EVALUATION OF ORGANIC RESOURCES FOR LIMING EFFICACY IN ACID SOILS

M.Sc. (Ag.) Thesis

by

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SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
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EVALUATION OF ORGANIC RESOURCES FOR LIMING EFFICACY IN ACID SOILS

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Anusuiya Panda

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CERTIFICATE - I

This is to certify that the thesis entitled **"Evaluation of organic resources for liming efficacy in acid soils"** submitted in partial fulfillment of the requirements for the degree of **"Master of Science in Agriculture"** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) is a record of the bonafide research work carried out by **Miss Anusuiya Panda** under my guidance and supervision. The subject of the thesis has been approved by Student's Advisory Committee and the Director of the Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate, award etc.). The published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by her.

Pramod Jha

Co-Chairman

Date: 21/7/15

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This is to certify that the thesis entitled **"Evaluation of organic resources for liming efficacy in acid soils"** submitted by **Miss Anusuiya Panda** to the Indira Gandhi Krishi Vishwavidyalaya Raipur (C.G.) in partial fulfillment of the requirements for the degree of **M.Sc. (Ag)** in the **Department of Soil Science and Agricultural Chemistry** has been approved by external examiner and Student's Advisory Committee after oral examination.

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Head of the Department ---------------------------

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Approved/Not approved ---------------------------

Director of Instructions ---------------------------

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"Education plays vital role in personal and social development and teacher plays a fundamental role in imparting education. Teachers have crucial role in shaping students,young people not only to face the further with confidence but also to build up it with aim and responsibility. There is no substitute for teacher pupil relationship".

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Anusuiya

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Date: 21/07/15

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+	Plus
-	Minus
@	At the rate of
^{o}C	Degree Celsius
%	Per cent

LIST OF ABBREVIATIONS

Al	Aluminum
Cu	Copper
Ca	Calcium
Ca^{2+}	Calcium ion
Cm	Centimeter
^{o}C	Degree Celsius
$dS\ m^{-1}$	Desi Siemens per meter
et al.	and co-worker/and others
Etc	Etcetera
EC	Electrical conductivity
Fe	Iron
Fig.	Figure
H^{+}	Hydrogen-ion
i.e.	That is
G	Gram
Kg	Kilogram
K	Potassium
Min.	Minutes
Mg	Milligram
Mg^{2+}	Magnesium ion
mm	Millimeter
Mn	Manganese
N	Nitrogen
nm	Nanometer
OC	Organic Carbon
pH	Logarithm of the reciprocal of the H^{+}ion activity
ppm	Parts per million
P	Phosphorus
S. No.	Serial number
Km^{-2}	Kilometer Square
Viz	That is to say / in other words
Zn	Zinc
Al^{3+}	Aluminium ion
CEC	Cation Exchange Capacity
FYM	Farm Yard Manure
BC	Biochar
EB	Electrostatically bonded
PFS	Paper factory sludge
FA	Fly ash
CF	Chemical Fertilizer
RHA	Rice Husk Ash

FP	Farmer’s Practice
RP	Recommended Practice
PL	Poultry Litter
MBC	Microbial Biomass Carbon
L	Lime
PM	Poultry Manure
CPHA	Cocoa pod husk ash
Na	Sodium
Na^+	Sodium Ion
NH_4^+ -N	Ammonical Nitrogen
NO_3^- -N	Nitrate Nitrogen

THESIS ABSTRACT

a) Title of the Thesis : "Evaluation of organic resources for liming efficacy in acid soils"

b) Full Name of the Student: Anusuiya Panda

c) Major Subject : Soil Science & Agricultural Chemistry

d) Name and Address of the Major Advisor : Dr. R. K. Bajpai Professor &Head, Deptt. of Soil Science & Agricultural Chemistry

e) Degree to be Awarded : Master of Science in Agriculture

Signature of the Student

Signature of Major Advisor

Signature of Co- Major Advisor

Signature of Head of Department

Date: 21/07/15

ABSTRACT

An experiment was conducted on *Alfisols* of Palampur and Ranchi to assess the impact of organic resources for their liming efficacy in acid soils. All together 9 treatment combinations comprising 4 crop residues (maize, wheat, rice and soybean) and their biochar were tested in completely randomized design. The incorporation of *Zea mays, Oryza sativa, Triticum aestivum* and *Glycin max* biochar and its crop residues increased soil pH compared with the initial value. The results emanating from Ranchi soil indicated that legume residue could be as effective as biochar for remediation of low soil pH provided the residue rate should be on C equivalent basis of biochar. The results clearly demonstrate that application of rice, maize, soybean and wheat biochar in acid soil enhancing the process of nitrification. In Ranchi, application of residues reduced the NH_4^+-N concentration significantly. The decrease in ammoniacal-N concentration

was probably due to the process of immobilization. Application of soybean biochar and residue significantly increased the Ca+Mg content of soil. Exchangeable K content of soil was increased by 5-20 folds after application of maize, soybean, rice and wheat biochar and its crop residues. Application of wheat, soybean, rice, maize biochar and its crop residues significantly ($P<0.06$) reduced the concentration of exchangeable Al during the incubation period. Significantly increase in fresh weight of Barley plant was recorded when an acid soil was amended with FYM and biochar.

शोधपत्र सारांश

- शोध पत्र का विषय : अम्लीय मृदाओं में चूना उपयोग क्षमता के लिए कार्बनिक संसाधनों का मूल्यांकन
- विद्यार्थी का पूरा नाम : अनुसुईया पण्डा
- मुख्य विषय : मृदा विज्ञान एवं कृषि रसायन
- मुख्य सलाहकार का पूरा नाम एवं पता : डॉ. आर. के. बाजपेयी प्राध्यापक एवं विभागाध्यक्ष मृदा विज्ञान एवं कृषि रसायन
- उपाधी प्राप्ति : मृदा विज्ञान में स्नातकोत्तर

Anusuiya
छात्र/छात्रा का हस्ताक्षर

मुख्य सलाहकार का हस्ताक्षर

Pramod Jha
सह सलाहकार का हस्ताक्षर

दिनांक 21/07/15

विभागाध्यक्ष का हस्तारक्षर

शोध सारांश

पालमपुर एंव राँची की अम्लीय मृदाओं (अल्फिसोल) में चूना उपयोग क्षमता के लिए कार्बनिक संसाधनों के मूल्यांकन पर प्रयोगशाला में निश्चित तापमान एवं नमी पर प्रयोग किया गया। इस प्रयोग में मक्का, गेहूँ, धान एवं सोयाबीन के अवशेष तथा इन्ही फसलों के अवशेषों द्वारा बायोचार तैयार किया गया। अनुपचारित उपचार सहित नौ उपचारों का यादृक्षिक रुपरेखा में परीक्षण किया गया। प्रयोग में पाया गया कि सभी फसलो के अवेशष एवं बायोचार के समावेश से अनउपचारित मृदा की तुलना में उपचारति मृदा का पी.एच. अधिक पाया गया। पालमपुर एवं राँची की मृदा पर प्रयोग यह दर्शाति है कि दलहनी फसलों के अवशेष की बायोचार उपचार के कार्बन समकक्ष आधार पर मृदा पी.एच. को बढाने में सक्षम है। फसलो के अवशेष उपयोग से मृदाओं में अमोनिकल नत्रजन की मात्रा में कमी पायी गयी, यह कमी सम्भवतः नाइट्रीकरण के कारण हुई है। सोयाबीन फसल के अवशेष एवं बायोचार मृदा में कैल्सियम एवं मैग्नीशियम को बढ़ाता है एवं विनिमयशील एल्युमीनियम की सान्द्रता कम करता है। गमलों में परीक्षण हेतु गोबर की

खाद एवं बायोचार उपचारित मृदाओं के परिणाम यह दर्शाते है कि जौ के ताजा भार में अनउपचारित मृदा की तुलना में वृद्धि पायी गयी।

CHAPTER - I

INTRODUCTION

Soil acidity is one of the most yield-limiting factors for crop production. Land area affected by acidity is estimated at 4 billion ha, representing 30% of the total ice-free land area of the world (Sumner and Noble, 2003). Soil acidity affects nearly 50 percent of the world's potentially arable land, particularly in humid tropics (von Uexkull and Mutert 1995). Soil acidity is quantified on the basis of hydrogen (H^+) and aluminum (Al^{3+}) concentrations of soils. For crop production, however, soil acidity is a complex of numerous factors involving nutrient/element deficiencies and toxicities, low activities of beneficial microorganisms and reduced plant root growth which limits absorption of nutrients and water (Fageria and Baligar, 2003).

Acid soils, which are soils with a pH of 5.5 or lower in 1:1 water extract (USDA 1970), are one of the most important limitations to agricultural production worldwide. Many factors contribute to phytotoxicity of these soils; however, in acid soils with a high mineral content, aluminum (Al^{3+}) is the major cause of toxicity. Soils become acidic for several reasons. Aluminium, whose pKa value is 5·0, hydrolysed in water to produce protons (Shazana,*et al*., 2011). The most common source of hydrogen is the reaction of aluminum ions with water. The equation for this reaction in very acid soils (pH<4.0) is:

$Al^{3+} + H_2O = Al\,(OH)^{2+} + H^+$

The species of aluminum ions present vary with pH. Potassium chloride extracted Al and Al saturation has an inverse relationship with pH (Chartres *et al*., 1990; Kariuki *et al*., 2007). Symptoms of Al toxicity are similar to those of nutrient deficiency probably owing to the inhibition of root development caused by the action of Al at the root tip. Increased soil acidity causes solubilization of Al^{3+}, which is the primary source of toxicity to plants at pH below 5.5 (Bohn et al., 2001; Ernani *et al*., 2002; Kariuki *et al*., 2007; Parker *et al*., 1989). The forms of aluminum are mostly exchangeable Al^{3+} under very acidic conditions (pH< 4.5) to aluminum-hydroxyl ions at higher pH (4.5–6.5) (Carson and Dixon, 1979).Al^{3+} toxicity is the single most important factor, being a major constraint for crop production on 67%of the total acid soil area (Eswaran *et al.*, 1997). Some of the major concerns of Al are mentioned below.

- When the soil pH drops below 5, Al^{3+} is solubilized into the soil solution and this is the most important rhizotoxic Al species.
- The primary symptom of Al toxicity is a rapid (beginning within minute's) inhibition of root growth, resulting in a reduced and damaged root system and limited water and mineral nutrient uptake.
- The rapidity of this response indicates that Al first inhibits root cell expansion and elongation; however, over the longer term, cell division is also inhibited.
- Stunted roots and reduced root zone of susceptible plant species such as clover, brassica, ryegrass and most crop plants. This leads to reduced drought tolerance.
- Dominance of tolerant species such as browntop in pastures and low clover content.
- Reduced availability of phosphorus through formation of Al-P complexes
- Reduced availability of other cation nutrients (K, Mg, Ca) through competitive interaction.

The application of lime and other calcareous materials most common management practice to ameliorate of soil acidity (Bolan *et al*., 2003). Soil liming is the main objective of acid soil to neutralize acidic inputs and improve the buffering capacity and also affects the solubility and availability of most plant nutrients, by reducing toxic concentrations of Aluminum and Manganese (Biswas and Mukherjee,1994).

The main factorof soil acidity are the nature of the parent material, weathering processes (Owolabi *et al.*, 2003), nitrification process, organic matter decomposition, acid rain (Sparks, 2003) and ammonium-based N fertilizer sources tonitrate causes a net H^+ release, which lowers the soil pH in the plant rooting zone (Garvin and Carver, 2003; Prasad and Power, 1997).

According to rough estimate about 48-49 million hectare of total geographical area of our country is under acid soil. Out of it, nearly 25 million hectares of land are having pH below 5.5 and 23 million hectares fall under the pH range of 5.6-6.5 (Mandal 1997). Greater part of these soils (54%) are found in North Eastern Region of India where more than 95% area is affected by soil acidity, with approximately 65% of the area being under extreme forms of soil acidity (pH below 5.5) (Sharma and Singh 2002).In India, approximately one-third of the cultivated land is affected by soil acidity (Mandal 1997).Crop productivity on such soils is mostly constrained by aluminum (Al) and iron (Fe) toxicity, phosphorus (P) deficiency, low base saturation, impaired biological activity and other acidity-induced soil fertility and plant nutritional problems (Patiram 1991; Manoj-Kumar *et al*., 2012).

The cost of conventional lime is away from the reach of the farmer. Lime may not be available locally andin many developing countries, lime application and transportation is very costly. Another alternative is the use of organic materials becauseOrganic matter also helps in soil revegetation and erosion control (Alexander 1999), for example farmyard manure maize stover alone or in combination with inorganic fertilizers, different crop residue (Haynes, 1986; Tang *et al*., 1999; Marschner and Noble, 2000; Yan and Schubert, 2000;Xu*et al*., 2005)(Sakala *et al*., 2004;)(Ojeniyi *et al.*,1999;Ano and Agwu, 2005; Kekong *et al.*, 2010) like wheat ,rice, chickpea,corn (*Zea mays* L.) and soybeans (*Glycine max* [L.] Merr.) (Aulakh *et al*. 1991), sugar beets (Falih and Wainwright 1996), and cottage cheese whey (Kelling and Peterson 1981) and industrial by-products such as papermill and cardboard sludge (Xiao *et al*., 1999, Rosen *et al*., 1999).etc leaf litters alsoneutralised soil acidity(Noble *et al*., 1996; Tang and Yu, 1999;).

Recent research has shown that additions of composts, green, or animal manures reduce Al toxicity and increasecrop yields (Hue and Amien, 1989; Wong and Swift, 2003;Vieira *et al*., 2009). Biochar also called charcoal or agrichar is a carbon (C) rich product resulting from the pyrolysis of organic material at low temperatures (<700°C) (Lehmann & Joseph, 2009)(Woolf *et al*.,2010).When biochar applied as a soil amendment, it improves crop yield bystimulation of beneficial soil microbes such as mycorrhizalfungi (Warnock *et al*., 2007), improves water holding capacity, and soil physical properties, (Kramer *et al*., 2004; Liang *et al*., 2010; Ogawa and Okimori, 2010) and store carbon for long time, ameliorates degraded soils and reduces soil acidity (Major *et al*., 2010a) and it can increase available nutrient larger potassium, phosphorus, and zinc availability, and to a lesser extent, calcium and copper (Lehmann *et al*., 2003)increases of soil base saturation (Glaser *et al*., 2002; Major *et al*.2010a)

Biochar applied in typical Ultisol, increases soil pH and cation exchange capacity (CEC) (Peng *et al*., 2011;Yuan and Xu (2011).The soil pH increased from 4.33 pH to 5.38, when biochar was added (Cheng *et al*., 2006).The biochar produced from corn straw, peanut straw, and soybean straw at a 300^0C temperature were all alkaline, but the pH of biochar from canola straw, wheat straw, and hull straw was 6.48, 6.42 and 6.43, respectively (Yuan *et al.*, 2011).

The application of organic residues to acid soils in order to minimize the need for lime and fertilizer P would be of considerable benefit to resource-poor, semi-subsistence farmers.Indeed, organic residues such as animal manures, composted wastes and grass and crop residues are usually readily available to such farmers albeit sometimes in limited amounts. Long term fertilizer experiments conducted in different locations of India also indicated FYM efficacy at par with lime in obtaining the good yield of crops. Here in all locations, FYM has been applied at a rate of 10-15t/ha/yr in addition of 100%NPK. Although this technology seems promising in amelioration of soil acidity problem however availability of FYM at such higher rate for crop production is a questionable proposition. Under these circumstances, there is need to develop an innovative alternative management strategies based upon the locally available resources for sustainable crop production in acid soil regions of India.

