic and neutral soils. In comparison to control, significantly higher exchangeable Ca and Mg contents were observed in acidic and neutral soil only. Irrespective of types and levels, application of biochar to all soils increased the exchangeable K significantly over control.

Increase in exchangeable bases in soil at different intervals 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).

In present investigation, the WB had higher amount of exchangeable bases than other two sources and thereby application of WB recorded higher exchangeable bases in acidic and neutral soil. In alkaline soils, the observed changes in exchangeable Ca, Mg and Na were found to be either on par with control or lower and followed no definite trend with biochar addition. This was mainly attributed to higher content these bases in native soil which masked effect of biochar addition or/and less dissolution of ash in alkaline soil. Similarly Van Zwieten *et al.* (2010) applied the paper mill waste biochar to a Ferrosol and Calcareous soil. Significant increase in pH, exchangeable Ca content and CEC over control was observed in Ferrosol where as a non significant effect on these parameters was observed in Calcareous soil with application of biochar.

Exchangeable K increased significantly with addition of biochar in all studied soils and at all application rates. Silber *et al.* (2010) studied the kinetics of release of K, Ca and Mg from corn straw biochar. The release of Ca and Mg was pH dependent and followed zero order reaction and their release was increased with decreasing pH. This pH effect can be explained for observed varied effect of biochar application on exchangeable

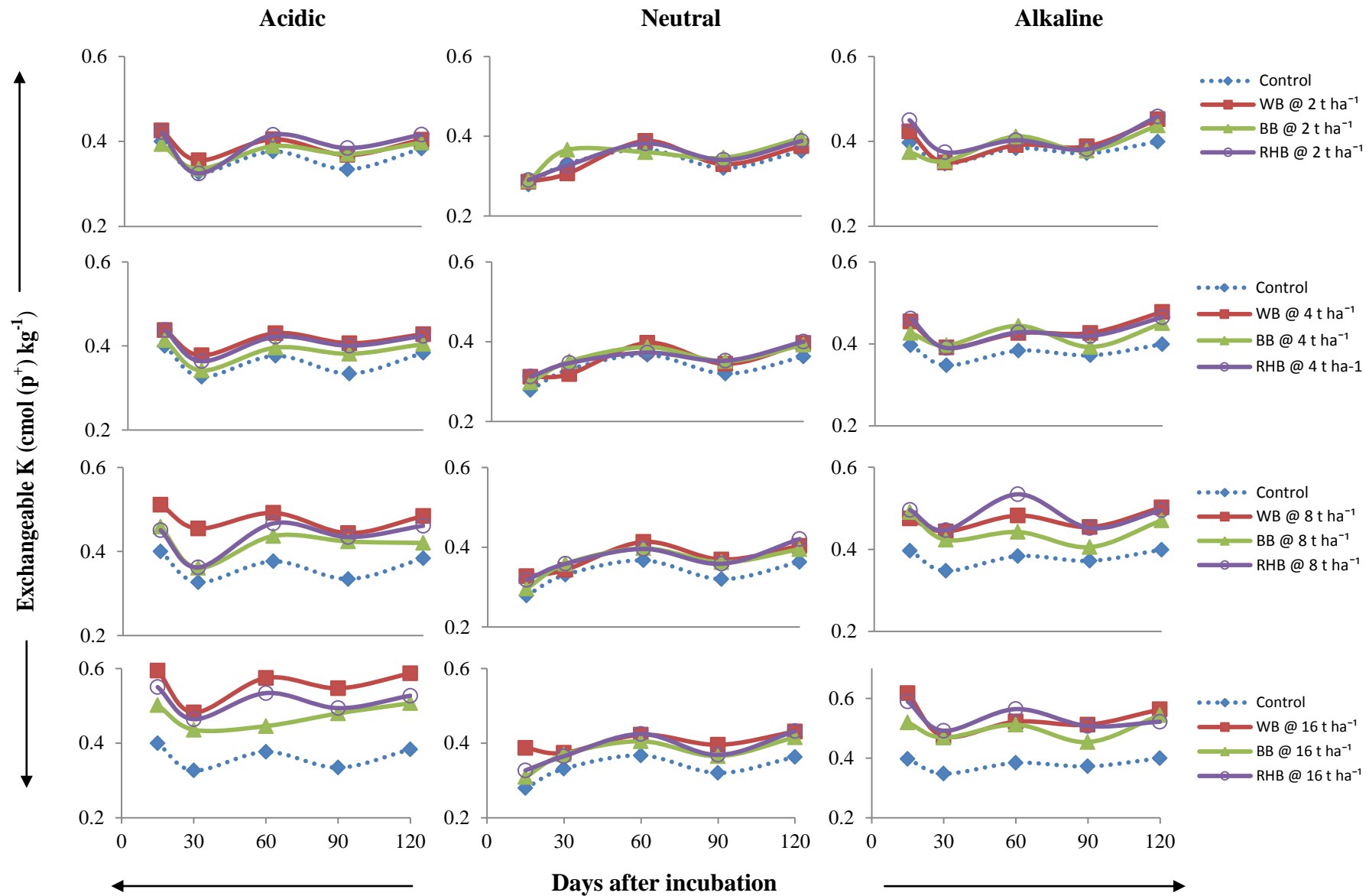


Fig. 4: Effect of different sources and levels of biochar application on exchangeable potassium [cmol (p⁺) kg⁻¹] in different soils

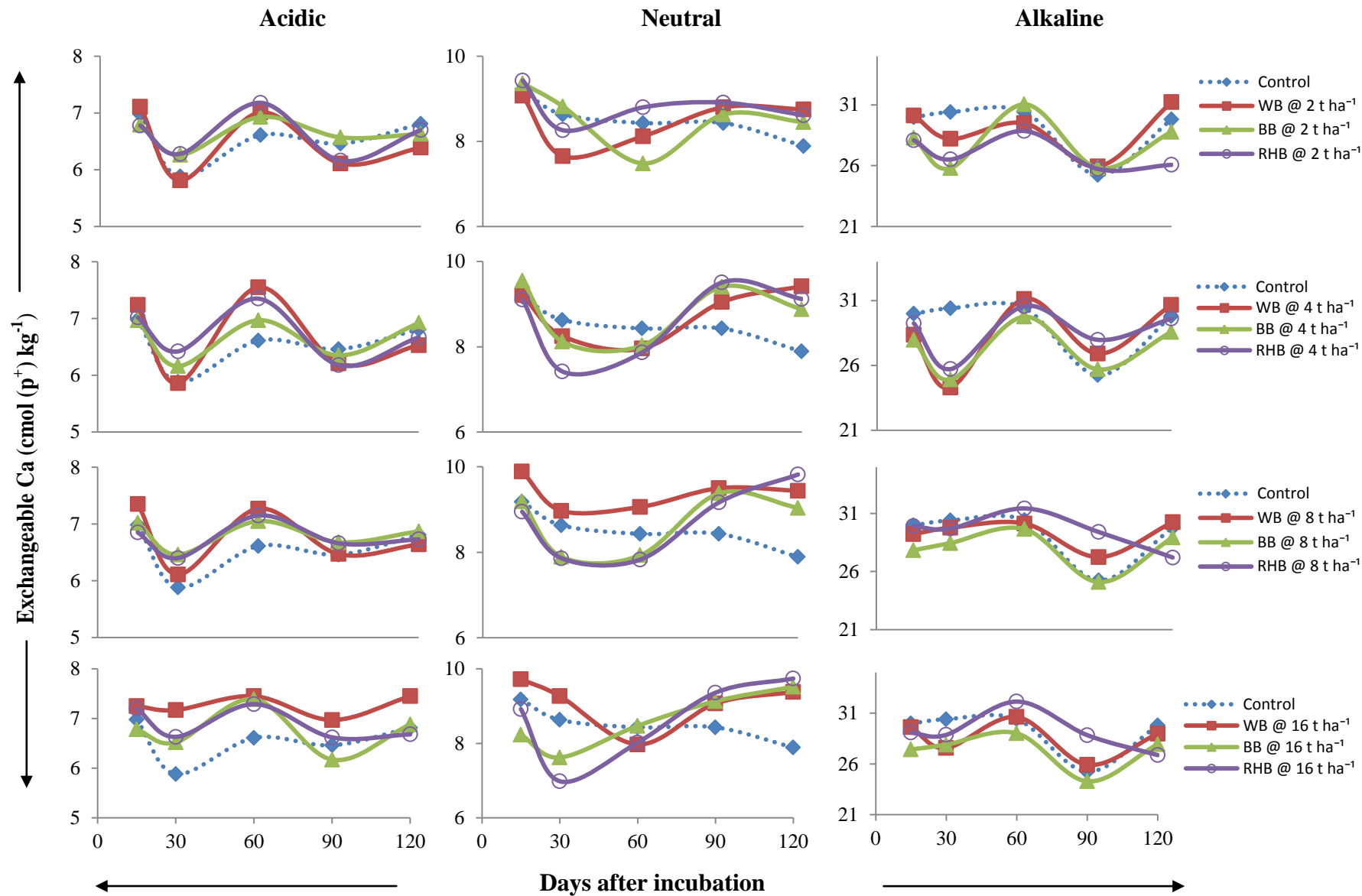


Fig. 5: Effect of different sources and levels of biochar application on exchangeable calcium [cmol (p⁺) kg⁻¹] in different soils

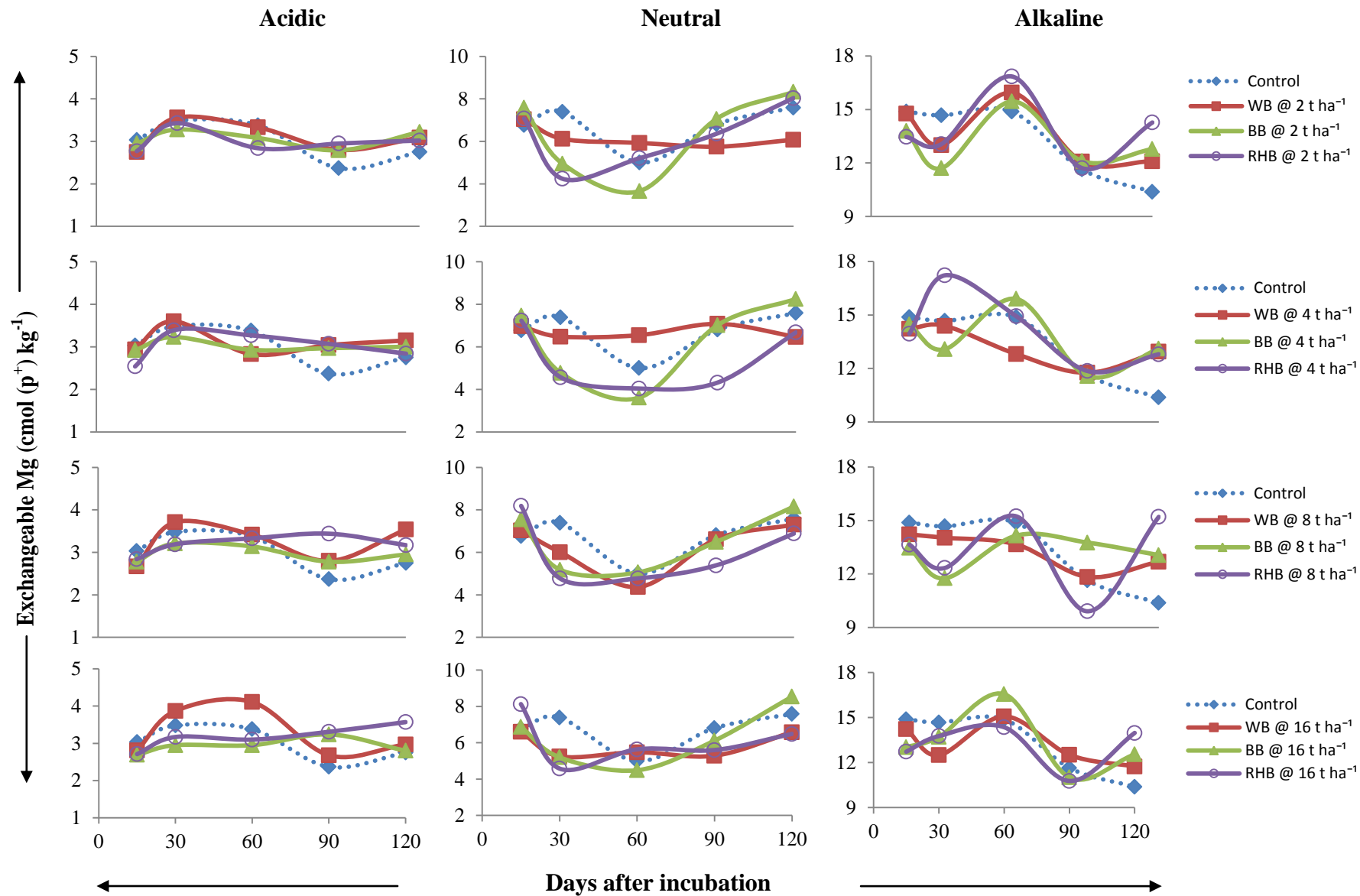


Fig. 6: Effect of different sources and levels of biochar application on exchangeable Magnesium [cmol (p⁺) kg⁻¹] in different soils

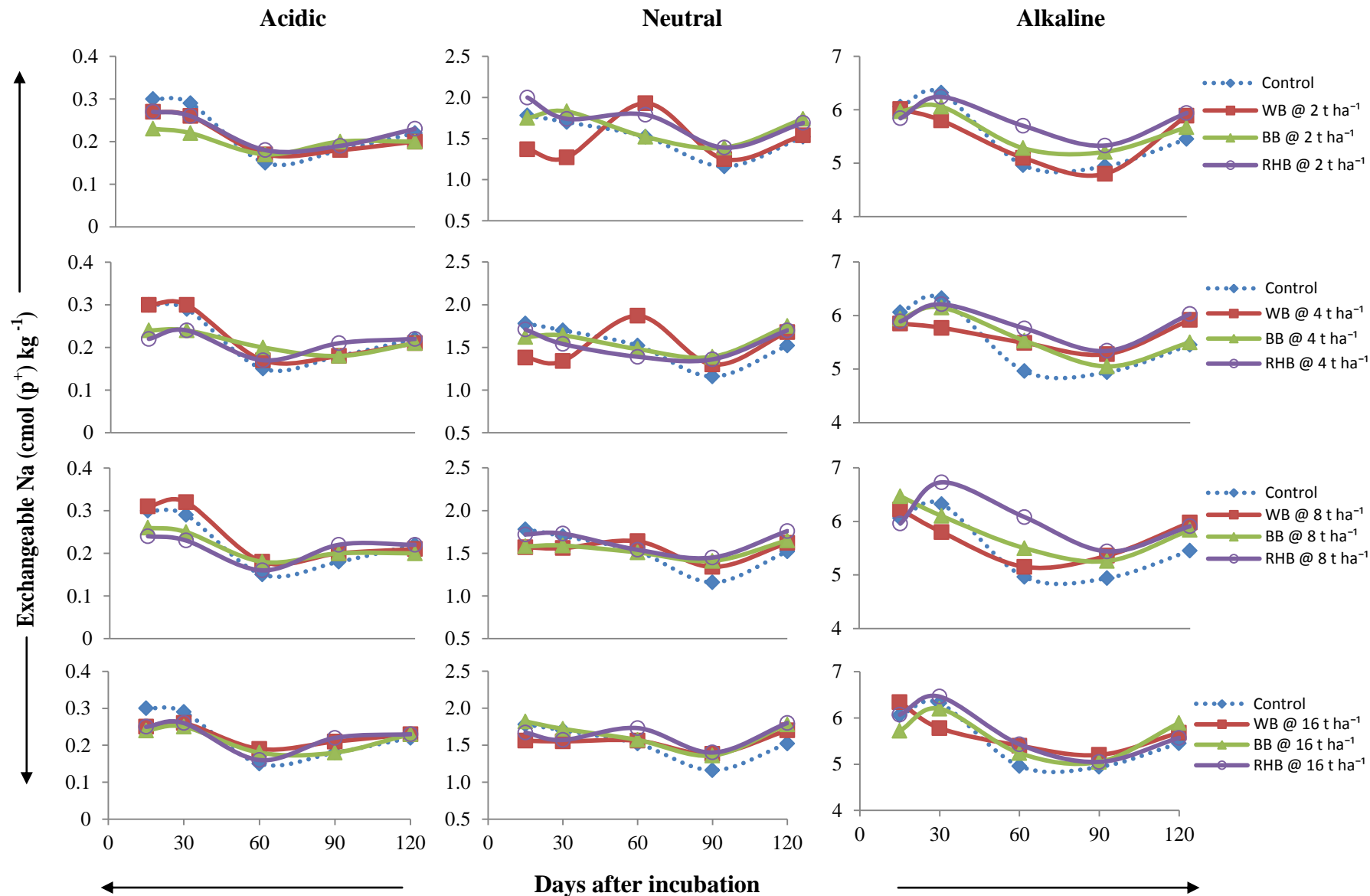


Fig. 7: Effect of different sources and levels of biochar application on exchangeable sodium [cmol (p⁺) kg⁻¹] in different soils

Ca and Mg in different soils of present study. Also they observed rapid release of K which was neither pH dependent nor followed zero order reaction. Thus there was an increase in exchangeable K content in all studied soils with application of biochar at all levels in present study.

In the present study, there was no definite pattern of increase or decrease in exchangeable bases with application of different biochars at different levels over a period of incubation time. This may be due to equilibrium balance between different pools of these bases. The water soluble, exchangeable and non exchangeable pools are always found to be in equilibrium. Increased level of water soluble bases by addition of biochar might have altered the equilibrium among different pools. Higher surface area of biochar might have also resulted in adsorption and desorption of these exchangeable bases. Most alkali and alkaline earth cations undergo non-specific adsorption with exchange complex (Abd-Elfattah and Wada 1981; Namgay *et al.*, 2010) and thereby exhibit variation in their content with time. Jien and Wang (2013) observed corresponding variation in CEC of biochar amended soil with incubation time suggesting contribution of biochar ability to sorb and desorb bases.

Application of different biochars and different levels improved the content of exchangeable bases in acidic and neutral soils. Whereas the higher exchangeable Ca and Mg content in alkaline soil masked the real contribution of biochar.

5.2.4 Studies on different sources and levels of biochar application on micronutrient content in different soil

Data pertaining to effect of application of biochar on micronutrient content are presented in Table 15 - 20 and Fig. 8 - 11.

There was no definite trend in micronutrient content with application of different types and levels of biochar over a period of incubation in both acidic and neutral soils. Among three different sources, application of RHB recorded higher Zn and Fe content in acidic and neutral soil while significantly reduced Fe and Mn content in alkaline soil at all intervals. The Fe content of non amended alkaline soil ranged from 2.31 to 4.04 ppm and reduced to 0.84 to 2.91 ppm by application of different levels of RHB over a period of incubation. Similarly the content of Mn ranged from 3.64 to 7.75 ppm in control reduced to 2.90 to 6.96 ppm with different levels of RHB over a period of incubation. In alkaline soil, irrespective of types and levels, application of biochar significantly reduced the Zn content but Cu content only at higher rates of application.

Application of WB in acidic and neutral soil reduced all micronutrient content over a period of incubation. However Zn and Cu content did not vary much with WB application in comparison to control. In acidic soil, Fe content in unamended soil ranged from 51.40 to 83.95 ppm and decreased to 50.81 to 73.48 ppm with WB application. Similarly Mn content of 45.35 and 36.30 were recorded in control and WB treated soil. In neutral soil, Fe content in control ranged from 30.70 to 42.05 ppm decreased to 28.06 to 41.58 ppm. Similarly Mn content in unamended soil ranged from 96.80 to 223.57 ppm and decreased to 84.01 to 182.07 ppm with application of WB.

The variation in micronutrient content in soil with the application of different biochars can be attributed to their physical and chemical properties. Biochars by virtue of its high surface area, high metal affinity, higher nutrient retention capacity, presence of acidic and basic functional groups and ability to alkalize soil might result in immobilization of micronutrients in soil. Such of these mechanisms of metal immobilization due to biochar application were also reported by Park *et al.* (2011), Vithanage *et al.* (2014), Cao *et al.* (2009), Novak *et al.* (2009) and Paz- Ferreiro *et al.* (2014).

Although there was an increase in Cu content with biochar application no definite pattern was obtained with application rate in the present study. 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.

Higher concentration of micronutrients with application of RHB may be due to its lower adsorption capacity. As noticed by Jindo *et al.* (2014) RHB exhibited lower adsorption property due to its lower production temperature. On the other hand application of RHB in alkaline soil reduced Fe, Mn and Cu content significantly than other two sources. However, specific reasons for such varied response of RHB in different soils are unexplainable.