Keeping in view the above facts, an investigation entitled **"Evaluation of organic resources for liming efficacy in acid soils"** was carried out with following **Objectives:**

- To understand the mechanism of action of different liming materials (organic resources).
- Effect of different liming materials on C, N and P transformations in soil.
- Evaluation of different materials for their liming efficacy.

CHAPTER- II
REVIEW OF LITERATURE

In this chapter a review of literature pertaining to study on "**Evaluation of organic resources for liming efficacy in acid soils**" carried out by various researches in Chhattisgarh, India and abroad has been briefly mentioned. The literature on the aspects is under following head:

2.1Effect of liming on crop productivity and soil acidity

2.2 Effect of alternate liming material on amelioration of acid soil

2.2.1 Crop residue as a liming material

2.2.2Biochar as a liming material

2.3 Effect of biochar on cropproductivity

2.4 Effect of FYM and different organic resources on crop productivity and soil acidity

2.1 Effect of liming on crop productivity and soil acidity

Jibrin *et al.,* (2002) conducted an experiment to evaluate that the effect of applied rock phosphate and lime to tropical cover crops and on the performance of P nutrition of succeeding maize crop.Results of the trial corroborated that*Chamaecrista rotundifolia, Lablab purpurens,Mucuna pruriens and* Maize-*Chamaecrista rotundifolia* inter crop reduced the leaf Al concentration of succeeding maize by more than 38%. Six cover crops significantly increased grain yields of succeeding maize crop. Liming raised the soil pH and significantly improved P uptake by maize.

The effectiveness of lime, chicken manure and leaf litter ash to ameliorate the soil acidity in an incubation study was investigated by Materechera *et al.,*(2002). The application of all the three amendments caused significant increases in soil pH and reduced exchangeable acidity were in the order; lime > chicken manure > ash.

Saha *et al*., (2007) studied the response of pea to application of lime along with balanced fertilizer application and found that the yield response of pea to application of lime (4.0 q/ha) was 13.7 and 19.0% over farmers' practice (FP) and recommended practice (RP), respectively. Yield response of pea were boosted up gradually as farmers' practice moved towards recommended practice through balanced fertilizer application coupled with liming of acid soils.

Torkashvand*et al.,* (2007) evaluated performance of basic slag on amelioration of acid soil . Results showed that the Slag increased soil pH and the rate of increase was proportional to the amount of slag used. The slag decreased Fe availability at pH range of 7.4 -8.5 but increased at higher pH,also use of slag proportionately increased the P and Mn availability.Torkashvand *et al*., (2010) also reported significant increased in soil pH with the application of paper mill lime sludge in an acid soil.

Hue (2008) recommended use of lime and acid tolerant crops (sugarcane, pineapple, tea and some wheat cultivars) for improving productivity of acid soils. Similarly, Jena *et al*., (2009) examined that the effect of lime and boron on yield of cabbage and okra in acid lateritic soil. They reported that application of boron along with lime significantly increased the yield of cabbage and okra.

Karmakar *et al.,* (2009) evaluated industrial solid waste viz. fly ash (FA), rice husk ash (RHA) and paper factory sludge (PFS) along with common lime, FYM and chemical fertilizer (CF) on agronomic performance of rice under acid lateritic soil. The rice growth, yield attributes and yield was highest under integrated use of FYM+RHA+CF followed by PFS+FA+CF. Similar was the opinionof Panda (2009) who also opined that apart from calcitic and dolomitic lime stones, industrial wastes such as lime sludge from paper mills, basic slag from steel mills, blast furnace slag, press mud, cement, and kiln wastes could be used as potential amendments for reclamation of acid soil.

Dolui *et al.*, (2010) examined the nature of acidity as influenced by lime in major soil series of Nagaland and also assessed the relationships with soil properties and found that the contributions of exchangeable acidity to total potential acidity were low. This indicated the presence of a relatively higher proportion of exchangeable acidity in Longsamtang series as compared to other soil series because of high acidity and it is due to monomeric Al^{3+}. Electrostatically bonded (EB) EB-H^{+} and EB-Al^{3+} acidities constituted 90.1 and 9.6% of exchangeable acidity, while EB-H^+, EB-Al^{3+}, exchangeable and pH-dependent acidities comprised 1.3, 12.5, 13.7 and 85.5% of total potential acidity.

Castro (2012) evaluated the efficiency of lime and calcium / magnesium silicate application on soil chemical attributes, plant nutrition, yield components and yield. Results showed that the application of silicate is more efficient than the lime for increasing phosphorus availability and reducing toxic aluminum.Effa *et al.,* (2012) studied two year field experiment of lime levels and N doses on popcorn yield. They reported thatapplication of N at 80 kg/ ha along with 500 kg / ha of lime significantly increased the crop productivity. It is also reported that application of lime along with integrated nutrient management practices increased maize productivity in acid soils (Kumar *et al*., 2012).

Manoj Kumar *et al.,* (2012)corroborated that the lime requirement of the soils even with similar pH may vary drastically based on differences in their organic matter content.Dwivedi *et al.*,(1992) reported highest yield of peas with B (1.5 kg/ha) and dolomitic limestone (3.0 t ha^{-1}).Gupta *et al*., (2000) studied the effects of P at 0, 25, 50 and 75 kg ha^{-1} and lime at 0, 50, 100 and 150 % of lime requirement on pea (cv. Bonneville) growth and yield characteristics. Increasing P levels resulted in corresponding increase in yield and yield parameters such as pod length, number of grains per pod and pod weight. Increasing levels of lime also resulted in an increase in yield and yield parameters of the crop. Similarly, Oluwatoyinbo *et al*., (2009) examined the effects of lime ($CaCO_3$) and compost application on the growth and yield of okra[*Abelmoschus esculentus* (L) Moench] in an acid soil and observed that lime application gave the highest yield of okra (4.4 Mt/ha). Addition of compost to lime gave lower but comparable growth and seed yield of the crop.

Edwards *et al.*,(2013) evaluated the effects of broadcast incorporated agricultural lime andbanded pelletized lime on bulk soil pH, exchangeable Al, Al saturation ,spatial pH change in the soil profile, wheat (Triticum aestivum L.) vegetative development, and grain yield. Results showed that the broadcast and incorporated agriculturallime was the most effective treatment in increasing soil pH, decreasing exchangeable Al and Al saturation and increasing soil exchangeable cations.Sadiq *et al.,* (2012) reported that the application of lime precipitates Al and Fe in the soil and result in higher rice yield. Furthermore, Improvement in soil pH, base saturation, Ca and Mg content and reduction in Al and Mn toxicity and increase in P uptake in high P fixing soil and plant rooting system through the application of lime was reported by Nduwumuremyi, 2013.

Kidanemariam *et al.,* (2013) studied wheat crop response to the application of Wurko lime and Sheba lime and N and P fertilizers. Results showed that the application of wurko and Sheba lime along with only recommended P and NP fertilizers correspondingly gives highest agronomic efficiency and apparent recovery. Hence, a combined application of adjusted lime rate and NP fertilizers are recommended to achieve sustainable wheat crop production on acidic soils.

2.2 Effect of alternate liming material on acid soil

2.2.1 Crop residue as a liming material

Tang*et al.,* (1999) examined the effect of applying legume residues differing in concentrations of N and excess cations/organic anions on pH change of five soils differing in initial pH.They concluded that magnitude of pH change depends largely on the concentration of organic anions in the residues, initial soil pH and the degree of residue decomposition. The incorporation of crop residues, especially those with high concentrations of excess cations, was recommended in minimizing soil acidification in farming systems.

In another experiment, the addition of plant residues and the appropriate management of *Arbuscular mycorrhizal* (AM) symbioses have been tested in an acidic soil by Borie (2002). They used organic amendments such as legume (lupine) and non-legume(wheat) crop residues. These organic amendments increased soil pH (wheat more than lupine), P availability and AM development (lupine more than wheat), plant performance and mineral acquisition (wheat more than lupine) and demonstrated the effect of AM inoculation on the reduction of Zn and Cu, and Mn and Al acquisition.

Xu *et al.,* (2005) studied the effect of plant residues on soil pH and attributed increase in soil pH due to the decarboxylation of organic anions (as indicated by excess cations) of added plant residues and ammonification of the residue N, whereas nitrification of mineralized residue nitrogen causes soil pH decrease, and that the association/dissociation of organic compounds also plays a role in soil pH change, depending initial pH of the soil.

Majule *et al*., (2008) evaluated acid ameliorative potential of organic residues*viz.* wild spikenard, cordia, cowpea and pigeon pea. The incorporation of such organic residue results better performance of crop and it may be due to reduction of soil acidity. Ameliorative potential of residue was directly related to the alkalinity of organic residue. Pigeon pea and cordia residue had higher alkalinity resulted high acid amelioration compared to senescent cowpea and wild spikenard which had lower alkalinity.

The work of Hue (2011) on two acid soils of Hawaii revealed that crop residues such as fresh cowpea leaves, dried cowpea leaves, fresh pineapple (*Ananas comosus*) crowns, ashed pineapple, *Desmodium intortum cv*. greenleaf were found effective for reducing Aluminium toxicity and Ca deficiency. The results indicated that crop residues may be used to alleviate soil acidity; the fresh cowpea amendment was most effective.

2.2.2 Biochar as a liming material

Jin-Hua *et al*., (2011) investigated the effect of crop residues and their biochar on an acid Ultisol. The results showed that the incorporation of biochar decreased soil exchangeable acidity and increased soil exchangeable base cations and base saturation, thus improving soil fertility.

Xu (2011) studied on effect of biochar on soil acidity and suggested the carbonate and organic anions are main form of alkalis in biochar. The content of carbonate increases with rise of pyrolysis temperature. Biochar from legume crop straws have greater alkalinity than the biochar from non-legume crop residues. Acid soils with low pH and low CEC are easy to be ameliorated by biochars. Biochar also increase the pH buffering capacity of acid soils.

A pot trial was carried out by Supriyadi *et al.*, (2012) to evaluate the effect of biochar for increasing P uptake on two types of acid soil. They used poultry litter (Pl) and rice husk (RH) biochar. Result showed that the P uptake was greater from a combination of PL and RHbiochar than when either was applied alone, providing evidence of synergistic benefits of biochar application

Jien*et al*.,(2013) evaluated that the effect of biochar produced from waste wood of white lead trees (*Leucaena leucocephala* (Lam.) de Wit) on the physicochemical and biological properties of long-term cultivated, acidic Ultisol. Results indicated that the application of biochar improved the physicochemical and biological properties of the highly weathered soils, including significant increases in soil pH, cation exchange capacity, base cation percentage and microbial biomass carbon (MBC).

Incorporation of biochar into tea garden soil was an effective way to increase soil pH, base cations and reduce Al saturation (Wang *etal.,* 2014). The magnitude of soil pH increase was reduced at higher biochar application rates, as further addition of biochar simply reduced exchangeable acidity without affecting the overall soil pH. Therefore, biochar is a suitable amendment for tea garden soils for the purpose of pH adjustment.

Abewa *et al*.,(2014) investigate the effect of biochar on soil properties and teff yield. They used five rates of amendments in which three rates of biochar, one rates of lime and no amendments with full, half and zero rates of the recommended N & P fertilizer rates.Results indicated the application of biochar increased soil pH, CEC, available P and organic carbon and significantly increased yield.Biochar combined with NP fertilizers increased yield significantly compared to plots that received fertilizer or lime alone. Mariati (2014) used alternative liming material such as maize cob biochar and rice husk charcoal for improving soil pH, soil nutrient availability and maize production. In this study the result showed highest maize yield with application of biochar.

Incubation and pot experiments was carried out by Masud *et al.,* (2014) to investigate the effect of alkaline slag and crop straw biocharon amelioration of an acidic Ultisol. They used lime, alkaline slag, peanut straw biochar, canola straw biochar, and combinations of alkaline slag and biochar.The results showed that all the liming materials increased soil pH and decreased soil exchangeable acidity and the combined application of alkaline slag with biochar led to the greatest reduction in soil acidity, increased soil Ca, Mg, K and P levels, and enhanced the uptake of Ca, Mg, K and P by soybean plants.Liard *et al.,* (2010)used biochar as a soil amendment to enhance the sustainability of biomass harvesting. The application of biocharto soilssignificantly increased total N, organic C and extractable P, K, Mg and Ca and indicated that biochar amendments have the potential to substantially improve the quality and fertility status of Midwestern agricultural soils.

2.3 Effect of biochar on crop productivity

Biochar as soil conditioner are warranted, obviously due to carbon sink function, but also, because of potential for increased nutrient use efficiency in farming (Brandstaka*et al*., 2010).Major *et al.,* (2010b) studied the effect of biochar application on crop yield. They concluded that the crop yield, nutrient uptake and availability of Ca and Mg were greater in soil where biochar was applied.

Effect of biochar on productivity of cassava based cropping system evaluated by Islami *et al.,* (2011). The application of biochar increases in yield of cassava and maize (15 Mg ha^{-1}). In an experiment conducted by Southavong *et al.,* (2011) the effect of two types of biochar (Downdraft Gasifier or Updraft Gasifier Stove) were evaluated at different levels on productivity of rice plants in acid soil. Biochar raised soil pH from 4.5 to 5.13 and 5.40 with the higher value for stove biochar. The level of biochar was raised from 0 to 24% showed a curvilinear increasethe biomass growth of rice (over 30 day period from planting) followed by a slight decline at higher levels.

The biochar and FYM applications at the rate of 25t and 5t ha^{-1} are recommended for improving maize growth and efficient weed control (Arif *et al*., 2012).Zhang *et al.,* (2013) used four biochar samples and studied their chemical properties. The results showed that wood biochar and bamboo biochar samples were 60%-80% more hydrophobic and better sorptive, aromatic, and humification properties than those of rice husk biochar and rice husk ash. Therefore it may be used as a bulking agent and a composting amendment during the solid waste composting process.Cornelissen *et al.,* (2014) studied that the effect of maize and wood biochar on maize yields. In sandy acidic soils, they reported that CF (Conservation Farming) and biochar amendment can be a promising combination for increasing harvest yield. Moderate but non-significant effects on yields were observed for maize and wood biochar in a red sandy clay loam ultisol east of Lusaka, central Zambia.

Prabha *et al.,* (2013) opined that the biocharapplication considerably influenced the growth profile and grain yield of the rice plants compared to other amendments and showed positive response.Hseu *et al.,*(2014) studied the effect of biochar application produced from rice hull on changes of physiochemical characteristics and erosion potential of a degraded slopeland soil. They concluded that available water contents significantly increased in the amended soils and biochar application could availably raise soil quality and physical properties for tilth increasing in the degraded mudstone soil.Also, biochar can stabilize carbon belowground and potentially increase agricultural and forest productivity (Krishnakumar *et al.,* 2014).

2.4 Effect of FYM and different organic resources on crop productivity and soil acidity

Haynes*et al.,* (2001) studied the incorporation of organic matter on amelioration of soil acidity. They reported that during residue decomposition there is, often a transitory increase in soil pH that induces a decrease in exchangeable and soil solution Al through their precipitation as insoluble hydroxyl Al compound. The increase in pH has been attributed to number of causes including oxidation of organic acid anions present in decomposing residues, ammonification of residue N, specific adsorption of organic molecules and reduction reaction induced by anaerobiosis. Thus organic residue may be used as a strategic tool to reduce the rate of lime and fertilizer P in acidic soil.