Application of biochars, specifically WB reduced Fe and Mn content in acidic and neutral soil which might be due to adsorption and possible immobilization. Application of BB and WB recorded higher pH than RHB and control at all intervals in present study. As pH and micronutrient availability are negatively correlated immobilization of micronutrient can be expected. Observed trend of decreased metal content with increased rate of biochar application was likely a function of the increase in total amount of active sites. Chen *et al.* (2011) in a study observed that increased adsorbent concentration (biochar) increased the percentage removal of heavy metal from aqueous solution.

Park *et al.* (2011) reported that addition of biochar to soils might modify some chemical properties such as cation exchange capacity and soil acidity, providing circumstances that are suitable for heavy metal immobilization and subsequently reducing their availability. The heavy metal immobilization and sorption onto biochars might be ascribed to several combined processes of ion exchange, chemisorption, complexation and surface interaction (Ahmad *et al.*, 2014b; Usman *et al.*, 2013; Park *et al.*, 2011; Cao *et al.*, 2009). Lu *et al.* (2012) reported that complexation of the heavy metals with biochar functional groups can be attributed to physical adsorption or the metal exchange with biochar alkali and alkaline earth cations.

5.2.5 Studies on different application of different sources and levels of biochar on CaCl₂ - Si in different soils.

Data presented in Table 21-23 and Fig. 12 revealed the significant effect of sources and levels of biochar application CaCl₂ - Si content in different soils.

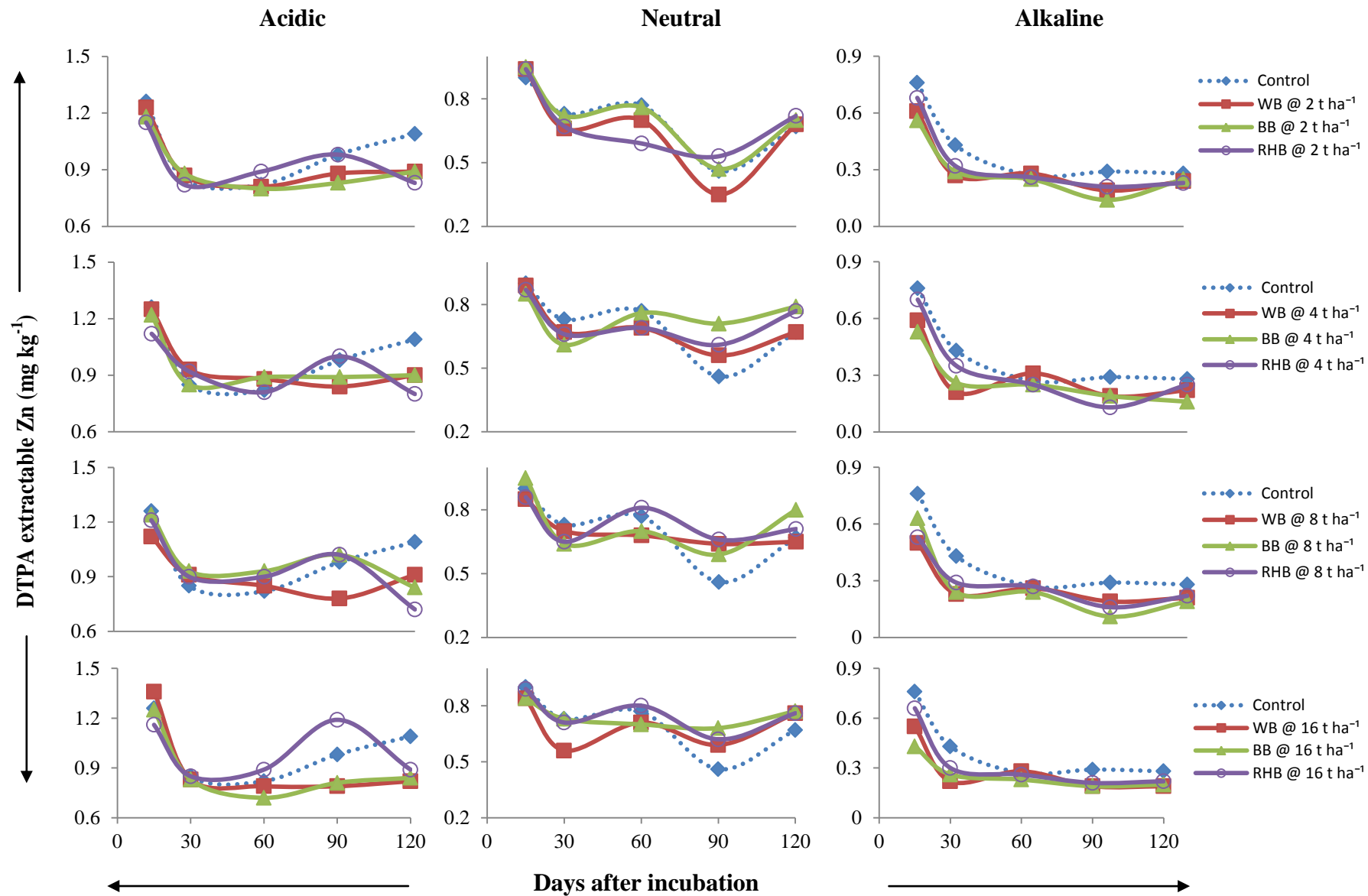


Fig. 8: Effect of different sources and levels of biochar application on DTPA extractable zinc (mg kg⁻¹) in different soils

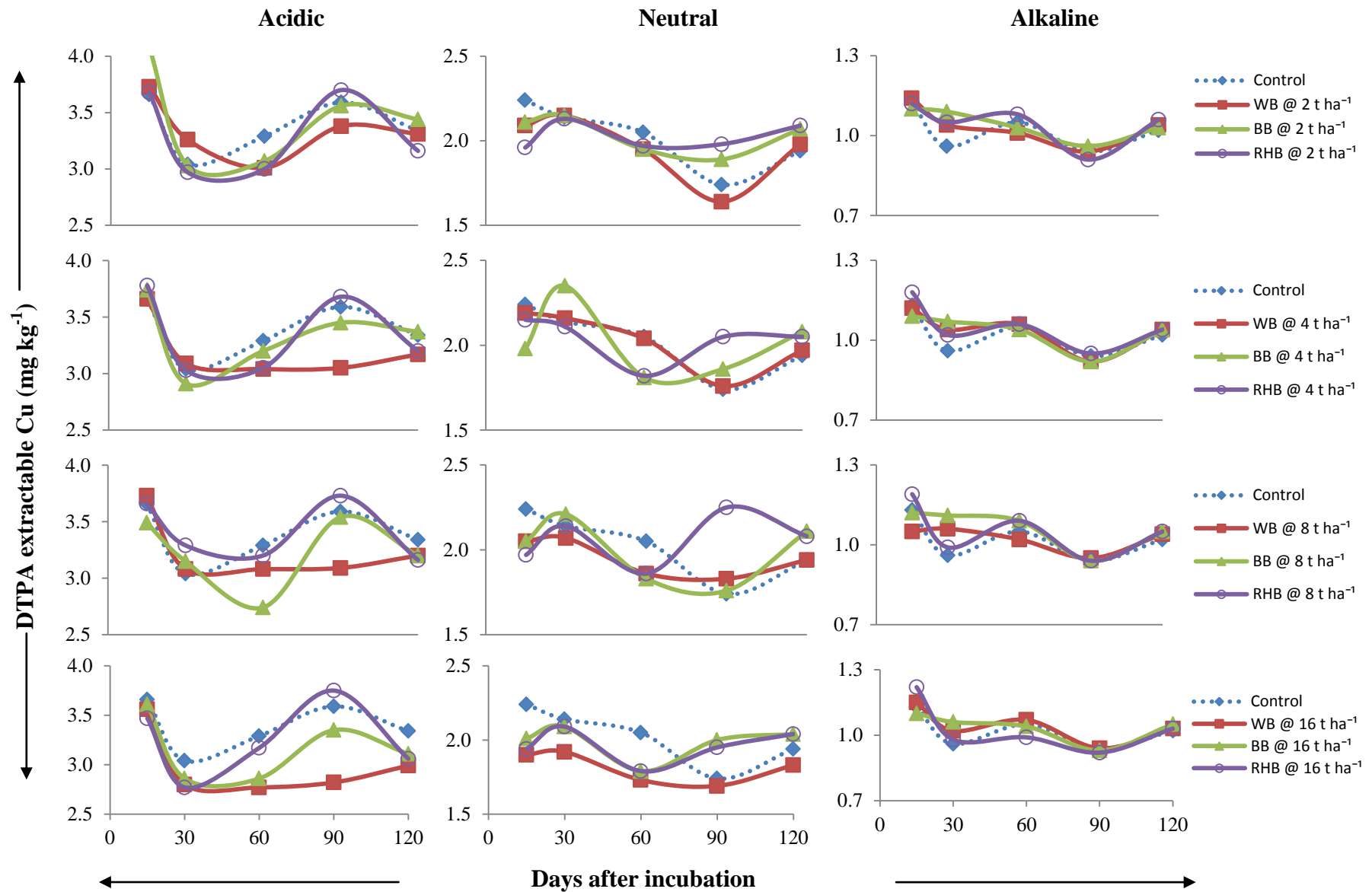


Fig. 9: Effect of different sources and levels of biochar application on DTPA extractable copper (mg kg^{-1}) in different soils

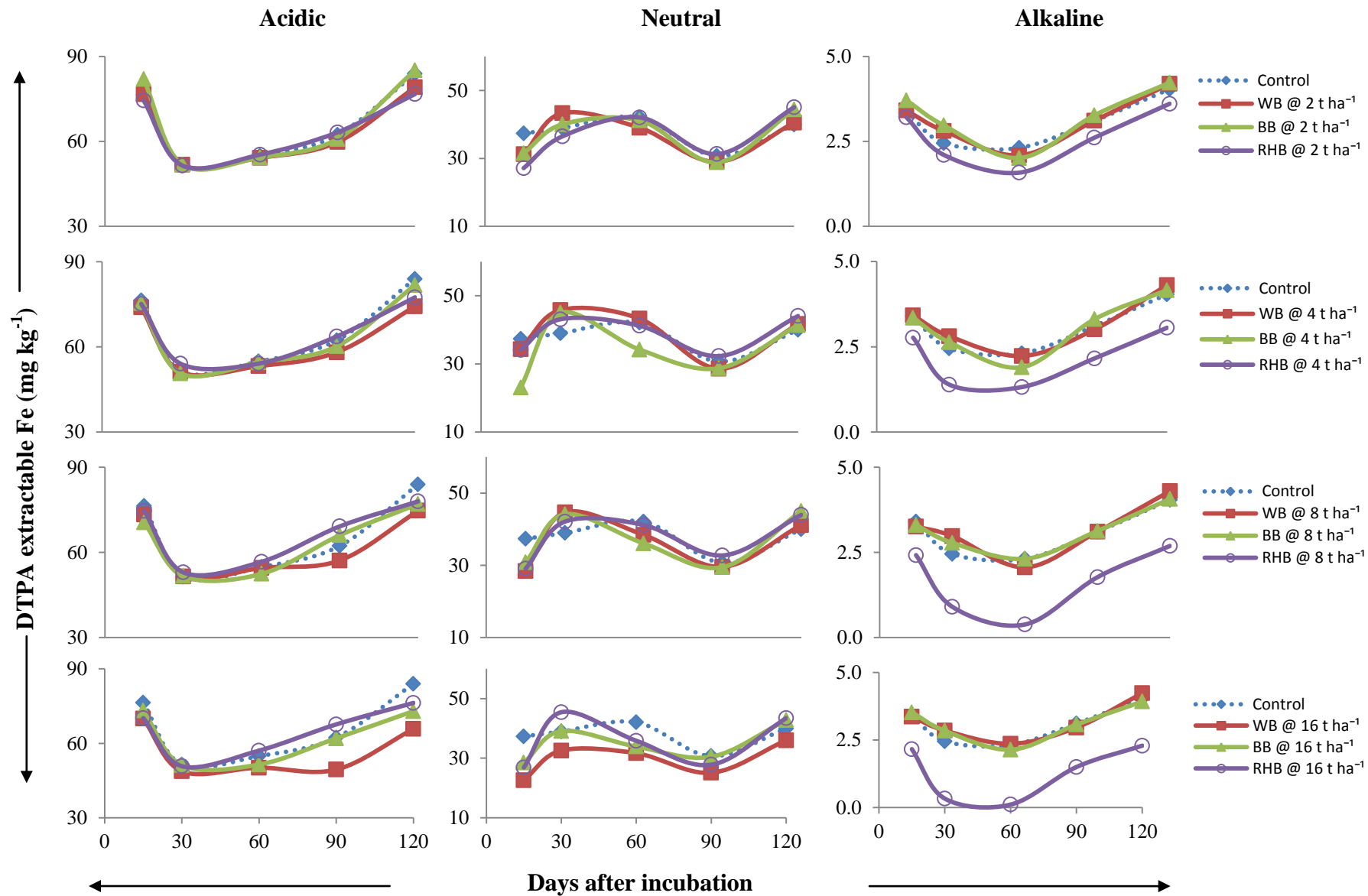


Fig. 10: Effect of different sources and levels of biochar application on DTPA extractable iron (mg kg^{-1}) in different soils

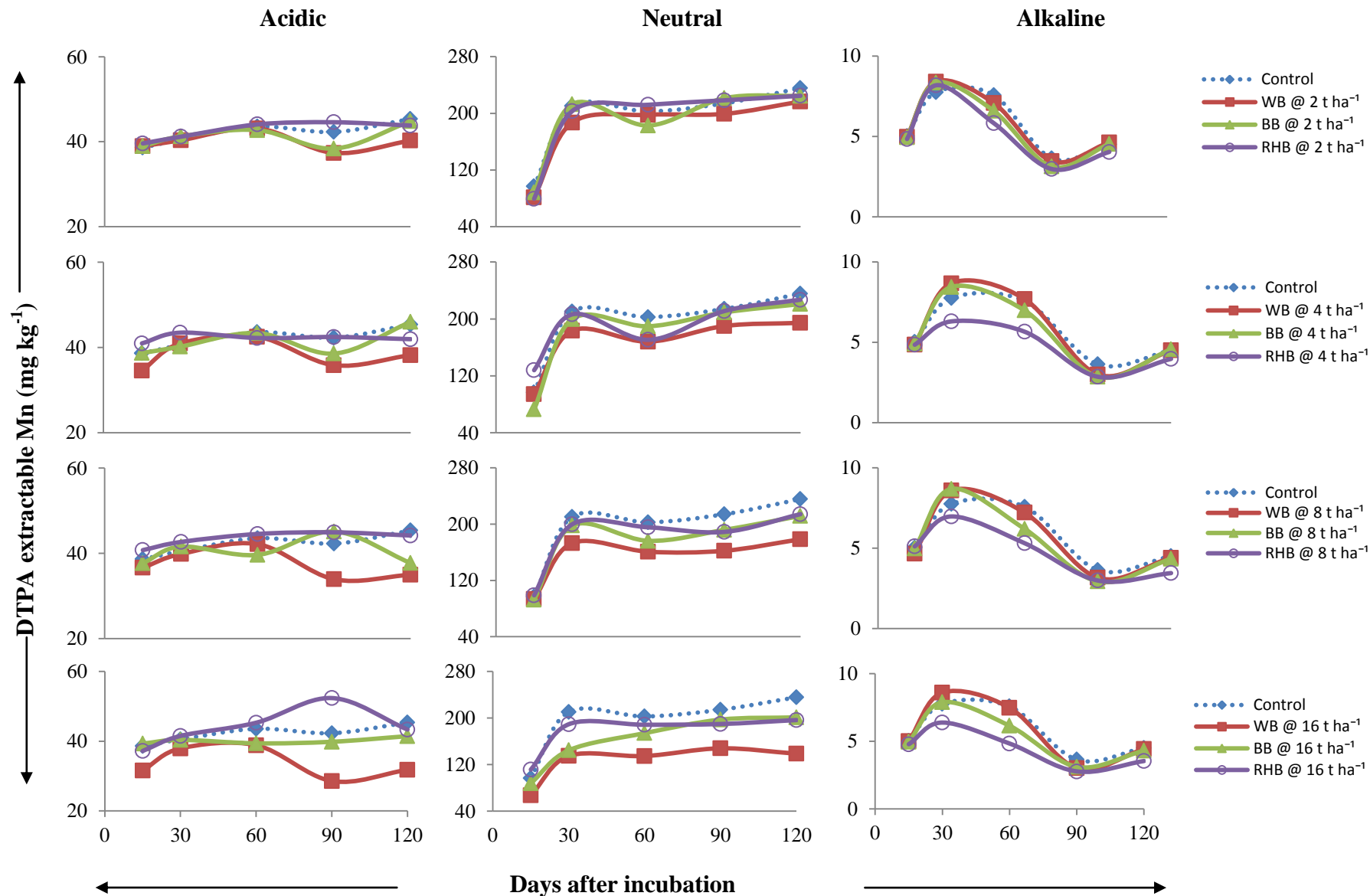


Fig. 11: Effect of different sources and levels of biochar application on DTPA extractable manganese (mg kg⁻¹) in different soils

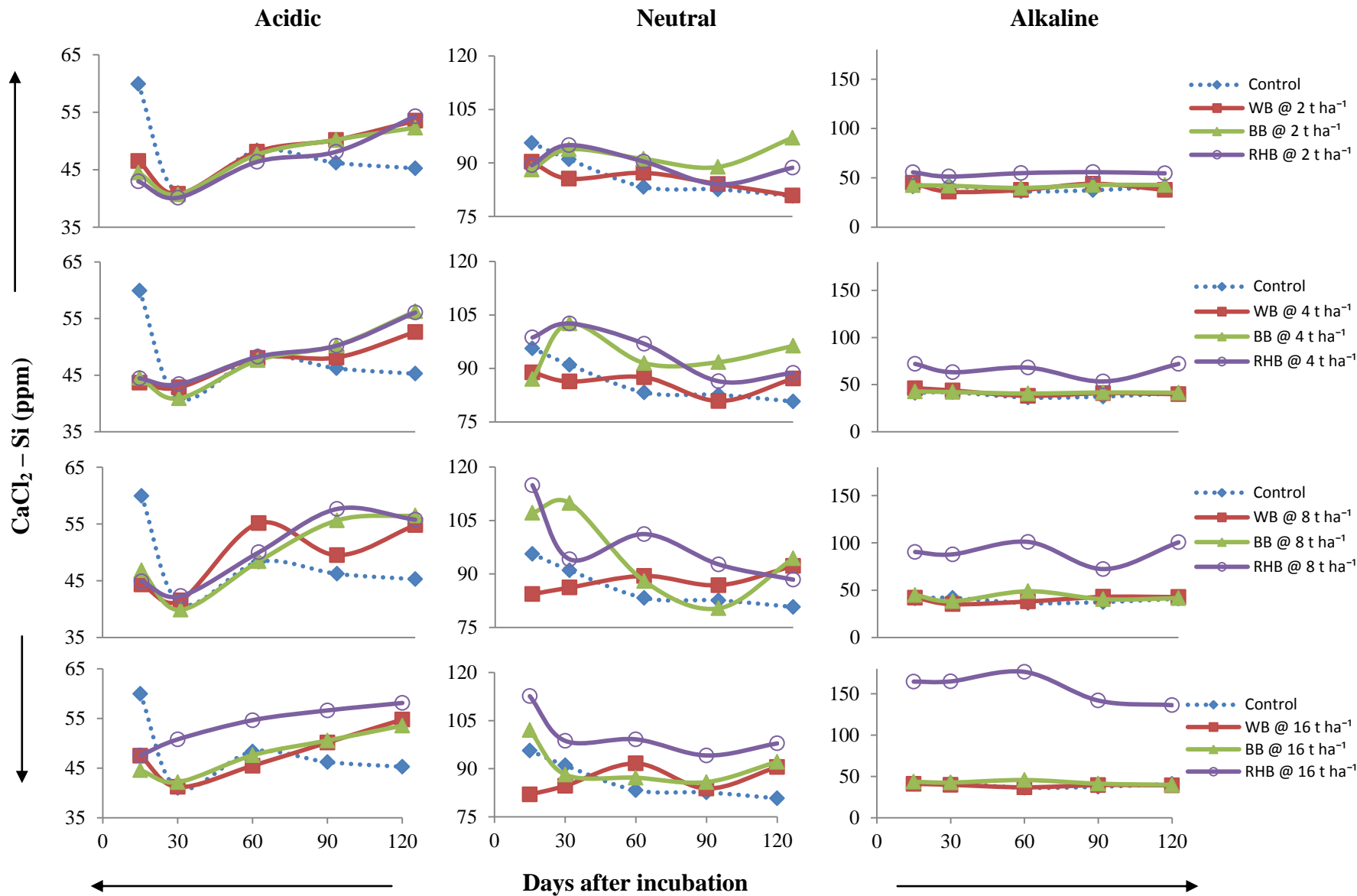


Fig. 12: Effect of different sources and levels of biochar application on CaCl₂ - Si (ppm) in different soils

Application of different kinds and levels of biochar in acidic soil recorded lower CaCl_2 - Si at 30 DAI (39.87 - 50.78 ppm) and there after gradual increasing trend was observed till end of incubation period (45.26 to 58.11 ppm). In acidic soil, increasing trend was observed with incubation time while no definite trend was followed in neutral and alkaline soil. Application of RHB @ 16 t ha^{-1} recorded highest CaCl_2 - Si content of 58.11, 97.88 and 136.13 ppm at 120 DAI in acidic, neutral and alkaline soils respectively.