On the productivity and economics of pea in an acid soil of Manipur Bhattarai *et al*., (2003) reported that integration of different nutrient including poultry manure along with full dose of nutrients recorded highest pods plant^{-1}, seeds pod^{-1} and seed yield.The highest maize grain yield (4.62 Mg ha^{-1}) was obtained with L (lime) + 10 Mg ha^{-1} PM (Poultry manure); with no amendment, the grain yield was 1.9 Mg ha^{-1}.Animal manure has the double role of checking soil acidity and raising soil nutrient levels and it should be considered as a viable alternative to chemical fertilizers and liming materials by resource-poor farmers in developing nations(Busari *et al*., 2008).

Effect of integrated use of organic manure and fertilizer N on the productivity of chickpea in Vertisol of Bijapur was studied by Tolanur and Badanur (2003).

They concluded that the integration of fertilizer N with different organics i.e. FYM, vermicompost sustains the productivity of chick pea and significantly improved the organic carbon, available N, P and K status of Vertisol after harvest.

Application of FYM at 25 t ha^{-1}, along with 75% of the recommended dose of inorganic fertilizer and vermicompost at 5 t ha^{-1}, gave the highest nutrient (N, P and K) uptake of Okra cv. Arka Anamika at Annamalainagar, Tamil Nadu, India (Barani and Anburani, 2004). On lateritic soil of Dapoli (Maharashtra, India), Dademal and Dongale (2004) revealed that the application of FYM at 7.5 t ha^{-1} along with N, P_2O_5 and K_2O at 150, 75 and 75 kg ha^{-1}, respectively was found most useful for maximization of okra fruit yield (85.01 q/ha).Prakash and Bhadoria (2004) evaluated relative efficacy of organic manures in improving productivity and they revealed that among the organic manures, FYM produced maximum fruit and shoot yield. Increase in fruit yield with FYM application was attributed to higher retensivity of soils for water and nutrients and higher uptake of major and minor nutrients.

In a field experiment conducted by Kumar *et al*. (2006) on the productivity of pea under Lahaul valley conditions at Himachal Pradesh, they reported that an application of 20 kg N, 60 kg P_2O_5 and 30 kg K_2O ha^{-1} resulted in a significantly higher seed yield, growth and yield contributing traits. The yield component values were higher with the application of 100% of the recommended rate of NPK + FYM as compare with NPK alone.

Negi *et al.*,(2007) evaluated the effect of *Rhizobium leguminosarum* (N fixer) and *Pseudomonas striata* (P Solubilizer) either alone or in combination with nutrient sources *viz*., FYM @ 10 t ha^{-1} + NPK (@ 25:25:25 kg/ha), FYM + NPK (half rates), and lime (amendment, 4 t/ha) and observed the positive effect on vegetable pea crop grown in a soil of Uttaranchal. Lime recorded highest green pod yield and the response was 89.77% followed by FYM + NPK (53.8%). The treatments FYM + NPK and NPK + lime further increased the green pod yield by 83.89 and 98.2% and protein by 18.2% and 19.4%, respectively.

Yeledhalli *et al*., (2007) conducted an experiment to study the effect of levels of fly ash (0, 25, 50, 75 and 100 tones ha^{-1}) on physico-chemical properties of Alfisols with two levels of fertilizers (control and recommended dose of NPK fertilizers). Application of graded levels of coal fly ash with or without recommended dose of NPK fertilizers increased the organic carbon, N, K, Ca, Mg, P, Zn, Fe, Mn and Cu in soil.Garcia Navarro *et al*., (2009) evaluated that the effect of application of by product (sugar foam waste) on red soils in Central spain. Results showed that the addition of sugar foam waste increasedsoil organic matter concentration,calcium carbonate, P,andsoil pH.

On an acid soil, Oluwatoyinbo *et al*., (2009) reported that okra growth was most favoured with application of 5 Mt ha^{-1} compost as compare with no compost. Industrial by-products are used for reclamation of acidic soil. It was reported by Torkashvand*et al*., (2011) that paper lime sludge could be the substitute for conventional calcite sources such as calcite as acidic soil modifiers that may reduce the disposal costs and possible environmental contamination of this by-product.

On an acid alluvial sandy loam soil, Rakshit (2009) observed that among the organic manures tested, FYM produced maximum fruit and shoot yield of okra. Poultry manure at 150% recommended nitrogen dose gave highest green pod yield (7.07 tonne/ha) of table pea (Meena *et al*. 2010).

Opala (2011) tested the organic materials as cheaper alternatives of lime to reduce soil acidity. The FYM, Tithoniadversifolia and agricultural lime, each applied alone or combination with TSP. only lime and FYM treatments significantly increased the soil pH. The most effective amendment in reducing exchangeable Al was lime followed by tithonia and FYM.

Ram *et al*., (2011) observed that fly ash had low bulk density, high water holding capacity and porosity, rich in silt-sized particles, alkaline in nature and contains reasonable plant nutrients. The major content of fly ash was SiO_2 considerable amounts of oxides of Ca, Mg, K, P, and S, micronutrients (Cu, Zn, Mn, Fe, etc.) and low in N content.Nyarko (2012) reported that lime, organic materials, acid tolerant crops and agroforestry are some of the best option for managing soil acidity.

Mwangi *et al*., (2012) suggested that liming, use of FYM alone or in combination with inorganic fertilizers and also use of non-acidifying fertilizers can reduce the soil acidity. In an experiment they found that the soil acidity improved with the application of agricultural lime and FYM, but the change was not instant as it was in case of lime. However, soil acidity improvement through manure would be more sustainable with time than use of lime.

Cocoa pod husk ash (CPHA) as fertilizer and liming materials on nutrient uptake and growth performance of cocoa (*Theobroma cacao*) seedlings in the nursery was evaluated by Adejobi *et al.*,(2013).The results showed that the cocoa pod husk ash increased the plant height, stem diameter, number of leaves, leaf area, number of branches, root and shoot lengths, root and shoot fresh weights, root and shoot dry weights, N, P, K, Ca, Mg of soil.Cocoa pod ash applied at 25 tons/ha was the most effective treatment improving cocoa growth and yield parameters, soil chemical composition.

Undie *et al.,* (2013) investigate the effects of incorporating moringa leaves on soil acidity amelioration. Results showed that the Moringa leaves are a promising soil amendment for the remediation of soil acidity and for sustainable production of garden egg plant.

Asrat *et al.,*(2014) studied that the combine action of lime manure and mineral P fertilizer on acid soils for wheat production and their impact on soil residualP status. Integrated use of lime, manure and mineral P fertilizer resulted increases the wheat yield and yield components and residual soil P of acidic soils.

Osundare (2014) examined the effects of different liming materials on the fertility status of Acid Alfisol and grain yield of Maize (*Zea mays L.*) They used different liming material such as CAN, $CaCO_3$ and Wood Ash. Liming resulted increase in maize grain yield. Wood ash gave the highest maize grain yield and yield components.

Ram*et al*., (2014) concluded that co-application of fly ash with other organic materials had enhanced nutrient availability and decreased bioavailability of toxic metals, pH buffering, organic matter addition etc. It is very important that the application of fly ash to soil must be very specific depending on the properties of the fly ash and soil.

Under continuous maize-wheat crop rotation in an acid *Alfisol*, Sharma *et al.,* (2014) corroborated integrated use of optimal dose of NPK and FYM for getting sustainable yields of crops.

Swarnam *et al.*,(2014) conducted an experiment to evaluate that the effect of organic wastes as liming material such as coconut husk, compost, poultry manure, vermicompost and gliricidia in comparisionwith lime. The results showed that the potential of poultry manure and coconut husk composted with either poultry manure or gliricidia may serve as alternate liming material for low input agricultural system.

CHAPTER- III

MATERIALS AND METHODS

This chapter deals with the concise description of the materials used and the techniques adopted during the course of investigation. The present investigation entitled **“Evaluation of organic resources for liming efficacy in acid soils”** was conducted at the IISS Bhopal.

3.1 Geographical situation

An acidic *Alfisol* (U.S. Soil Taxonomy) used in this study was collected from the long-term fertilizer experiment plot of Palampur, Himachal Pradesh (32^{o}N, 76’E) and Ranchi, Jharkhand (23.35° N, 85.33° E).

3.2 Experimental site

The experiment was conducted at ICAR-Indian Institute of Soil Science, Bhopal. The details of soil phyico-chemical properties are mentioned in Table 3.1. Also general characteristics of the biochar and different crop residues are mentioned in Table 3.2 and 3.3, respectively.

3.3 Treatments

3.3.1: Incubation study

An incubation study was conducted in laboratory at Indian Institute of Soil Science, Bhopal. Two types of acidic soil were taken for this study i.e. Palampur and Ranchi soil. A 100 gram of soil sample was weighed and transferred in 100 ml plastic beakers and subsequently 40 ml distilled water was added in each beakers to maintain 60 % of water holding capacity of soil. Biochar 2 gram and crop residue 3.5 gram was taken to maintain approximate equivalent amount of C in each soil. Soil moisture level was maintained throughout the study. Soil sample were analyzed at 7, 15, 30, 45 and 90 days after incubation. Treatment in incubation studies were as follows in Table 3.4

3.3.2: Pot Experiment

A green house experiment was conducted by taking Barley as a test crop at Indian Institute of Soil Science Bhopal during *Rabi* season 2014. The details of the treatments are given in Table 3.5. The soils for pot experiment were collected from Ranchi having a pH of 6.2.

Table 3.1: Physico-chemical properties of experimental soil

S. No.	Particulars	Palampur Soil	Ranchi Soil
1.	Sand (%)	30	66
2.	Silt (%)	46	9
3.	Clay (%)	24	25
4.	Soil pH	4.52	4.75
5.	EC (dSm^{-1})	0.11	0.13
6.	OC %	0.85	0.39
7.	Mineral ammonical nitrogen(NH_4-N)ppm	46.70	11.90
8.	Nitrate nitrogen(NO_2 – N)ppm	49.9	14.7
9.	Exchangeable Ca^{2+} (meq/100 gm soil)	1.03	1.2
10	Exchangeable Mg^{2+}(meq/100 gm soil)	0.14	0.13
11.	Exchangeable K^{+}(ppm)	120	95.5
12.	Exchangeable Na^{+}(ppm)	30.5	35.8
13.	Exchangeable Al^{3+} (meq H)	3	0.45
14.	ExchangeableCa^{2+}+ Mg^{2+}(meq/100 gm soil)	1.27	1.33
15.	Available P (ppm)	15.59	19.04

Table 3.2:General characteristics of maize, rice, wheat and soybean biochar used in incubation study

Parameters	Maize Biochar	Rice Biochar	Wheat Biochar	Soybean Biochar
pH(H_2O)	4.9	5.4	5.2	7.7
EC(dSm^{-1})	1.13	1.54	1.24	1.96
Total C	58.89	29.9	43	54.0
Total N %	4.71	1.41	1.10	1.11

Table 3.3: General characteristics of maize, rice, wheat and soybean residues used in incubation study

Parameters	Maize Residue	Rice Residue	Wheat Residue	Soybean Residue
Total C	42.42	38.19	42.18	43.24
Total N %	0.42	0.30	0.35	0.60

Table 3.4: Details of treatments used in incubation study

Treatments	Treatments detail
T_1	Soil only
T_2	Soil + Maize Biochar
T_3	Soil + Maize Residue
T_4	Soil + Rice Biochar
T_5	Soil + Rice Residue
T_6	Soil + Wheat Biochar
T_7	Soil + Wheat Residue
T_8	Soil + Soybean Biochar
T_9	Soil + Soybean Residue

Note for the Table 3.4

No. of replication : Three

Statistical design : Completely randomized design

Table 3.5:Details of treatment used in pot experiment

Treatments	Treatments detail
T_1	Soil only
T_2	Soil + NPK
T_3	Soil + NPK + Biochar 1%
T_4	Soil + NPK + Biochar 2 %
T_5	Soil + NPK + Biochar 3 %
T_6	Soil + Biochar 1%
T_7	Soil + Biochar 2%
T_8	Soil + Biochar 3%
T_9	Soil + FYM 1%
T_{10}	Soil + NPK + FYM 1%
T_{11}	Soil + NPK + FYM 1% + Biochar 1%
T_{12}	Soil + NPK + FYM 1% + Biochar 2%
T_{13}	Soil + NPK + FYM 1% + Biochar 3%

*NPK dose : GRD .,214: 142:107 (mg/pot)

Note for the Table 3.5

No. of replication : Three

Total Number of pots : 39

Statistical Design : Completely randomized design.

3.4Sowing

Barley seed was sowing on 25th November 2014. Eight seeds were sown in each pot and six were retained for study. Pots were irrigated at every alternate day.

3.5 Nutrients management practices

N, P and K fertilizers were applied to crop in two splits application as per the general recommended dose.

3.6 Harvesting

The barley plant was harvested on 14th January 2015.

3.7 Method of Analysis

3.7.1 Soil Analysis

3.7.1.1 Soil reaction

Soil pH was determined by glass electrode pH meter taking 1:2.5 soil water suspensions after stirring it for 30 minutes as described by (Jackson, 1973).

3.7.1.2 Electrical conductivity

Electrical conductivity was determined by taking supernatant liquid of soil water suspension prepared for pH determination by using electrical conductivity meter (Black, 1965).

3.7.1.3 Organic carbon

Organic carbon was determined by Walkley and Black's rapid titration method as described by Piper (1967).

3.7.1.4 Ammonium (NH_4^+-N) and nitrate (NO_3^--N) nitrogen

The concentration of ammonium (NH_4^+-N) and nitrate (NO_3^--N) in soil were determined by shaking 5g soil with 50 ml of 2*M* KCl for 1 hour, followed by centrifugation and filtration through a filter paper. NH_4^+ and NO_3^--N in filtered extracts were determined colorimetrically using flow injection analyzer (FOSS).

3.7.1.5 Exchangeable Ca^{2+} and Mg^{2+}

Exchangeable Ca^{2+} and Mg^{2+}were extracted with neutral 1*M* ammonium acetate and determined by versenate titration method (Hesse, 1971).

3.7.1.6 Exchangeable K^+ and Na^+

Exchangeable K^+ and Na^+were extracted with neutral 1*M* ammonium acetate and determined by flame photometry (Chapman and Pratt, 1961).

3.7.1.7 Exchangeable Al^{3+}

Exchangeable Al^{3+} was extracted by shaking 5g soil with 50 ml of 1*M* KCl for 30 minutes, followed by centrifugation and filtration and Al concentration in filtered extracts were then determined by titrimetric method (Page, A.L., 1982).

3.7.1.8 Available P

Soil available P was determined by Bray's method (Bray and Kurtz, 1945).

3.7.2Biochar preparation and analysis

Rice, Wheat, Soybean and Maize residues were collected locally and then pyrolized under oxygen limited conditions at 300^{0}C for 2 hours in a muffle furnace. They were cooled to room temperature overnight. Subsequently, the biochar was crushed manually and ground to pass through a 2-mm sieve.

3.7.2.1 pH and electrical conductivity

Biochar pH and electrical conductivity (EC) were determined in 1: 5 biochar to deionized water extraction (Gaskin *et al.* 2008).

3.7.2.2 Total Carbon

Total C in original biomass and biochar sample were determined by dry combustion method using Shimadzu TOC analyzer.(Shimadzu 5000 VA)

3.7.3 Incubation study

The soils were amended according to treatment as mentioned in section 3.4.1with residues and with their biochars. The soils were incubated at 25^{o}C and sub-sampled at 0, 7, 15, 30, 45 and 90 days after incubation.There were 3 replicates for each treatment.Soil samples were taken at each sampling date from each beaker through a spatula and the disturbed soils were leveled out. Soil pH, EC and exchangeable bases (K^{+}, Ca^{2+}, Mg^{2+}, Na^{+}), exchangeable Al and Mineral N and available P were determined on each sampling date to test the efficacy of biochar and residues.Soil moisture content was determined gravimetrically at each sampling stage for expression of results on dry weight basis.

3.7.4Plant chemical analysis

3.7.4.1 Sample preparation

Plant samples were dried in oven at 60°C until constant dry weight obtained. The plant samples were grinded and used for following chemical analysis.

3.7.4.2 Total Nitrogen content

Nitrogen content was determined by Microkjeldahl methods as described by Chapman and Pratt, (1961).

3.8 Statistical analysis

SPSS window version was used for statistical analysis. One way analysis of variance (ANOVA) was performed for each time interval of the incubation for comparisons of means. Significant effects of various treatments were measured using the t-test.

CHAPTER- IV
RESULTS AND DISCUSSION

The investigation entitled **"Evaluation of organic resources for liming efficacy in acid soils"** was conducted at the Indian Institute of Soil Science, during the period July 2014 to June, 2015, for evaluating the efficacy of different crop residues and their biochar for amelioration of soil acidity. Results presented and reasons for significant variations due to different treatments during incubation study and pot experiment have been explained in this chapter.

4.1 Soil pH and electrical conductivity

Changes in soil pH due to incorporation of crop residues and their biochar in soil are presented in table 4.1 andfig. (4.1, 4.2, 4.3 and 4.4).Soil pH was monitored periodically after 7, 15, 30, 45 and 90 days after incubation. In Ranchi soil, incorporation of *Zea mays, Oryza sativa, Triticum aestivum and Glycin max*biochar and its crop residues to soil increased soil pH compared with the initial value (4.75) ($P < 0.05$).It was observed that incubating soil for longer period of time resulted in slightly increase in soil pH. Even the control soil pH increased from 4.75 to 5.35 after 90 days of incubation (DAI). In case of Ranchi soil, it was observed that incorporation of either crop residues or biochar to soil significantly increased soil pH at all the sampling stages. In all the cases surge/increase in soil pH due to addition of biochar/residues were found up to15 DAI and thereafter a slight decline in soil pH was recorded till termination of study. The maximum rise in soil pH was observed after one week of incubation thereafter a slight decrease in soil pH was recorded till the termination of incubation study. At the end of incubation study, the maximum increase in soil pH (6.54) was recorded in case of incorporation of soybean residue and biochar, which was significantly ($P < 0.05$) higher than the rest of the treatments. After 7 days of incubation (DAI), the maximum increase in soil pH (7.38) was recorded in case of wheat residue incorporation. Similarly, the maximum pH of 7.81 was recorded in case of soybean biochar incorporation at 15 DAI, which was statistically at par with soybean residue (fig. 4.2). The trend was continued till the termination of study. The results emanating from Ranchi soil indicated that legume residue could be as effective as biochar for remediation of low soil pH provided the residue rate should be on C equivalent basis of biochar. The results were similar in case of other crop residues and biochar also. In case of maize, it was observed that maize residue was more effective than maize biochar in remediation of acid soils of Ranchi.

The initial pH of the unamended Palampur soil was (control) 4.52. Here also, application of soybean residues and biochar significantly increased soil pH. The maximum increase in soil pH (5.90) was recorded in case of soybean residue incorporation, which was significantly higher than the rest of the treatments. The increase in soil pH was higher in the beginning of the study thereafter it decreased gradually till completion of incubation study (fig 4.4). The mean increase in soil pH compared with control was 1.11 and 1.38 units with soybean residue and biochar, respectively. In case of Palampur soil, residue and biochar of crops other than soybean did not make any significant change in soil pH.The maximum rise in soil pH was observed after one week of incubation thereafter a slight decrease in soil pH was recorded till the termination of incubation study. The decline of soil pH was ascribed to the nitrification of NH_4^+ in soil. Soil pH fluctuations showed a similar trend irrespective of the biochar addition rates. Beyond 300^{o}C, the C started to become ashed and alkali salts began to separate from the organic matrix, increasing the biochar pH to above 10. After all the alkali salts were ‘‘leached” from the pyrolytic structure (Shinogi and Kanri, 2003), the pH became constant at 350 and 500^{o}C. Higher pH of biochar indicates their potentials as amendments to neutralize soil acidity (Abe, 1988). Generally, legume materials have higher ash alkalinity due to the unbalanced uptake of cations and anions, and thus have greater amelioration effects on soil acidity than non-legume materials (Wang et al., 2009). The input of ash alkalinity and the mineralization of organic N are two main factors contributing to increased soil pH early in the incubation study, while nitrification of NH_4^+-N would contribute to decreased soil pH later in the incubation; the balance of these reactions determined the final soil pH (Yuan *et al.*, 2011). Decarboxylation of organic anions of added organic material consumes proton and thereby increases soil pH (Yan *et al*., 1996; Tang and Yu, 1999).

Table 4.1:Effect of maize, rice, wheat and soybean biochar and its crop residues on soil pH during incubation period

Ranchi Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	4.75	5.62a	5.58a	5.88a	5.35a	5.35a
Maize biochar	4.75	6.57c	5.83ab	5.96a	5.52ab	5.52a
Maize residue	4.75	6.41c	6.33bc	5.57a	5.82ab	5.82a
Rice biochar	4.75	6.46c	6.65c	6.55b	5.83c	5.83a
Rice residue	4.75	6.14bc	6.26bc	5.80a	5.76ab	5.76a
Wheat biochar	4.75	6.01b	6.15ab	6.00a	5.95b	5.95a
Wheat residue	4.75	7.38d	5.99ab	5.79a	5.45ab	5.45a
Soybean biochar	4.75	7.09d	7.81d	7.66c	6.52d	6.52b
Soybean residue	4.75	5.37a	7.79d	7.65c	6.54d	6.54b
Palampur Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	4.52	4.86ab	5.04b	4.65b	4.94c	4.94b
Maize biochar	4.52	5.12ab	4.67a	4.28a	4.57a	4.57a
Maize residue	4.52	5.18ab	4.96b	4.56b	4.85a	4.85ab
Rice biochar	4.52	5.06ab	5.02b	4.65b	4.89b	4.89ab
Rice residue	4.52	4.92ab	4.70a	4.31a	4.57a	4.57a
Wheat biochar	4.52	4.67a	4.72a	4.39a	4.61a	4.61a
Wheat residue	4.52	5.78c	4.51a	4.26a	4.56a	4.56a
Soybean biochar	4.52	5.37b	6.00d	5.57c	5.63d	5.63c
Soybean residue	4.52	4.95ab	5.48c	5.77d	5.80d	5.90d

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments.

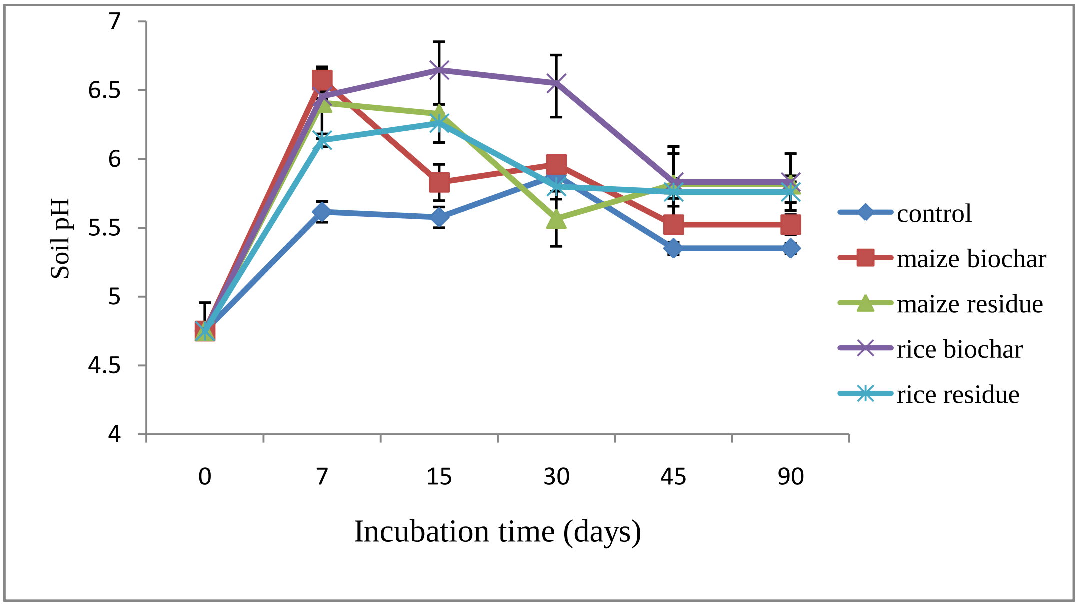

Fig. 4.1 Changes in soil pH at Ranchi as affected by incorporation of residue and biochar of maize and rice

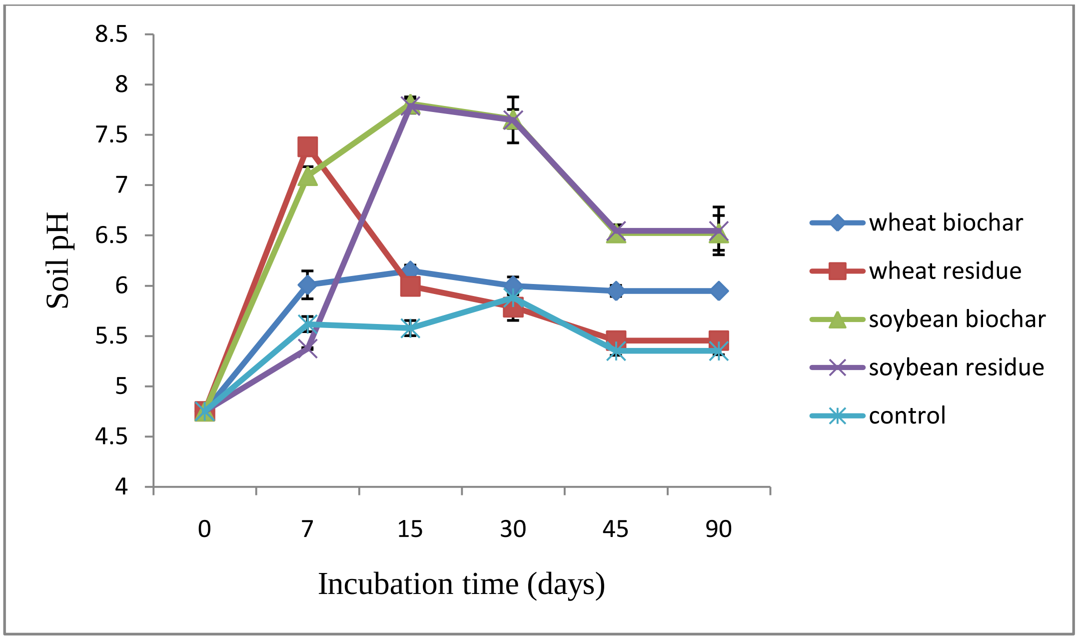

Fig. 4.2 Changes in soil pH at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

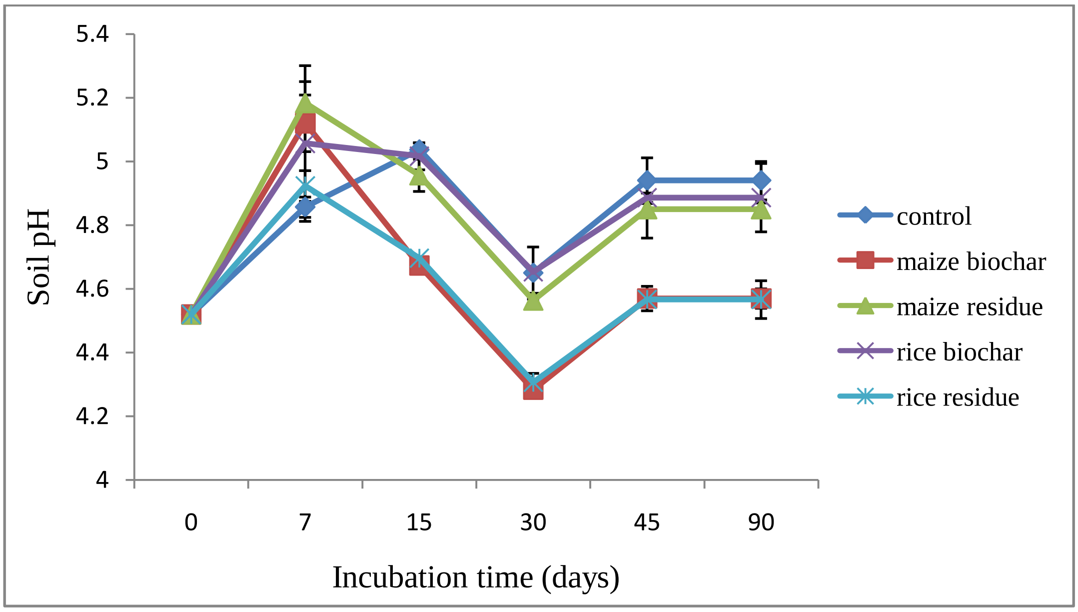

Fig. 4.3 Changes in soil pH at Palampur as affected by incorporation of residue and biochar of maize and rice

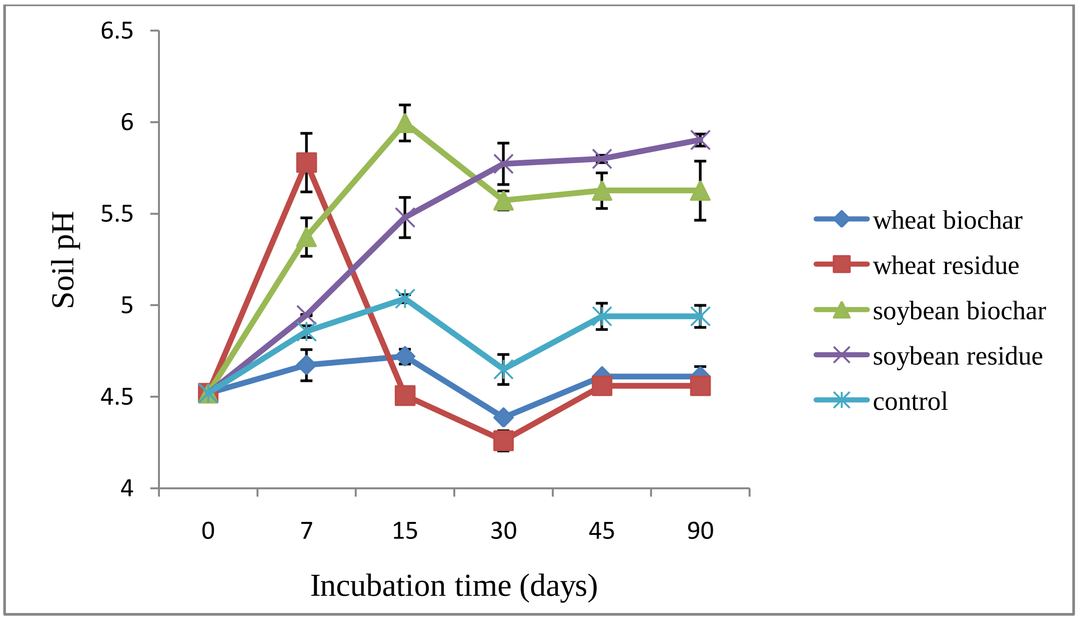

Fig.4.4 Changes in soil pH at Palampur as affected by incorporation of residue and biochar of wheat and soybean

Electrical conductivity

Change in soil electrical conductivity with the application of maize, rice, soybean and wheat biochar and its crop residues were measured periodically during the incubation experiment (Fig. 4.5, 4.6, 4.7 and 4.8). No significant difference between the EC of initial and amended soil (biochar unamended) ($P<0.05$) were recordedat the end incubation study. However, it was observed that application of residues and biochar significantly increased soil EC at 2^{nd} and 3^{rd} sampling stages (7 and 15 DAI). Application of biochar and crop residuesslightlyincreased the EC of soil ($P<0.05$). In Ranchi, the EC of initial soil was 0.13 dS m^{-1}, which was increased to 0.31, 0.35, 0.75 and 0.49 by incorporation of maize biochar, maize residue, rice biochar and rice residue, respectively at the end of incubation study (fig. 4.5). Similar trend was recorded for Palampur soil also. Novak *et al.*, (2009) also did not observe any significant difference in leachate EC with increasing biochar addition.