Among the three different biochar used in the present study, RHB produced at lower temperature and having highest Si content (32.5 %) recorded higher CaCl_2 - Si content in all the soils at all intervals. Application of WB which had lowest Si content recorded lower CaCl_2 - Si in neutral and alkaline soil, while on par with BB in acidic soil at all intervals.

Increased rate of application of different biochars increased the CaCl_2 - Si in all soils at all intervals. Increase in pH of solution increased the dissolution rate of biochar phytoliths and availability of Si. As soil pH increased with increased rate of biochar application, higher CaCl_2 - Si contents were noticed at higher rate of application.

Highest CaCl_2 - Si contents were observed at 120, 30 and 15 DAI in acidic, neutral and alkaline soil. Dissolution of SiO_2 is due to nucleophilic attack of water molecules that cause the breaking of siloxane bonds, >Si-O-Si< , at the particle surface. Increase in pH leads to the deprotonation of surface silanol groups, thereby facilitate further breaking of bridging siloxane bonds. Such increased dissolution of phytoliths was also reported by Fraysse *et al.*, (2006); (2009); Nguyen *et al.* (2014); Tavakkoli *et al.* (2011); Houben *et al.* (2014). Hence gradual increase in CaCl_2 - Si content was recorded due to gradual dissolution of phytoliths in acidic soil of present investigation.

Dove (1995) observed that adsorption of Al and other bi and trivalent metals on to the phytoliths affect their surface properties and decrease the dissolution rate. Hence in acidic and neutral soil, adsorption of Al and Mn might have reduced dissolution rate of different biochar and thereby reduced CaCl_2 - Si in soil solution. However in alkaline soil, higher CaCl_2 - Si content was observed due to higher dissolution rates.

Houben *et al.* (2014) reported that at the same pH value, the chemical composition and accessibility of phytoliths in the structure of biochar can partly control its dissolution. Thus WB which had high sorption and lower Si content recorded lower CaCl_2 - Si content at all intervals and in all studied soils of present investigation. Further, they also revealed that biochar derived from Miscanthus grass has greater ability to replenish soil Si and least by wood biochar.

5.3 Studies on the effect of biochar application on growth and yield of aerobic rice

5.3.1 Growth attributes of rice

Different growth attributes such as plant height and number of tillers recorded at critical stages of crop growth differed significantly with application of different sources and levels of biochar in all studied soils (Table 24-27).

Though application of different types of biochar recorded a non significant effect on plant height in acidic and neutral soil, there was a significant effect in alkaline soil. Among different treatment combinations, BB @ 4 t ha⁻¹ (110.93 cm), WB @ 4 t ha⁻¹ (78.60 cm) and WB @ 4 t ha⁻¹ (75.33 cm) recorded highest plant height at harvest in acidic, neutral and alkaline soil respectively. Among different biochars, application of WB recorded significantly highest plant height (70.52 cm), number of tillers (2.42) and SPAD reading (39.96) over RHB in alkaline soil at harvest. In acidic (10.75) and neutral (8.75) soil, application of RHB recorded higher number of tillers at harvest. SPAD reading was also found to be higher with application of RHB in acidic (44.21) and neutral (40.33) soil.

There were many factors contributing to the improvement of growth attributes of crop with biochar application. These factors can either work individually or simultaneously. Indeed, decrease in soluble Al and Fe, rise of pH, balanced and 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 different soils. All such improvements in physical and chemical properties of soil in biochar amended soils are in line with other studies (Liang *et al.*, 2006; Gundale and De Luca, 2007; Warnock *et al.*, 2007; Amonette and Joseph 2009 a and b).

The variations in the effect of different biochars are due the variation in their physical and chemical properties and variation in dissolution rate of different nutrients in soil. Among all the biochars, RHB recorded highest N (0.78 %) and Si (32.5 %) content. As RHB was produced at lower temperature might have mineralized most of its N and made plant available. Nitrogen is limiting nutrient in crop production and increased availability of N will increase plant height, number of tillers and SPAD reading. Hence, RHB recorded higher number of tillers and SPAD reading in acidic and neutral soil. While in alkaline soil, lower number of tillers and SPAD reading due to application of RHB might be attributed to low rate of mineralization. On contrary higher sorption capacity of WB might have reduced the salt injury and there by improved the growth and development of aerobic rice compared to other biochars.

Higher chlorophyll content in RHB treated plants indicated higher availability of N as witnessed in both acidic and neutral soils of present investigation. Nitrogen being a structural component of the plant would help in cell multiplication and differentiation and formation of tissues and tillering (Malavolta *et al.*, 1997). In general, RHB treated plants recorded higher number of tillers than other two biochars due to availability of higher N in acidic and neutral soils. Similarly, Barbosa Filho (1991), Navin *et al.* (1996) Mauad *et al.* (2003), reported higher number of tillers due to increased N availability. On the other hand, significant effect of WB and BB application on growth attributes over control can be attributed to creation of favorable pH and addition of nutrients such as Ca in acidic and neutral soil and reducing Na ion injury in alkaline 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.

In the present study WB improved growth attributes by increasing pH, favorable physical condition and reducing metal toxicity in different soil and RHB by providing nutrients and Si in acidic and neutral soils. The beneficial effect of Si on rice plant height and number of tillers have been reported by Nayar *et al.* (1982); Anderson, (1991); Gascho and Korndorfer (1998) and Raid *et al.* (1992). Vaculik *et al.* (2009) reported that control maize plants grown without Si were shorter than those cultivated with Si. Significant increase in number of tillers was noticed due to the supplement of calcium silicate at 2 t ha⁻¹ (Liang *et al.*, 1994).

The highest plant height, number of tillers and SPAD readings were recorded at the application rate of 8 t ha⁻¹, 4 t ha⁻¹ and 2 t ha⁻¹ in acidic, neutral and alkaline soil respectively. C:N ration WB, BB and RHB used in the present study was 557.69, 198.68 and 50.42 respectively. As application rate increases, C:N ratio of biochar amended soil increases and thus inhibit N nutrition. In N limited condition, rate and extent of protein synthesis are depressed showing clear stunted growth of vegetation. The short and long term implications of biochar on N immobilisation and mineralization are specific to individual soil-biochar combinations. In acidic soil, application of biochar at 16 t ha⁻¹ recorded higher pH and might have reduced the available N content. In neutral soil, which had high initial N, application of biochar beyond 8 t ha⁻¹ might have caused adsorption of NO₃⁻ and in alkaline soil which usually show N deficiency due to less microbial activity, application of biochar at 4 t ha⁻¹ might have greatly affected the properties of soil. Such adsorption and immobilization of nitrogen in biochar amended soil are often reported in literature. Asai *et al.* (2009) reported decreased chlorophyll content with application of biochar at 16 t ha⁻¹ possibly through a reduction in the availability of soil nitrogen. Adsorption of NH₄⁺ has been examined by Yao *et al.* (2012) who revealed that nine out of thirteen biochars tested in the sorption experiment could remove NH₄⁺ from solution to an extent of 1.8 - 15.7 per cent varying with feedstock and pyrolysis temperature.

Long term plant growth enhancement upon rice husk biochar applications was reported by Ogawa and Okimori (2010) in Japan which was due to the fertilization effect of ash-rich rice husk of biochar. Also on volcanic-ash soils, effects of biochar on soil quality and plant growth of soybean decreased with increasing biochar additions to an extent of 71% after 15 Mg ha⁻¹ biochar application (Kishimoto and Sugiura, 1985).

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.

5.3.2 Studies on effect of different sources and levels of biochar application on yield attributes of rice in different soils

Results of effect of different sources and levels of biochars application on panicles pot^{-1} and panicle length are presented in Table 28.

Application of RHB (11.75) and BB (1.42) recorded significantly higher number of panicles pot^{-1} in acidic and alkaline soil respectively and a non significant effect on panicle length in acidic and neutral soil. In alkaline soil, significantly higher panicle length was recorded with application of WB (14.63 cm). Panicles pot^{-1} varied significantly with application of different rates of biochar in all soils. Application level of 8 t ha^{-1} (11.67), 4 t ha^{-1} (8.44) and 4 t ha^{-1} (1.56) recorded highest number of panicles pot^{-1} in acidic, neutral and alkaline soils respectively. Significantly higher number of panicles pot^{-1} and panicle length was observed with application of biochar in acidic soil, recording highest with RHB @ 16 t ha^{-1} . In neutral soil, higher number of panicles pot^{-1} (8.67) and panicle length (18.67 cm) were observed with application of RHB @ 4 t ha^{-1} . Significantly highest panicle length (17.33 cm) was observed with application of BB @ 2 t ha^{-1} in alkaline soil.

Significant increase in number of panicles pot^{-1} and panicle length in biochar amended plants can be ascribed to addition of nutrients by biochar itself and also ability to maintain adequate and balanced level of nutrients throughout crop period. Mauad *et al.* (2003) reported that number of panicles occurs as a function of number of tillers. The treatment receiving RHB recorded higher number of tillers and thereby higher number of panicles pot^{-1} . Increased rate of biochar application increased panicles pot^{-1} due to increased availability of nutrients. 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). Ankit and Inubushi (2014) recorded higher number of panicles with combined application of biochar and N fertilizer than their single application. In alkaline soil, lower performance of RHB in comparison to other two biochars may be attributed to lower adsorption of sodium and decreased availability of micronutrients which finally reflected in reduced number panicles pot^{-1} and panicle length.

5.3.3 Studies on effect of different sources and levels of biochar application on straw and grain yield of rice in different soils

Application of different sources and levels of biochar recorded a significant effect on straw and grain yield of rice in all studied soils (Table 29 and Fig. 13). Among different biochars, application of RHB recorded significantly higher straw and grain yield and followed a trend of RHB > WB > BB in both acidic and neutral soils. In alkaline soil, application of BB and WB recorded on par straw and grain yield but application of RHB recorded significantly lower yields.

Among different rates of application, 8 t ha^{-1} recorded significantly higher straw and grain yield in acidic soil. In neutral and alkaline soils, 4 t ha^{-1} recorded higher straw and grain yield. Highest straw yield of 20.28 (RHB @ 16 t ha^{-1}), 18.10 (RHB @ 4 t ha^{-1}) and 4.83 (WB @ 2 t ha^{-1}) g pot^{-1} were recorded in acidic, neutral and alkaline soil

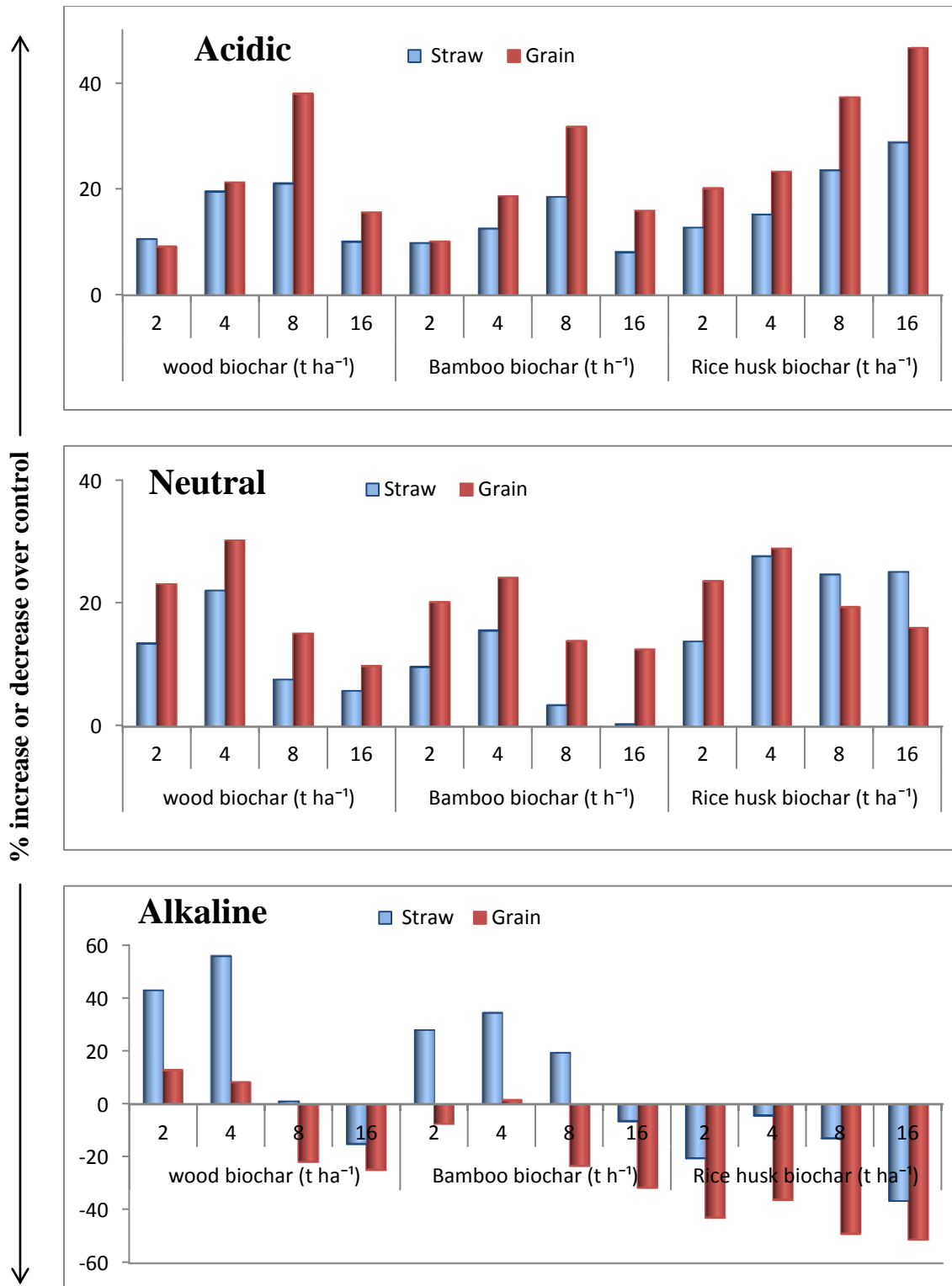


Fig. 14: Effect of different sources and levels of biochar application on per cent increase or decrease of straw and grain yield over control in different soils

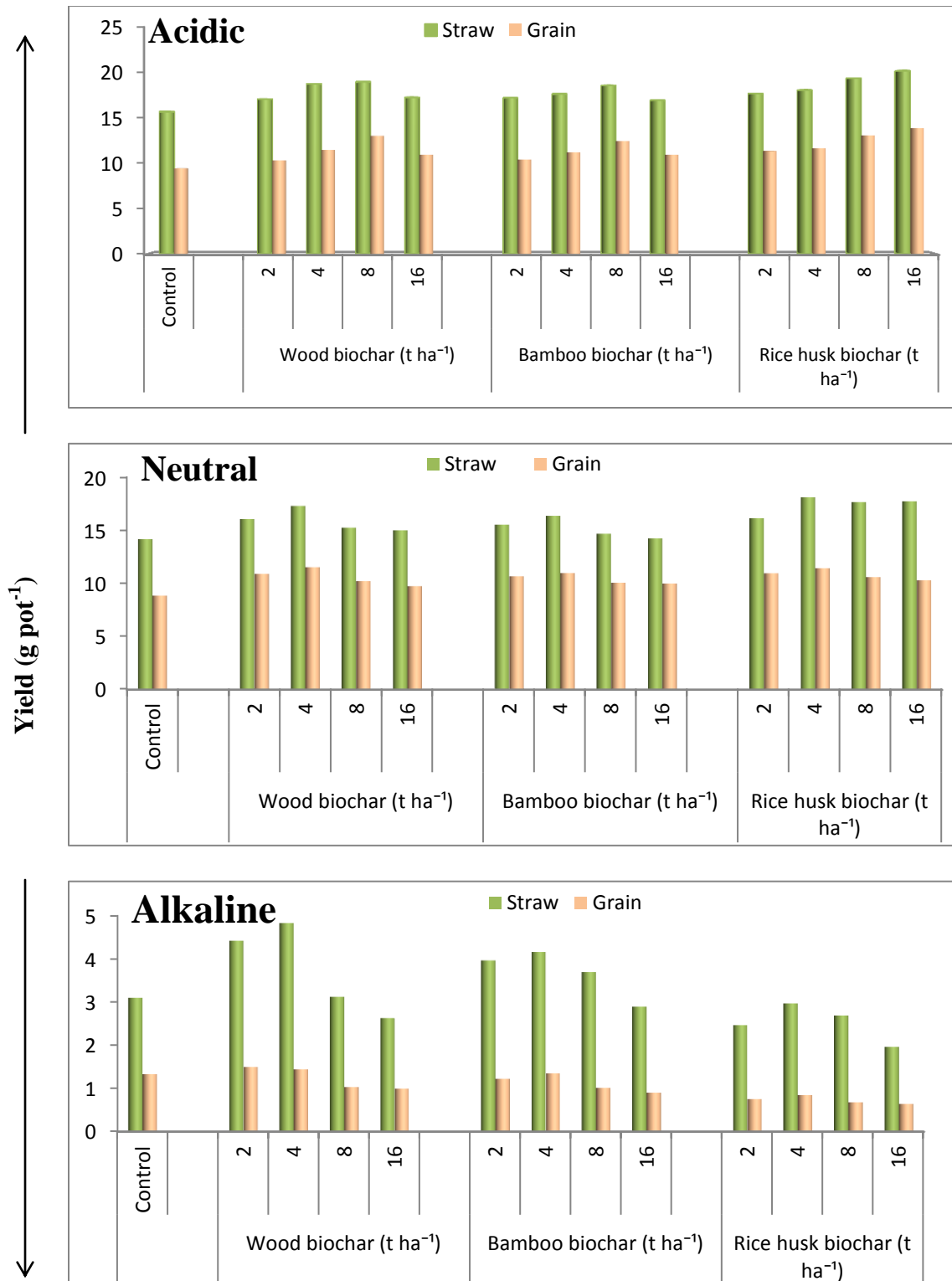


Fig. 13: Effect of different sources and levels of biochar application on straw and grain yield in different soils

respectively (Table 29 and Fig 13). Application of RHB @ 16 t ha⁻¹ (13.89 g pot⁻¹), RHB @ 4 t ha⁻¹ (11.42 g pot⁻¹) and WB @ 2 t ha⁻¹ (1.5 g pot⁻¹) recorded highest grain yield in acidic, neutral and alkaline soil, respectively. Application of biochar increased straw yield by 8.13 to 28.84, 0.35 to 27.64, and -36.56 to 55.18 per cent in acidic, neutral and alkaline soil respectively. Grain yield increase ranged from 9.19 to 46.47, 9.82 to 28.29 and -51.00 to 12.78 per cent in acidic, neutral and alkaline soils, respectively (Fig 14).

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;). Reported yield advantage ranged from 10 to > 200 per cent with application rate varying from < 1 to 100 t ha⁻¹. Improvements in plant growth and yield following biochar application also 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). The yield advantages upon biochar addition are dependent on soil type and biochar properties (Tryon, 1948; Spokas and Reicosky, 2009; Van Zwieten *et al.*, 2010).

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.

In a recent meta-analysis, the positive effect of biochar application on plant growth was attributed to increased availability of water and pH along with nutrient retention (Jeffery *et al.*, 2011). According to study conducted by Dong *et al.* (2015), soil pH (r^2 - 0.425) and moisture (r^2 - 0.460) was highly correlated to yield with the application of rice straw biochar. In present study, application of WB improved the soil pH to a greater extent and there by improved the nutrition of P, Ca and Mg and contributed for higher yield advantages in acidic and neutral soils. On the other hand, application of RHB though reduced soil pH and had less exchangeable bases improved the crop growth to a greater extent than WB in acidic and neutral soil. Possible reason for higher yield with application of RHB may be due to higher availability of nutrients especially P which was also reflected in tissue P content of RHB treated plants. Increased availability of P through biochar application is thought to be cause for yield advantages in many of the studies (Haefele *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).

However, the effect of Si content of biochar on yield of crop, particularly in rice is less often discussed in literature. Rice is Si accumulator plant, and its increased availability will increase the yield (Nayar *et al.*, 1977; Savant *et al.*, 1997b; Gontijo, 2000; Korndorfer *et al.*, 2001 and Meyer, 2001). In the present study, application of RHB recorded highest straw and grain Si content and thus positive effect of Si on yield can be explained. Better development of flag leaf and leaf erectness is observed as a function of increased availability of Si. Maintenance of high photosynthetic activity and higher utilization of light and translocation of assimilated product to sink with Si application could be possible reason for increased crop yield (Singh *et al.*, 2006).