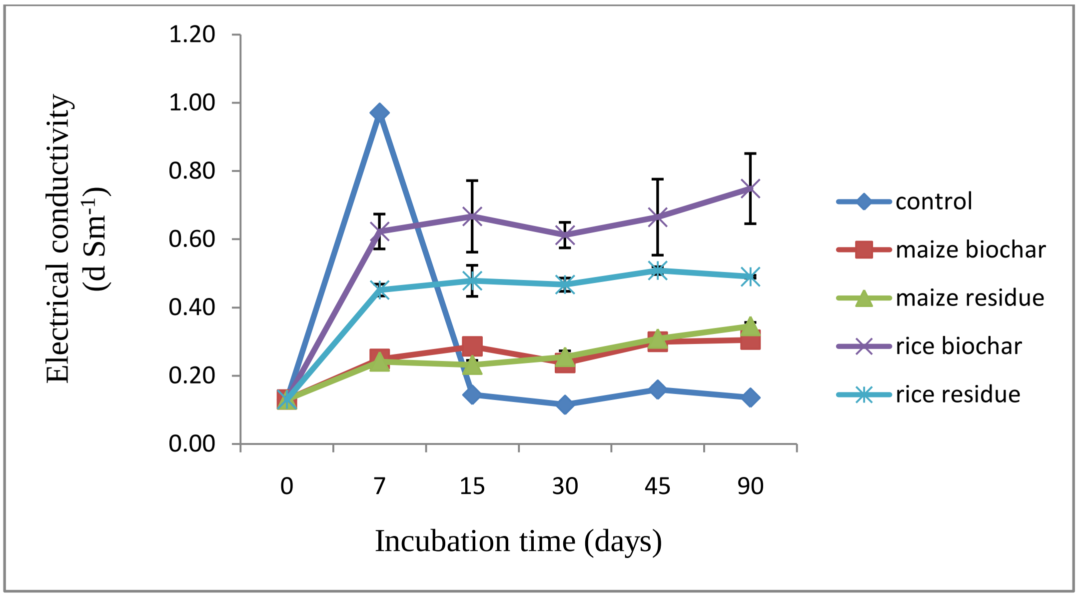

Fig. 4.5 Effect of incorporation of residue and biochar of maize and rice in changes in EC of Ranchi Soil

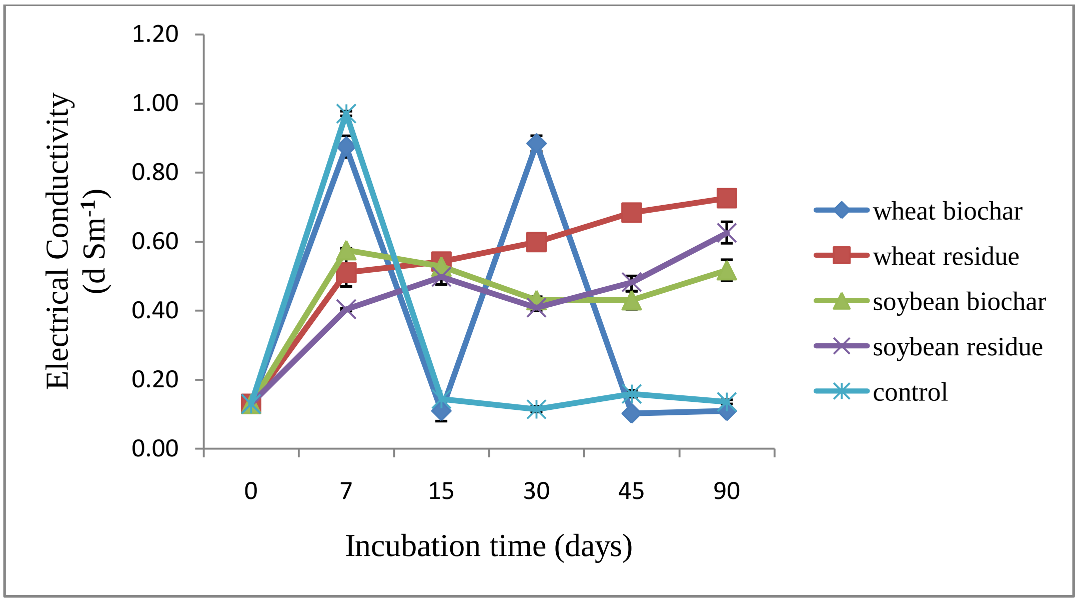

Fig. 4.6 Effect of incorporation of residue and biochar of wheat and soybean in changes in EC of Ranchi Soil

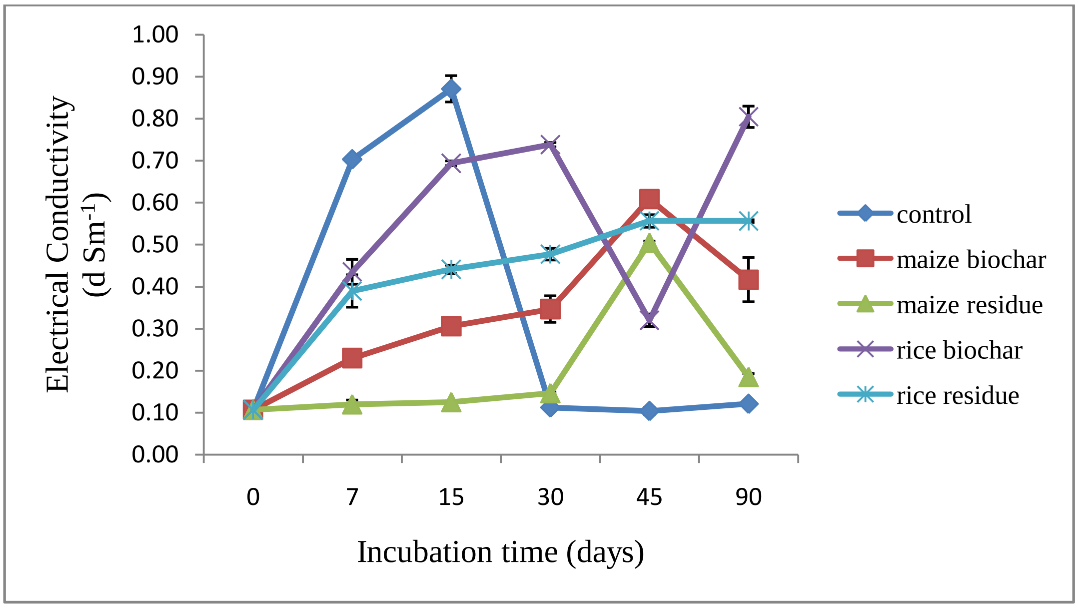

Fig. 4.7 Effect of incorporation of residue and biochar of maize and rice in changes in EC of Palampur Soil.

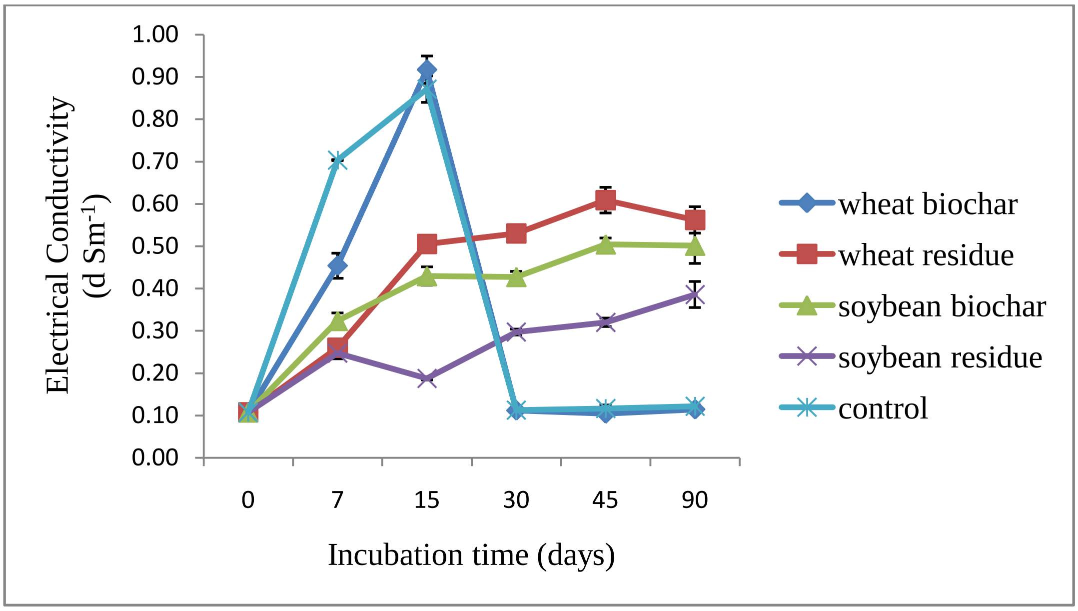

Fig. 4.8 Effect of incorporation of residue and biochar of wheat and soybean in changes in EC of Palampur Soil

4.2 Ammoniacal and nitrate-N content

Effect of different crop residues and biochar application in changes of NH_4^+-N and NO_3^--N concentration during the incubation are shown in fig.(4.9, 4.10, 4.11 and 4.12) and fig.(4.13, 4.14, 4.15 and 4.16). The changes in N dynamics with application of biochar are not fully understood (Clough *et al.*, 2010; Lehmann 2007; Singh *et al.*, 2010). In general, the concentration of NH_4^+-N increased with the lapse of time in Ranchi soil under control treatment. Application of biochar and crop residues significantly reduced the concentration of NH_4^+-N in soil ($P<0.05$) (Table 4.2). The impact of crop residues was more than the biochar in all the cases. In present study, acid (*Alfisol*) soil of Palampur and Ranchi contain majority of mineral nitrogen in ammoniacal form. Approximately, 85-90% of mineral N present in these soils were in NH_4^+-N form. Ammonification is a biotic process driven primarily by heterotrophic bacteria and a variety of fungi (Stevenson and Cole, 1999) and NH_4^+-N is the predominant form of N in extreme acid soil.Application of maize, soybean, rice and wheat residues significantly reduced in NH_4^+-N concentration in Ranchi soil and maize, rice, wheat residues reduced in NH_4^+-N concentration in Palampur acid soils ($P<0.01$). It was observed that application of crop residues and biochar maintained almost similar level of

NO_3^--N in Ranchi soil whereas it was significantly increased in Palampur soil where biochar of different crop residues was applied. The results clearly demonstrate that application of rice, maize, soybean and wheat biochar in acid soil enhancing the process of nitrification because biochar is used as a driver of nutrient transformations and more important as a soil conditioner and less so as a primary source of nutrients (Glaser *et al.*, 2002; Lehmann *et al.*, 2003).As the time of incubation increased the NH_4^+-N content decreased in Ranchi soil where the biochar of different crops were applied. In Ranchi soil, application of residues reduced the NH_4^+-N concentration significantly.The decrease in ammoniacal-N concentration was probably due tothe process of immobilization. Similar trend was recorded in Palampur soil also.

Application of rice, maize, soybean, wheat biochar and rice, soybean residues significantly favors the process of nitrification in acid soil (Table 4.3). In fact, there was significant decline in nitrate-N content in maize residue in both the acid soils. Nitrification ismediated by autotrophic organisms and it is essentially a biotic process, so it is most commonly like bacteria and archaea, in agricultural and forest soils (Stevenson and Cole, 1999; Grenon *et al.* 2004). The transformation of N from ammoniacal to nitrate N during the incubation was due to the input of ash alkalinity and subsequent increase in soil pH. Biochar has been found to increase net nitrification rates in temperate and boreal forest soils that otherwise demonstrate no net nitrification (Berglund *et al.*, 2004; DeLuca *et al.*, 2006). It is well understood that autotrophic nitrifying bacteria are favoured by less acidic soil conditions (Stevenson and Cole, 1999). Thus biochar additions to mineral soil that increase soil pH are likely to favourably influence soil nitrification.

The rapid response of the nitrifier community to biochar additions in soils with low nitrification activity and the lack of a stimulatory effect on actively nitrifying communities suggest that biochar may be adsorbing inhibitory compounds in the soil environment (Zackrisson *et al.*, 1996), which then allows nitrification to proceed.

Table 4.2: Effect of maize, rice, wheat and soybean biochar and its crop residues on ammonical nitrogen (NH_4^+-N)concentration (ppm) during incubation period

Ranchi Soil	Incubation time (days)					
Treatment	0	7	15	30	45	90
Control	11.90	54.05bc	50.28e	66.29f	103.06e	86.87d
Maize biochar	11.90	61.91c	53.87e	79.58g	96.77e	109.15e
Maize residue	11.90	26.17a	3.24a	5.61a	4.67a	33.83b
Rice biochar	11.90	54.40bc	46.78de	64.68f	81.97d	90.20d
Rice residue	11.90	57.43c	21.12b	14.74b	28.37b	44.02bc
Wheat biochar	11.90	55.31bc	75.48f	54.94e	72.81d	91.65d
Wheat residue	11.90	28.71a	1.35a	5.44a	5.53a	2.15a
Soybean biochar	11.90	46.13b	33.46c	36.22c	35.98bc	37.79bc
Soybean residue	11.90	31.64a	41.84d	43.10d	42.17c	51.10c
Palampur Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	46.70	90.21c	76.57c	97.41bc	99.51c	113.07c
Maize biochar	46.70	98.38cd	104.20ef	114.88c	103.57c	116.48c
Maize residue	46.70	28.41a	9.69a	5.43a	8.77a	10.77a
Rice biochar	46.70	92.86c	107.1f7	99.92bc	100.88c	106.41c
Rice residue	46.70	44.77b	46.87b	80.66b	100.06c	108.57c
Wheat biochar	46.70	92.31c	95.77de	102.60ba	104.69c	109.17c
Wheat residue	46.70	29.10a	6.35a	5.70a	21.96b	33.75b
Soybean biochar	46.70	104.31d	91.67d	112.40c	108.12c	108.30c
Soybean residue	46.70	30.49a	16.69a	8.42d	129.98d	179.45d

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments.