Haefele *et al.* (2011) conducted an extensive field study in rice systems and found that yield increase to the extent of 16 to 35 per cent in non fertile soil and no effect in fertile soils upon application of rice husk biochar. The improved nutrient contents in the soil such as available Ca, Mg, K and P could enhance nutrient uptake and benefit the crop (Major *et al.*, 2010). The improvement in yield by biochar application was also explained by Ankit and Inubushi (2014). Biochar application can enhance nutrient availability due to presence of carbon. It can also increase soil fertility by stimulation of soil microorganisms that consequently lead to increase the nutrient cycling. 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).

Application of RHB to alkaline soil drastically reduced the plant growth and yield possibly due to its high ash content. Application of ash rich RHB might have increased concentration of salts and also CaCl_2 - Si content to greater extent as noticed in incubation study, which might have interfered with uptake of other nutrient as reflected in the plant nutrient content (N, Ca, S, Zn, Mn, Cu and Fe). As RHB was produced at lower temperature, it might have exhibited lower surface area and hence lower adsorption of Na. On other hand WB and BB might have sorbed higher Na ion as observed in present incubation study.

The straw and grain yield differed significantly with different application rates of biochar. Such responses with application rates were also reported by Chan *et al.* (2007); Chan *et al.* (2008); Asai *et al.* (2009); Major *et al.* (2010) and Van Zwieten *et al.* (2010). Lehmann *et al.* (2003) observed an increase in yield to an extent of 38 to 45 per cent with application of biochar at different rates (0, 10 % and 20 % w/w) in *Anthrosol* due to improved availability of P, Ca, Mn, and Zn with biochar application.

Chan *et al.*, (2008) applied poultry litter biochar at four rates (0, 10, 25, and 50 t ha^{-1}), with and without nitrogen application (100 kg N ha^{-1}). Biochar application, without N fertilizer, increased the dry matter yield of radish, even at lowest application rate. The yield increase (%), compared with the unamended control increased from 42 to 96 per cent with the application rates of 10 and 50 t ha^{-1} and increase in yield was attributed largely to the ability of these biochars to increase N fertilizer use efficiency.

In the present investigation higher application rates of different biochars decreased yield response in all the soils. Similarly, Uzoma *et al.* (2011b) found that maize yield was significantly increased by 150 and 98 per cent with biochar application rate of 15 and 20 t ha^{-1} , respectively as compared with the control. These results suggest that, higher rates of biochar application reduced yield responses. Such observations were also observed by Major *et al.* (2010).

5.3.4 Studies on effect different sources and levels of biochar application on major and secondary nutrient content and uptake by straw and grain in different soils

Application of biochar had significant effect on nutrient content and uptake of straw (30-33) and grain (Table 37-40).

In general, application of different sources and levels of biochar varied the primary and secondary nutrient content and uptake both in straw and grain. Improvements in soil fertility status with biochar application were reflected in increased crop productivity, nutrient content and uptake by plant.

The magnitude of variation in nutrient content of biochar treated plants in comparison to control was dependent on biochar type, rate of application and nutrient involved. For instance, application of WB recorded lower N content than RHB. This may be due to the variation in the C:N ratio of different biochars. Of different application levels, increased level of application increased the tissue content of N with the application of RHB and decreased with higher rates of WB. Rajkovich *et al.* (2012) conducted correlation study between biochar properties and N uptake by corn. N uptake by corn at 0.2 per cent application rate correlated positively with tissue N concentration and negatively with C:N ratio of biochar and trend become more apparent at higher rates of application.

Independent of type of biochar, increased level of application increased tissue P, K and Ca content in both straw and grain. Higher uptake of nutrients by biochar amended plants reflects the synergistic effect between applied fertilizer and biochar. Increased nutrient retention by biochar application will improve its availability to plants. Most of nutrient (N 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. Mg content was found to decrease in acidic soil with increased rate of biochar application possibly due to higher Ca content. As biochar contained higher Ca content in comparison to Mg, application of biochar at higher rates certainly increased the Ca content in soil to a greater extent.

Increase in pH of acidic and neutral soil may decrease Al activity, hence better root growth and nutrient uptake can be expected. Nutrient uptake is a function of nutrient content and biomass production. Increased rate of application increased biomass production which obviously increased nutrient uptake. Major *et al.* (2010) also found an increased uptake of Ca and Mg over four years of maize cultivation. 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. Xu *et al.* (2014) with application of rice straw biochar recorded a cumulative uptake of N 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.

5.3.5 Studies on effect different sources and levels of biochar application on micronutrient content and uptake by straw and grain in different soils.

Though application of biochar differed micronutrient content and uptake by straw and grain significantly in different treatments no definite trend was observed (34, 35, 41 & 42). In general, application of biochar improved Cu content and uptake in both straw and grain in acidic and neutral soils over control. Application of different biochar at higher rates, in comparison to control significantly reduced the Mn content and uptake in both grain and straw in acidic and neutral soils. Though Zn content in straw and grain were reduced due to biochar application in acidic and neutral soil, higher uptake was noticed. Fe content of grain decreased in acidic and neutral soil while there was an increase in its uptake. Decreased straw Fe content and uptake was noticed in acidic soil while reverse trend was observed in neutral soil.

Decreased micronutrient availability of 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. Decrease in Zn content and increase in its uptake in acidic and neutral soil may be due to dilution effect of increased biomass over control.

Among different sources, application of WB reduced all micronutrient content in grain and Mn and Cu content in straw of both acidic and neutral soils. In alkaline soil, application of RHB recorded lower content of all micronutrient in straw and grain except Cu in grain. Application rate of 16 t ha⁻¹ recorded lowest Zn and Mn content in both straw and grain in all soils. For Fe and Cu no definite trend of increase or decrease was observed with different application rates of biochar. WB by virtue of its higher pH and exchangeable bases, increased the pH to a greater extent compared to RHB. Not only pH variation, adsorption and formation of stable complexes were also responsible for reduction in tissue content of micronutrients. As adsorption is surface phenomenon and the biochar produced at high temperature will have higher surface area and hence WB might have adsorbed these micronutrients to greater extent than RHB produced at low temperature.

Variation in immobilization of micronutrients depending upon feedstock was also observed by Antonio *et al.* (2013) who found that application of olive prune biochar decreased all micronutrient concentration while application of wheat straw biochar decreased only Fe and Mn content in wheat crop. Smider and Singh (2014) also observed decreased micronutrient content of shoot with application of tomato green waste biochar in hybrid sweet corn.

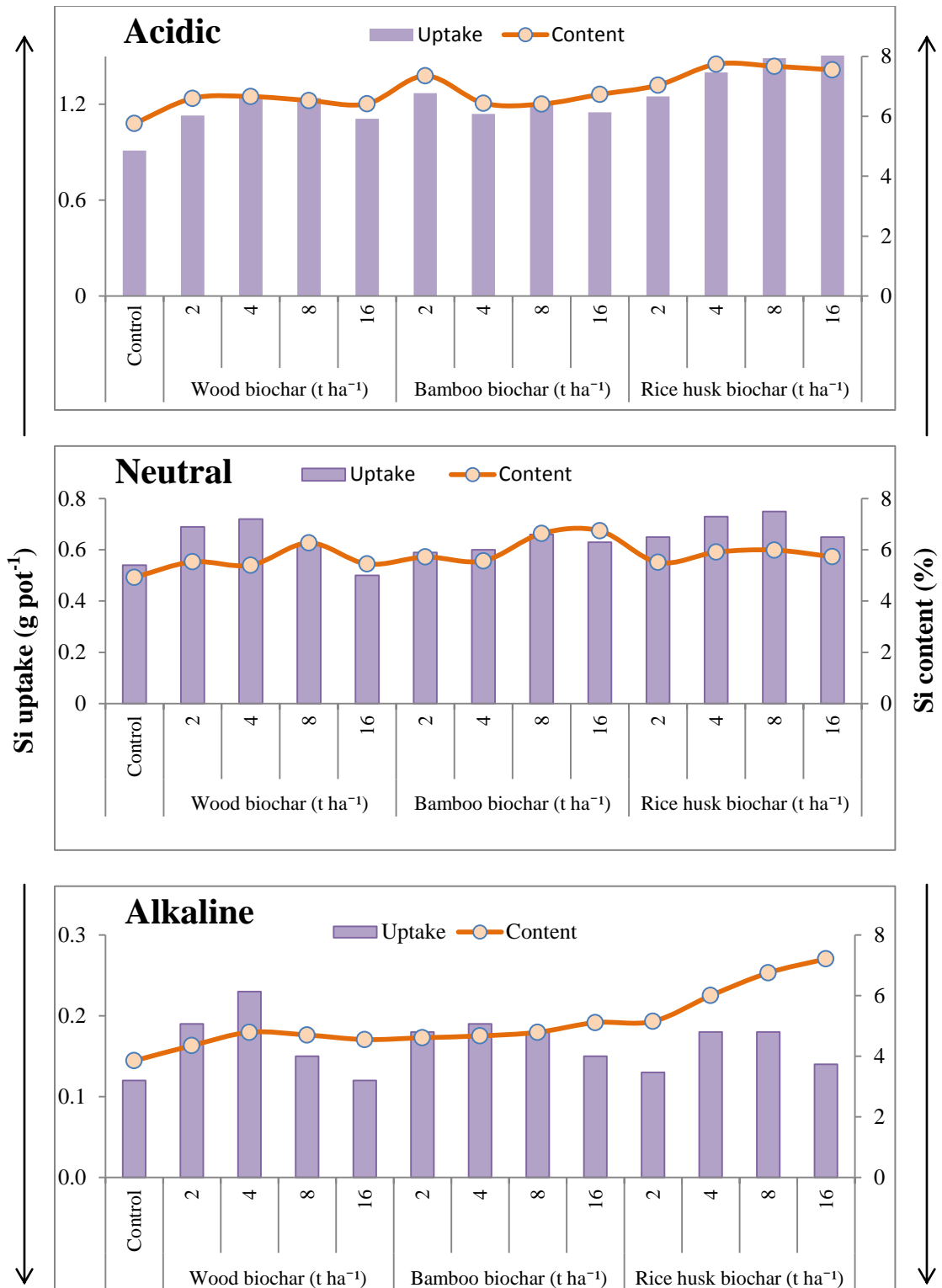


Fig. 15: Effect of different sources and levels of biochar application on Si content and uptake by straw in different soils