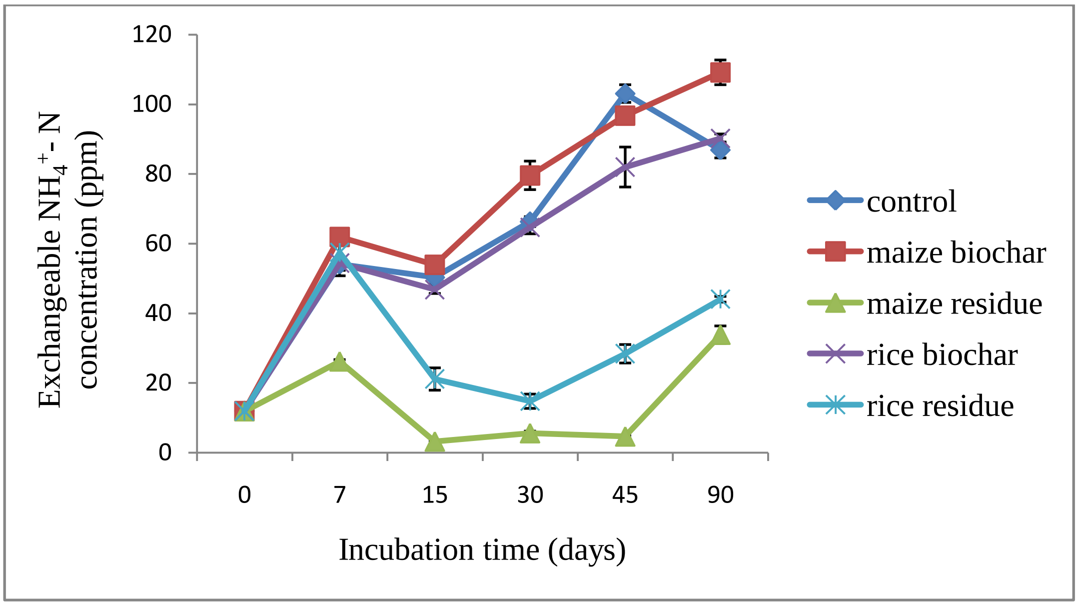

Fig. 4.9 Changes in soil ammonical nitrogen (NH_4^+-N) at Ranchi as affected by incorporation of residue and biochar of maize and rice

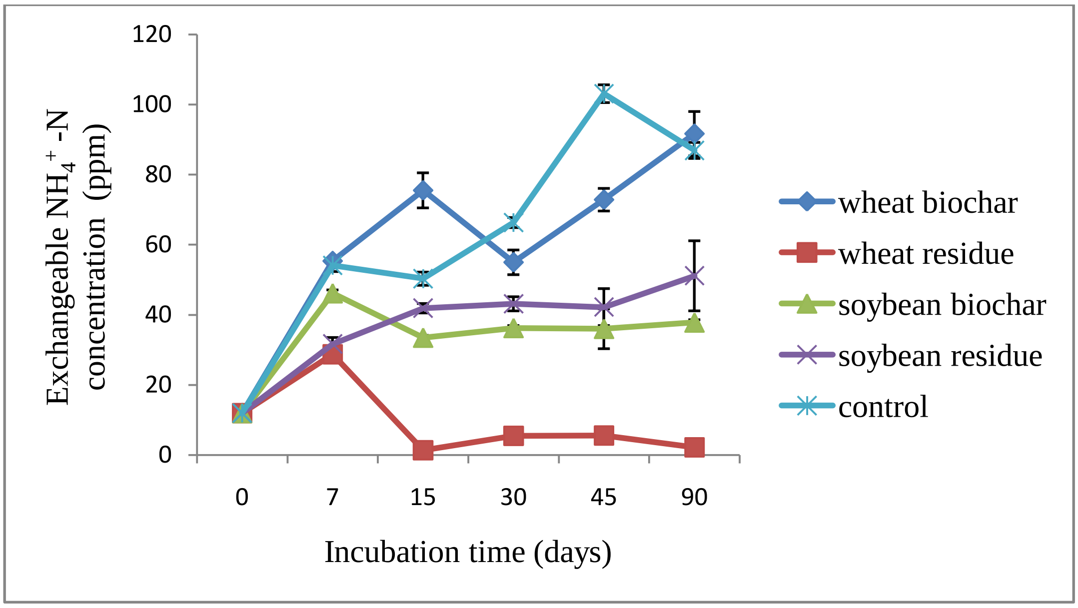

Fig. 4.10 Changes in soil ammonical nitrogen (NH_4^+-N) at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

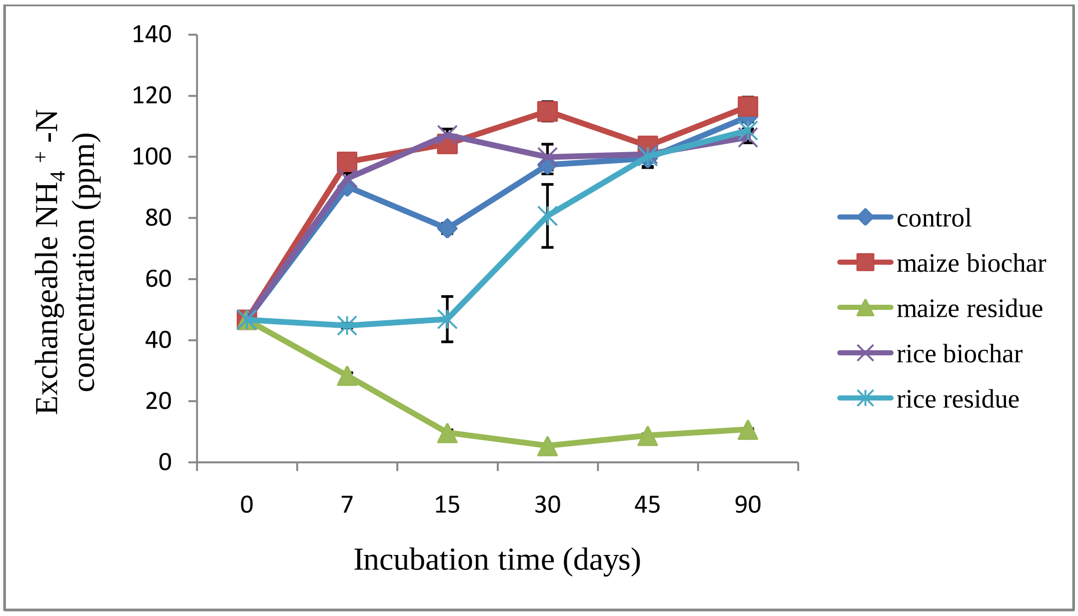

Fig. 4.11 Changes in soil ammonical nitrogen (NH_4^+-N) at Palampur as affected by incorporation of residue and biochar of maize and rice

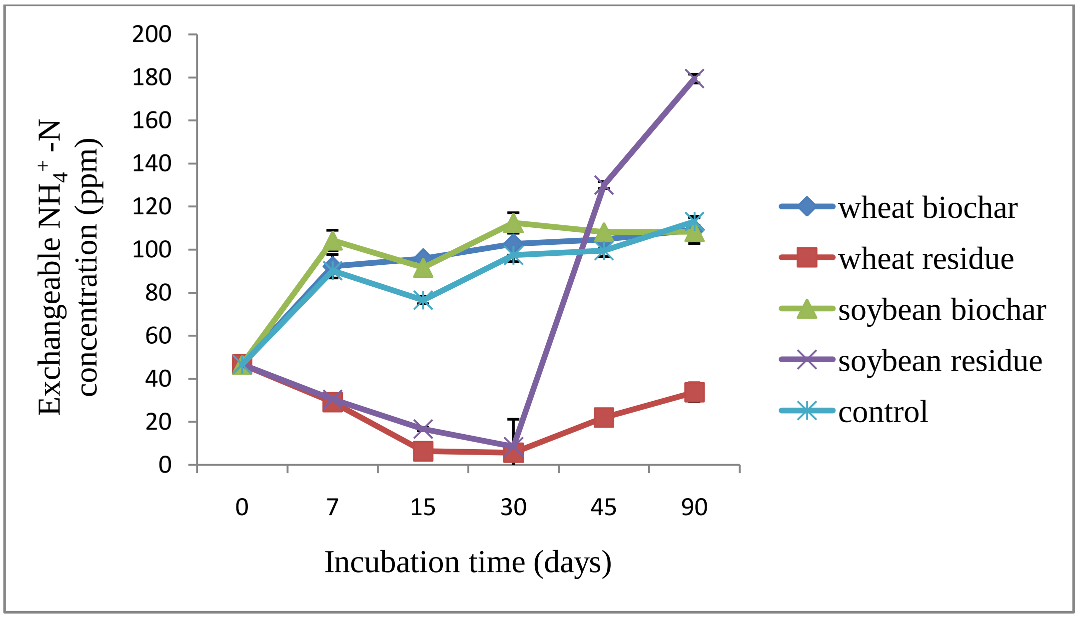

Fig. 4.12 Changes in soil ammonical nitrogen (NH_4^+-N) at Palampur as affected by incorporation of residue and biochar of wheat and soybean

Table 4.3: Effect of maize, rice, wheat and soybean biochar and its crop residues on nitrate nitrogen (NO_3^--N)concentration (ppm) during incubation period

Ranchi Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	14.7	1.73a	2.74bcd	0.19a	5.75b	3.77ab
Maize biochar	14.7	1.53a	3.19d	2.68b	5.39b	4.45b
Maize residue	14.7	1.34a	2.17abc	1.85b	5.52b	2.12a
Rice biochar	14.7	1.70a	3.12d	4.52b	6.33b	2.92ab
Rice residue	14.7	1.34a	2.75bcd	3.49c	6.33b	4.53ab
Wheat biochar	14.7	1.83a	2.88cd	2.58b	5.53b	2.28a
Wheat residue	14.7	1.60a	2.30abc	2.40b	1.36a	1.97a
Soybean biochar	14.7	1.72a	1.89a	2.21b	15.94c	49.24d
Soybean residue	14.7	1.49a	2.03ab	2.33b	19.33d	37.67c
Palampur Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	49.9	2.60a	1.77a	0.57a	8.23a	3.13a
Maize biochar	49.9	18.19d	38.75c	46.63d	47.66d	37.92d
Maize residue	49.9	1.75a	2.44a	0.31a	5.04a	1.98a
Rice biochar	49.9	22.27e	37.51c	42.61d	41.47bc	29.66c
Rice residue	49.9	7.81b	26.62b	28.27b	40.39bc	17.78b
Wheat biochar	49.9	3.50a	36.05c	44.74d	37.83b	28.02c
Wheat residue	49.9	1.49a	1.83a	3.90a	5.24a	2.08a
Soybean biochar	49.9	10.84c	35.29c	35.30c	43.67c	33.80cd
Soybean residue	49.9	1.81a	3.60a	0.72a	6.54a	2.92a

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments.

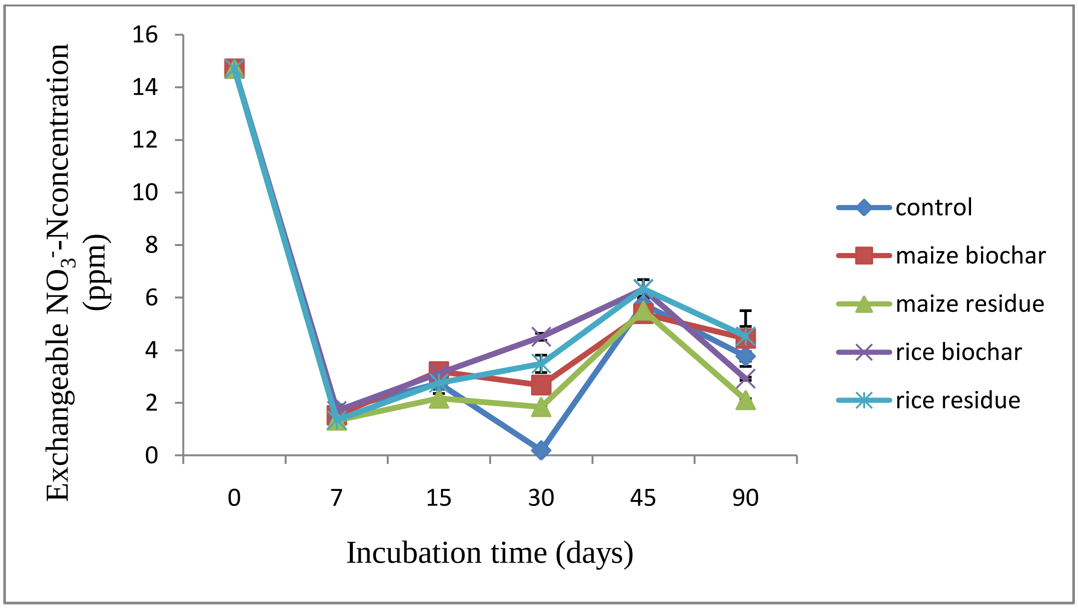

Fig. 4.13 Changes in soil nitrate nitrogen (NO_3^--N) at Ranchi as affected by incorporation of residue and biochar of maize and rice

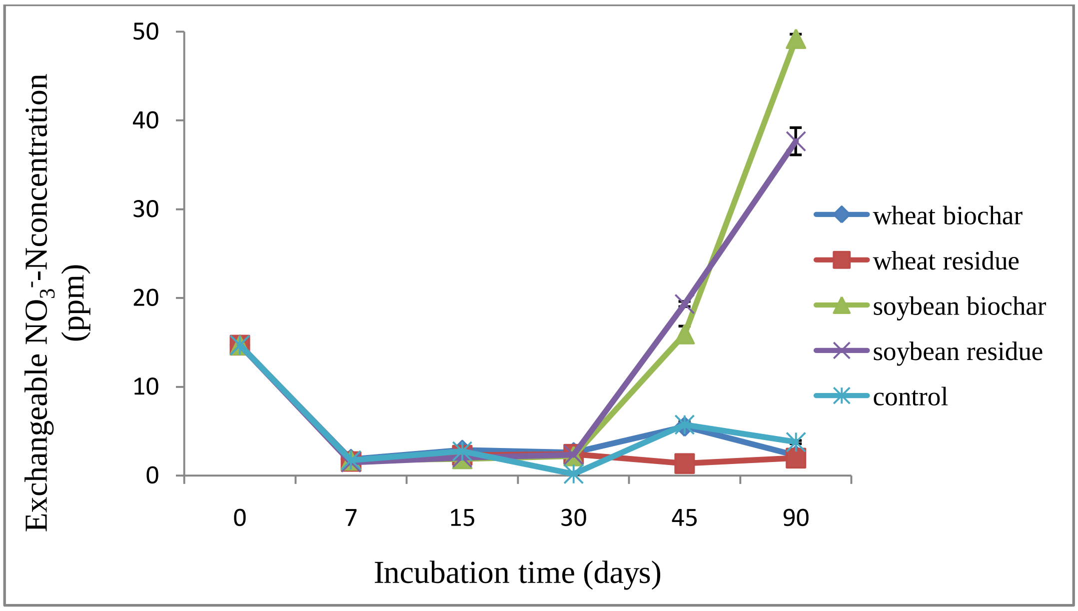

Fig. 4.14 Changes in soil nitrate nitrogen (NO_3^--N) at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