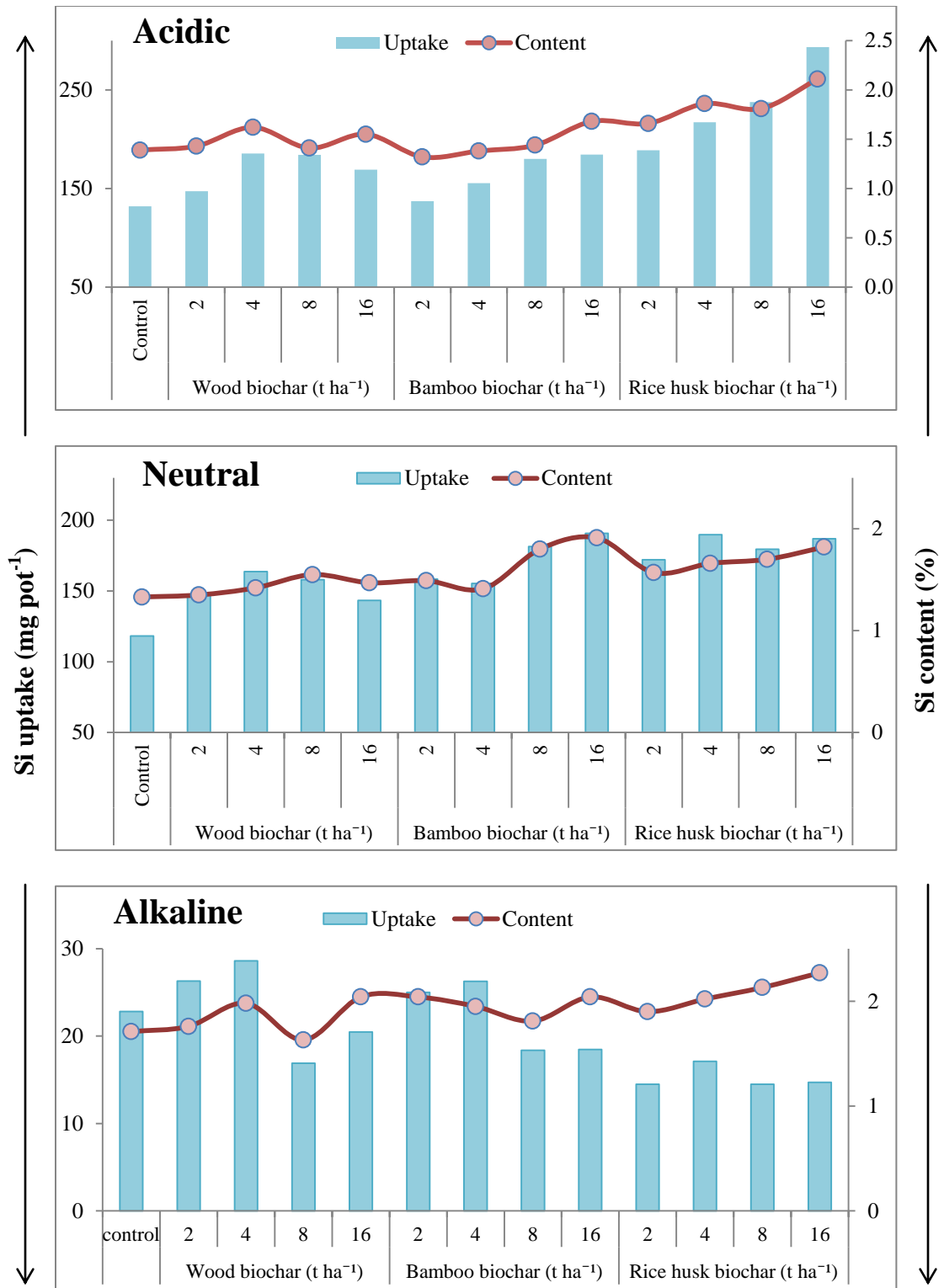


Fig. 16: Effect of different sources and levels of biochar application on Si content and uptake by grain in different soils

5.3.6 Studies on effect of application of sources and levels of biochar on Si content and uptake by straw and grain in different soils

The data presented in Table 36 and 43 and Fig. 15 and 16 revealed the significant effect of source, levels and their interaction on content and uptake of Si by straw and grain.

Independent of soil type application of RHB recorded higher content of Si in both straw and grain. Straw Si content of 7.50, 5.78 and 6.18 per cent was observed in acidic, neutral and alkaline soil respectively, with application of RHB. Higher uptake of Si by both straw and grain were noticed with application of RHB in acidic and neutral soil. In alkaline soil higher uptake of Si by straw and grain was observed with application of WB.

Independent of biochar type, increased rate of biochar application increased the uptake of Si by straw and grain in all studied soils. The highest availability of Si in soil with application of RHB as observed through incubation study was reflected in tissue content and uptake. Increased tissue Si content with increased Si availability in soil was also observed by Singh *et al.* (2006). Application of Si from 60 to 180 kg ha⁻¹ increased the Si content in both straw and grain from 3.52 to 3.80 and 1.03 to 1.17 per cent respectively. CaCl₂ - Si content generally represents the ability of soil to supply adequate Si for rice production. Zang *et al.* (1982) also observed a significant correlation between rice shoot Si content and soil CaCl₂ - Si content.

In addition to direct contribution of Si from biochar, increase in pH of soil might be the reason for higher Si content in biochar treated plants. The highest increase in pH of WB treated soil might have improved Si content in rice straw and grain. Similarly, Liu *et al.* (2014) observed an increase in shoot Si content with application of wheat straw biochar possibly due to increase in pH and direct contribution of Si from biochar.

Future line of work

- Need to understand the effect of biochar application on nutrient retention and its availability in different soils
- There is need to study the long term effect of biochar application on crop growth in different soils
- Need to assess the performance of biochar in mitigating soil chemical stress like Fe, Mn and Al toxicity in acidic soil and Na toxicity and other salts in alkaline soil

VI SUMMARY

The present investigation entitled “Characterization of biochar, nutrient release and its effect on growth and yield of aerobic rice” was conducted during 2014 at UAS, GKVK, Bengaluru. The findings of incubation and pot culture experiments are summarized below:

6.1 Characterization of biochar for physico-chemical properties

The influence of feedstock type and pyrolysis temperature on physical and chemical properties of biochar was observed. Among different biochars, WB recorded lower BD (0.31 g cm^3), PD (1.32 cm^3), ash content (8.8 %), Si (2.03 %), N (0.13 %) content and higher porosity (73.83 %), MWHC (213.31 %), pH (10.5), EC (4.99 dS m^{-1}), CCE (31.00 %) in comparison to RHB and BB.

RHB recorded highest ash content (39.4 %), CEC ($38.63 \text{ cmol (p}^+) \text{ kg}^{-1}$) and Si content (32.50 %) and lowest pH (7.39), EC (1.62 dS m^{-1}) and carbon (39.33 %) content compared to WB and BB.

WB recorded higher amount of all exchangeable bases than other two sources while RHB recorded highest P (0.24 %) and N (0.78 %) content.

6.2 Release of nutrients and silicon from biochar in acidic, neutral and alkaline soil

Nutrient and silicon release from biochar in different soils was dependent on biochar type and pyrolysis temperature.

Although application of different kinds and levels of biochar increased the pH of soil over control, greater increase in pH was noticed with application of WB @ 16 t ha^{-1} in all soils.

The balance between the input of ash alkalinity by biochar and decomposition of organic matter in biochar amended soil determines the final pH of soil. RHB which has high mineralizable aliphatic C due to lower production temperature recorded lower pH values in all soils.

No definite trend was observed on the electrical conductivity of soils with application of biochar, as addition of salts by biochar has temporal effect.

Application of RHB at different rates recorded higher available P_2O_5 content in all soils than other two sources. Application of RHB @ 16 t ha^{-1} recorded available P_2O_5 content of 167.96 - 186.89, 148.75 - 2333.98, 27.56 - 35.34 kg ha^{-1} in acidic, neutral and alkaline soils, respectively over a period of incubation.

Application of different kinds and levels of biochar significantly increased the exchangeable Ca, Mg and K concentration in acidic and neutral soils over control during study period. But in alkaline soil, application of biochar did not improve exchangeable

Ca and Mg content. In acidic soil, application of WB recorded highest exchangeable Ca (6.24 to 7.32 c mol (p⁺) kg⁻¹) and Mg content (2.79 to 3.68 c mol (p⁺) kg⁻¹) in comparison to control.

In all the soils, there was a significant increase in the exchangeable K content with the increased rates of biochar application.

Application of different sources and levels of biochar decreased the Zn content in acidic and neutral soils at the end of incubation period. Similarly there was a decrease in Cu content at 120 DAI when compared to 15 DAI in all treatments.

Application of WB at different rates decreased the Fe and Mn content in acidic and neutral soils while application of RHB reduced these micronutrient content in alkaline soil. Application level of 16 t ha⁻¹ recorded lower micronutrient content at all intervals and in all studied soils.

Significantly higher CaCl₂ - Si content was recorded with application of RHB at all intervals and in all studied soil. Application of RHB @ 16 t ha⁻¹ recorded 47.53 to 58.11, 94.13 to 112.59 and 136.13 to 176.41 ppm of CaCl₂ - Si in acidic, neutral and alkaline soil, respectively.

Although WB contained lowest total Si, its application in acidic soil recorded on par Si content with BB.

6.3 Effect of biochar application on growth and yield of rice

Application of different types of biochar at different levels significantly increased the number of tillers, SPAD reading and number of panicles pot⁻¹ in comparison to control. Application of RHB recorded highest number of tillers, SPAD reading and number of panicles pot⁻¹ in both acidic and neutral soil. While in alkaline soil, RHB recorded significantly lower number of tillers, plant height, SPAD readings compared to other two sources.

Application of biochar increased straw yield by 8.13 to 28.84, 0.35 to 27.64, and -36.56 to 55.18 per cent in acidic, neutral and alkaline soils, respectively. Grain yield increase ranged from 9.19 to 46.47, 9.82 to 28.29 and -51.00 to 12.78 per cent in acidic, neutral and alkaline soil, respectively with application of different sources of biochar.

The content of N, P, Mn, Cu and Si was found to be higher with application of RHB and that of K, Zn and Fe with application of WB in rice straw of acidic soil. Similar trend was also followed for uptake of these nutrients in acidic soil.

Application of RHB in neutral soil recorded higher content and uptake of N, P, Ca, Mg, S and micronutrients by straw. Application WB recorded higher uptake of all nutrients in alkaline soil.

Application of different kinds and levels of biochar significantly varied nutrient content and uptake by rice grain in all soils.

Present investigation clearly suggested that the biochar is having a promising role in achieving higher performance of the aerobic rice. However, the choice of biochar and the level of biochar application need to be evaluated in different soils before any recommendation.

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