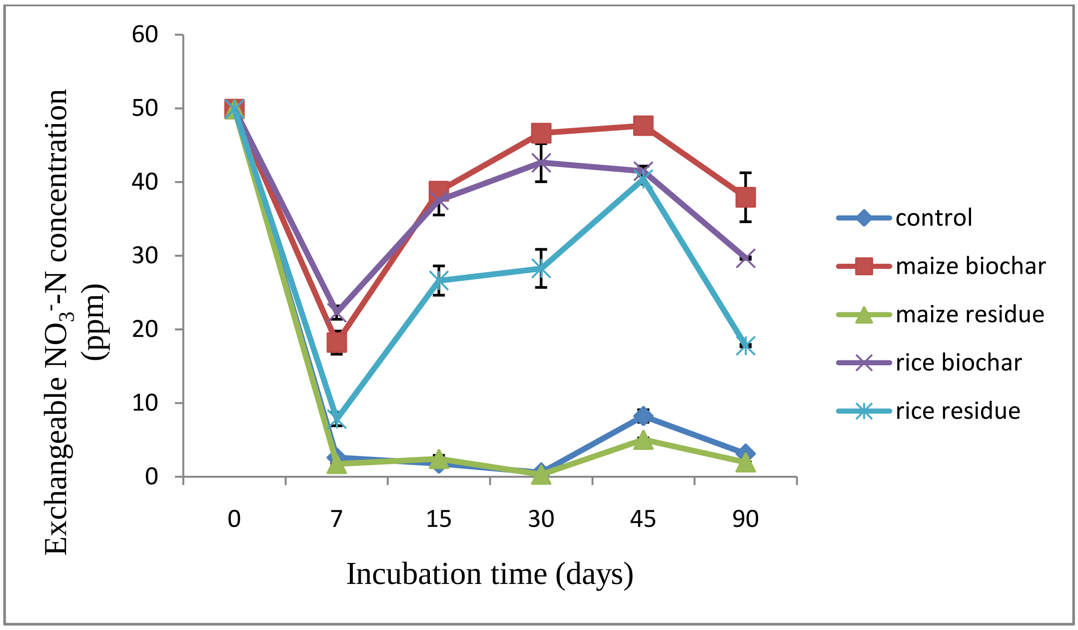

Fig. 4.15 Changes in soil nitrate nitrogen (NO_3^--N) at Palampur as affected by incorporation of residue and biochar of maize and rice

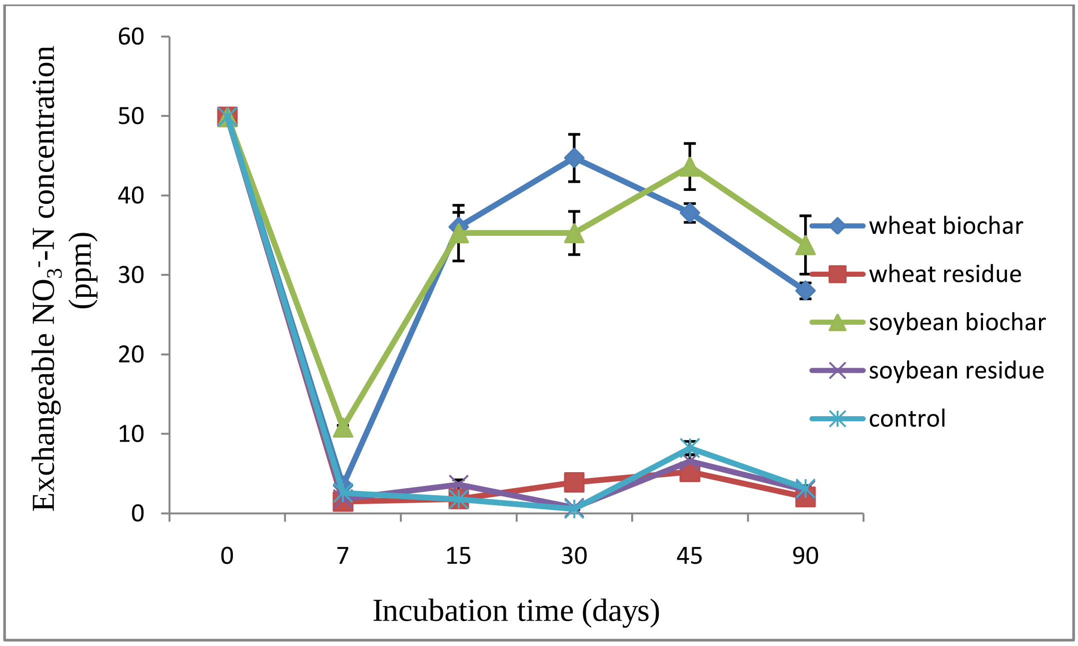

Fig. 4.16 Changes in soil nitrate nitrogen (NO_3^--N) at Palampur as affected by incorporation of residue and biochar of wheat and soybean

4.3 Exchangeable base cations

The application of biochar and its crop residue did not have any significant impact on exchangeable base cations (Ca^{2+}+Mg^{2+}) of the Ranchi soil (fig. 4.17 and 4.18)($P < 0.05$). However, application of soybean biochar and residue significantly increased the Ca+Mg content of soil. In general, exchangeable base cations like Ca+Mg increased with the lapse of incubation time. The initial concentration of Ca+Mg were 1.21 meq/100 g soil which was increased to 9.12 and 6.77 meq/100g after 90 days of incubation under soybean biochar and residue treatments, respectively. Soybean biochar amendments elevated exchangeable Ca+Mg level in the Ranchi soil (fig. 4.18). Similar trend was also recorded in Palampur soil.In Palampur soil soybean biochar and its crop residue incorporation increased the concentration of Ca+Mg in comparison to control (fig. 4.20). Residue contains base cations (Wang *et al.,* 2009) and after pyrolysis, these base cations in original biomass were retained in the biochar samples (Yuan and Xu, 2011). During incubation period, base cations released from the biochar and crop residue samples exchanged with Al^{3+} and H^{+} and enriched soil with these exchangeable base cations. When the biochar and crop residues were incorporated into the soil, these base cations released into the soil and occupied soil exchange-sites. Therefore, the incorporation of biochar not only decreased soil acidity, but also improved soil fertility (Yuan *et al.,* 2011). The data suggests that the basic cations (K, Ca+Mg, Na) in the biochar and crop residues sample released quickly leading to the quick rise in soil pH during the incubation period. Thus the addition of maize, rice, wheat, soybean biochar and rice, wheat, soybean crop residues induced a greater increase in Ca+Mg concentration at each sampling stage compared with control. The neutralization of soil exchangeable acidity by biochar and crop residues application is also evident from the decrease in exchangeable Al content of soil. The decrease in soil exchangeable Al further reduced the potential toxicity of Al in acid soils.

Table 4.4: Effect of maize, rice, wheat and soybean biochar and its crop residues on Exchangeable Ca^{2+}+Mg^{2+}concentration (meq/100gm of soil) during incubation period

Ranchi Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	1.21	3.22a	4.19ab	3.42a	6.11a	5.19bc
Maize biochar	1.21	3.76a	4.19ab	3.80ab	5.39a	5.52bc
Maize residue	1.21	5.37b	4.40abc	4.47ab	6.83ab	5.35bc
Rice biochar	1.21	4.92b	4.82bc	5.70c	6.29a	6.52cd
Rice residue	1.21	5.28b	5.14bc	5.61c	6.83ab	5.02b
Wheat biochar	1.21	5.01b	5.24c	5.80c	6.56ab	3.76a
Wheat residue	1.21	3.67a	3.77a	4.75bc	5.93a	5.44bc
Soybean biochar	1.21	6.53c	7.44d	8.08d	8.53b	9.12e
Soybean residue	1.21	6.17c	7.55d	8.75d	6.02a	6.77d
Palampur Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	1.31	2.16a	3.95a	3.18a	5.03ab	5.23ab
Maize biochar	1.31	3.63b	4.25a	3.53a	4.43a	4.74ab
Maize residue	1.31	5.78c	3.85a	3.80a	5.81b	4.60ab
Rice biochar	1.31	7.84e	4.74a	5.38a	7.64c	6.21ab
Rice residue	1.31	6.76d	6.62b	5.03b	5.12ab	5.02ab
Wheat biochar	1.31	7.64de	4.55a	5.21b	6.25b	5.44ab
Wheat residue	1.31	5.68c	4.55a	3.09b	6.25b	4.18a
Soybean biochar	1.31	8.72f	8.79d	8.74d	7.90c	7.11c
Soybean residue	1.31	7.15de	7.31c	6.97c	8.94d	7.04c

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments.

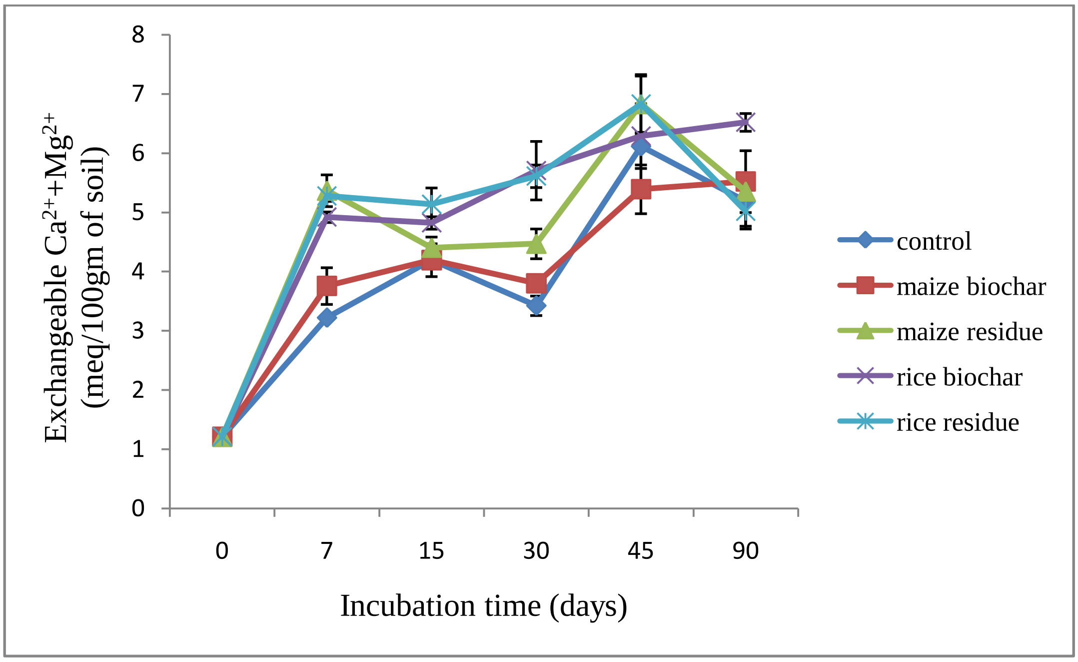

Fig. 4.17 Changes in soil exchangeable Ca^{2+} + Mg^{2+} concentration at Ranchi as affected by incorporation of residue and biochar of maize and rice

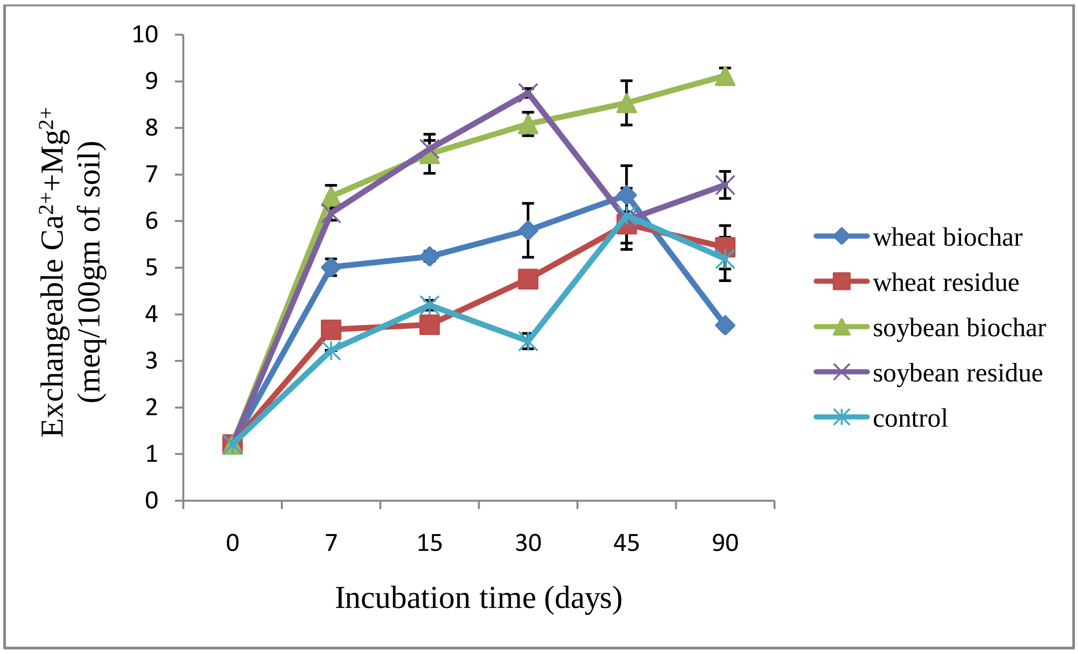

Fig. 4.18 Changes in soil exchangeable Ca^{2+} + Mg^{2+} concentration at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

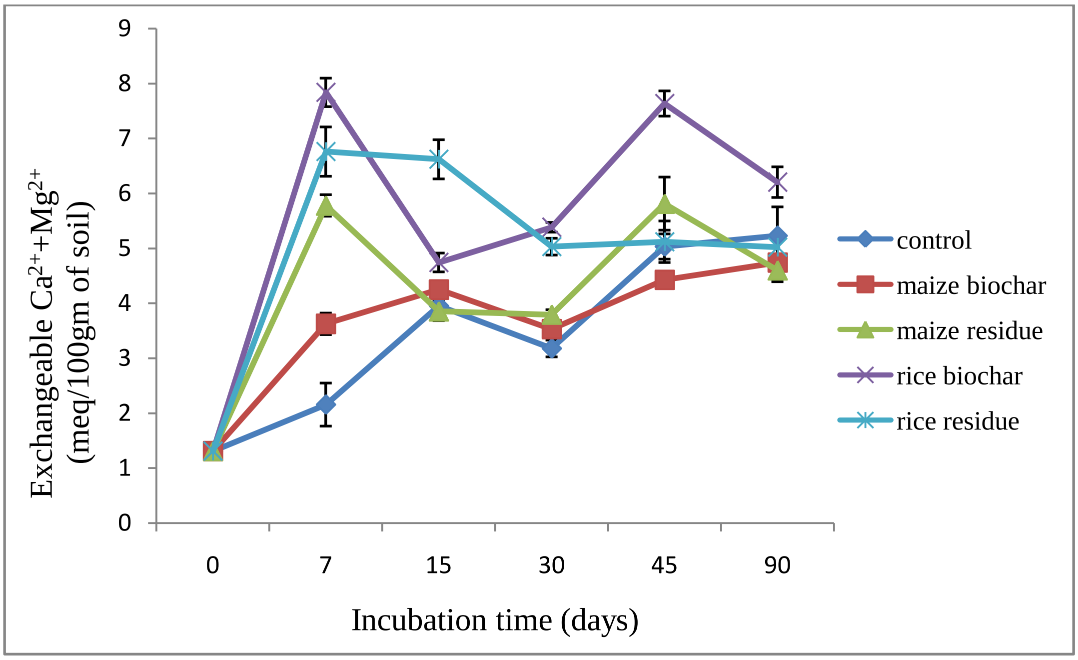

Fig. 4.19 Changes in soil exchangeable Ca^{2+} + Mg^{2+} concentration at Palampur as affected by incorporation of residue and biochar of maize and rice

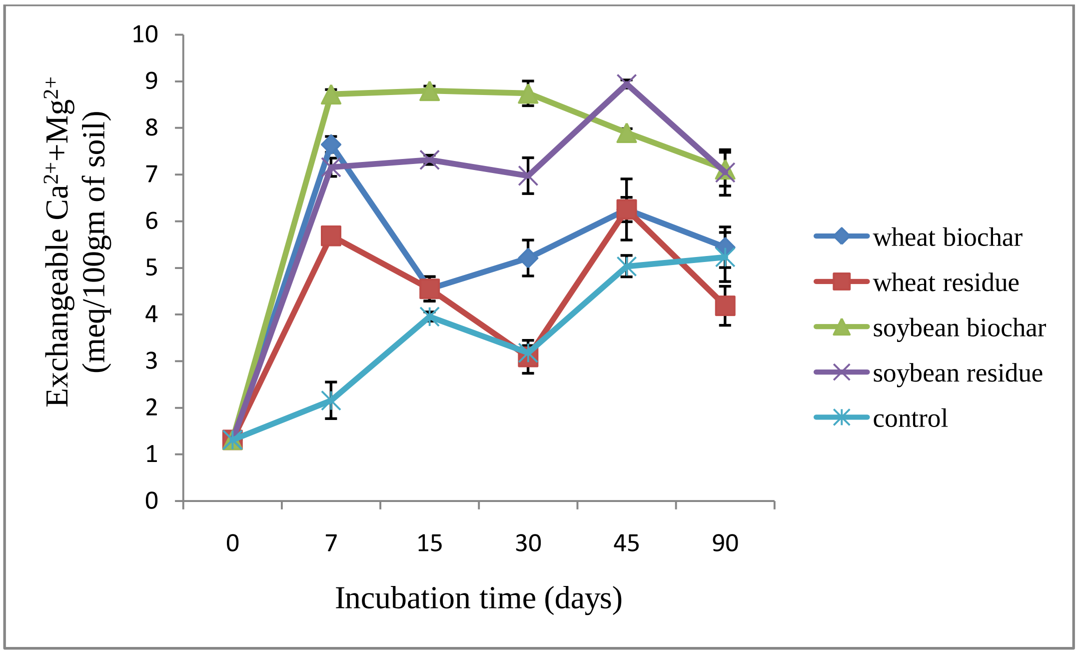

Fig. 4.20 Changes in soil exchangeable Ca^{2+} + Mg^{2+} concentration at Palampur as affected by incorporation of residue and biochar of wheat and soybean

Similar trend was observed for exchangeable K and Na. The addition of biochar and crop residues led to greater increase in soil exchangeable K. The acidic soilsused in the incubation study were poor in terms of exchangeable potassium (Ranchi 92.5 and palampur soil 120 mg/kg). Exchangeable Kcontent of soil was increased by 5-20 folds after application of maize, soybean, rice and wheat biocharand its crop residues (Table 4.5 and fig. 4.21, 4.22, 4.23 and 4.24). Similar results for K were reported by Lehman *et al*., (2003) when biochar was added to Oxisol of Brazilian Amazon. Generally acid soils of India are poor in terms of exchangeable K concentration as the soil clay is mostly dominated by 1:1 type (kaolinitic) clay minerals. Under these circumstances, legume biochar could be the potential amendment not only for soil pH correction but also for substitution of potassic fertilizer. Exchangeable K was lower than the exchangeable Ca+Mg of the soil; however, the biochar sample contains higher K content than the Ca+Mg. Therefore, biochar incorporation could provide alternate source of potassium in acid soils (Yuan and Xu, 2011).

Table 4.5: Effect of maize, rice, wheat and soybean biochar and its crop residues on ExchangeableK concentration (ppm) during incubation period

Ranchi Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	95.5	120.46a	168.46a	202.78a	194.79a	153.18a
Maize biochar	95.5	641.99b	641.99b	731.06c	943.26e	683.98e
Maize residue	95.5	614.61b	941.23c	1264.19f	838.30d	561.94d
Rice biochar	95.5	1252.49d	2668.59e	1043.27e	1462.10g	1198.56g
Rice residue	95.5	621.00b	1032.14c	569.52b	571.09b	511.60cd
Wheat biochar	95.5	1432.72e	1432.72f	888.72c	1351.64f	465.94c
Wheat residue	95.5	628.76b	1523.08d	879.02d	997.34e	351.59b
Soybean biochar	95.5	904.81c	1023.74c	1135.64e	1020.26e	1025.32f
Soybean residue	95.5	557.58b	690.04b	772.78c	703.09c	692.94e
Palampur Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	120	136.99a	217.30a	224.26a	162.05a	238.33a
Maize biochar	120	801.91d	905.01c	645.30b	599.06b	557.77bc
Maize residue	120	566.94b	625.43bc	595.31b	653.07b	569.86c
Rice biochar	120	1724.81g	2336.90e	1233.40e	1361.49d	1184.55f
Rice residue	120	674.93c	689.22b	573.25b	823.54bc	1184.55b
Wheat biochar	120	1458.34f	2798.23f	1443.25f	1412.41d	500.50g
Wheat residue	120	542.94b	1217.61d	854.24c	1025.88c	681.92d
Soybean biochar	120	1056.89e	1089.04d	1010.95d	1011.27c	763.38e
Soybean residue	120	637.93c	1106.69d	638.09b	666.36b	528.96bc

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments

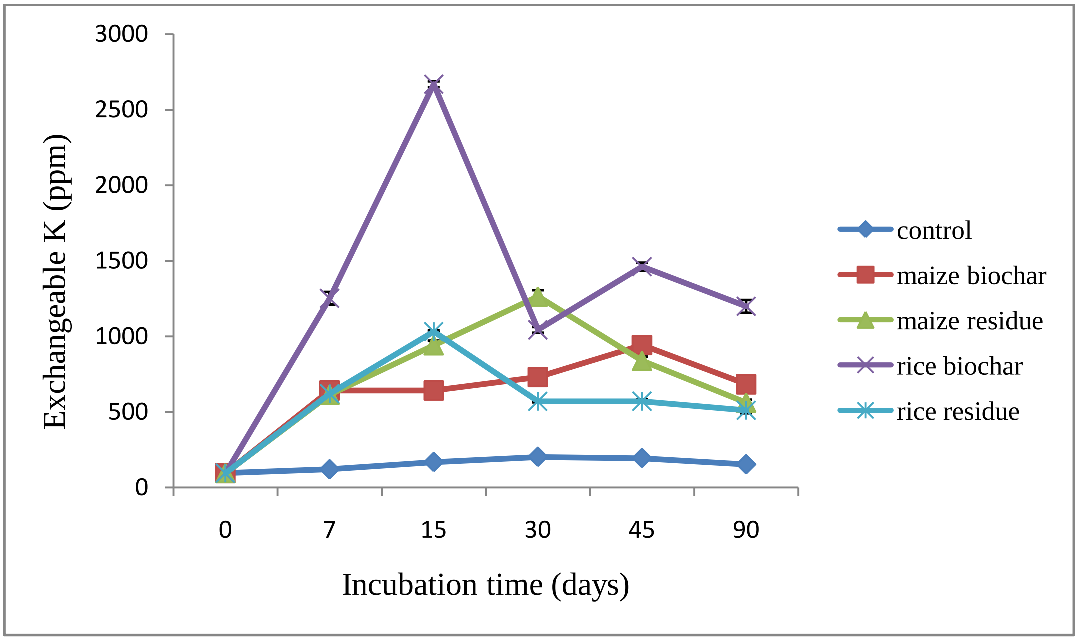

Fig. 4.21 Changes in soil exchangeable K concentration at Ranchi as affected by incorporation of residue and biochar of maize and rice

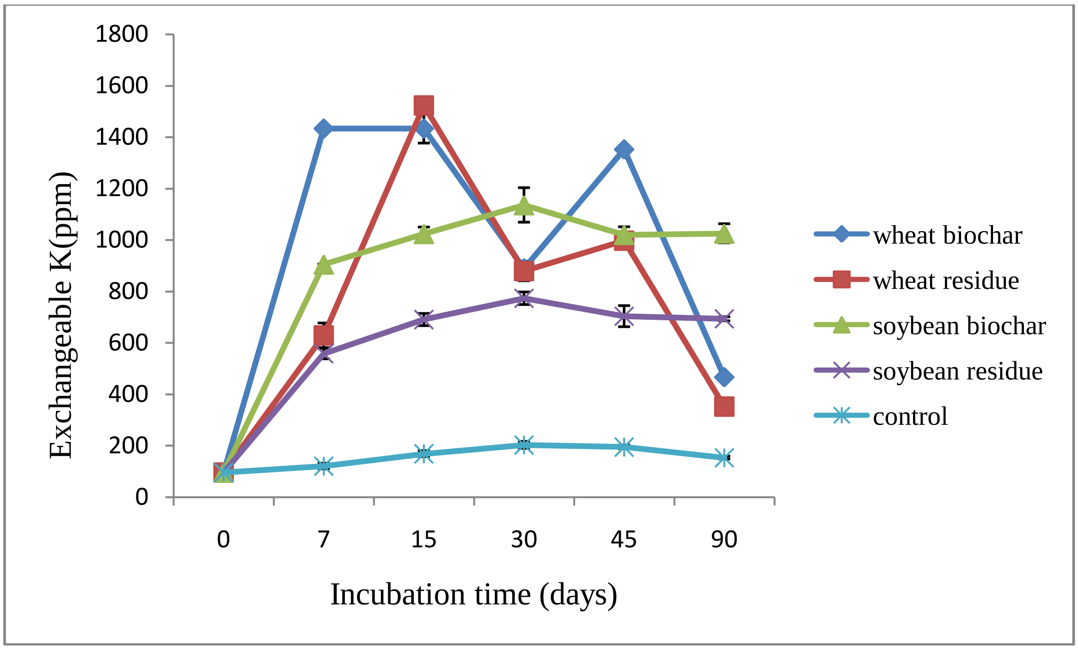

Fig. 4.22 Changes in soil exchangeable K concentration at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

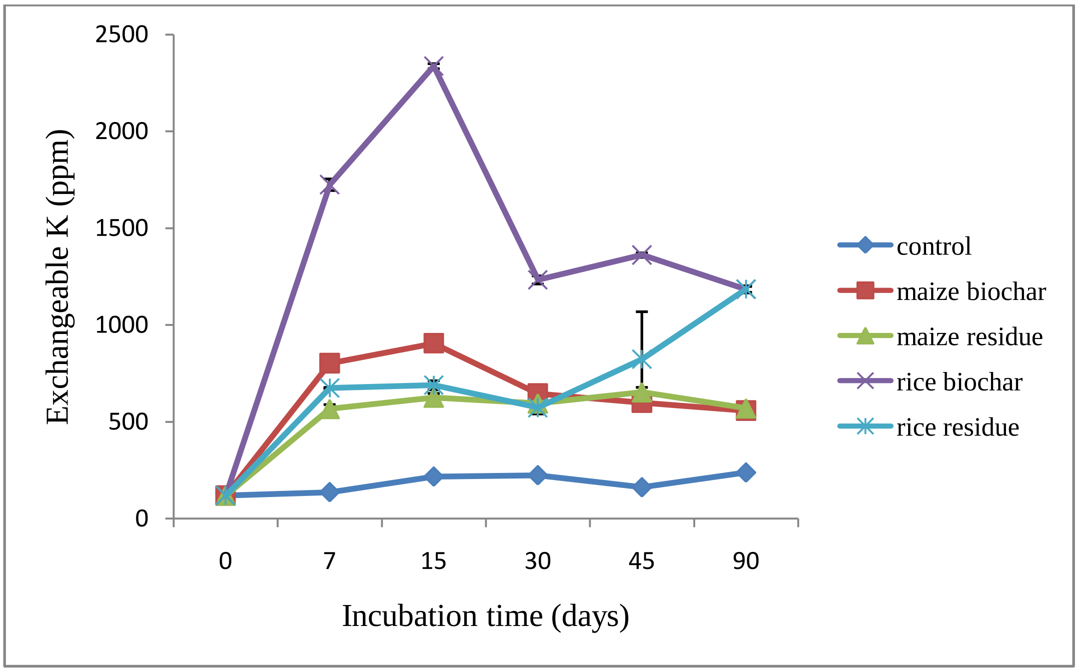

Fig. 4.23 Changes in soil exchangeable K concentration at Palampur as affected by incorporation of residue and biochar of maize and rice

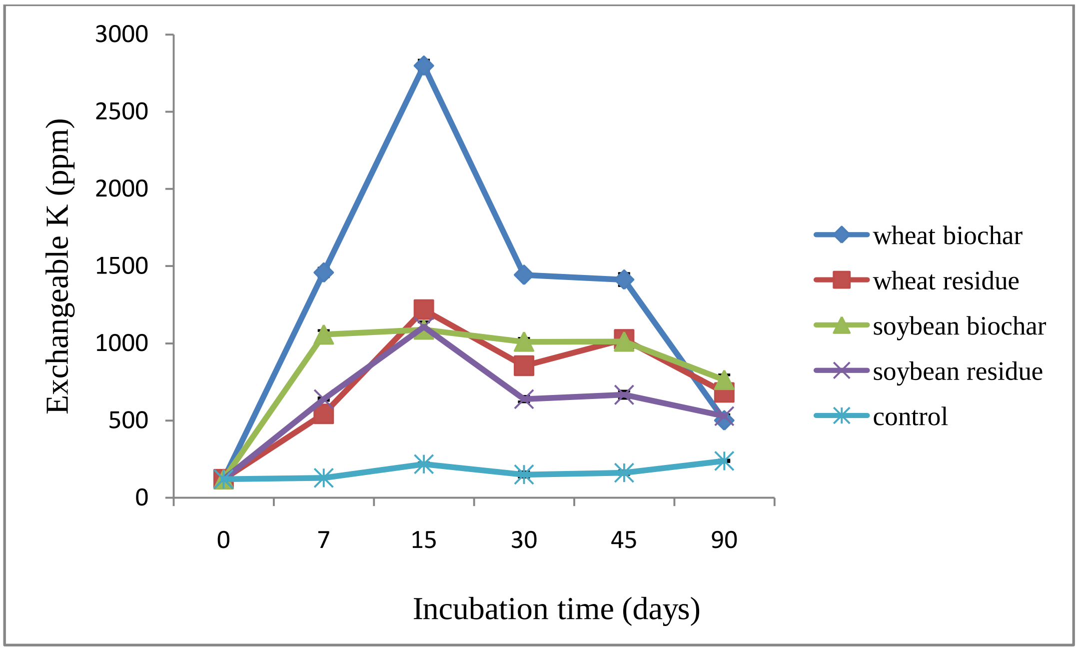

Fig. 4.24 Changes in soil exchangeable K concentration at Palampur as affected by incorporation of residue and biochar of wheat and soybean

The impact of the addition of rice, maize, soybean, wheat biochar and its crop residues in soil, exchangeable Na concentration during the incubation period is shown in (Table 4.6 and Fig. 4.25, 4.26, 4.27, 4.28). The exchangeable Na concentrations are much higher in case of rice biochar application in both the soils. The increasing trend was recorded till 45 days of incubation thereafter a decrease in concentration was recorded at 90 days after incubation.

Table 4.6: Effect of maize, rice, wheat and soybean biochar and its crop residues on Na^+concentration (ppm) during incubation period

Ranchi Soil			**Incubation time (days)**			
Treatment	0	7	15	30	45	90
Control	35.8	36.96a	48.13ab	50.45ab	41.25a	46.08b
Maize biochar	35.8	36.50a	55.10bc	51.91ab	39.90a	52.06b
Maize residue	35.8	41.07ab	57.22bcd	55.79b	31.17a	52.48b
Rice biochar	35.8	50.19b	59.90cd	66.90c	44.50d	79.79d
Rice residue	35.8	47.91ab	48.13ab	47.06ab	41.30a	49.07b
Wheat biochar	35.8	49.73b	55.08bc	51.91ab	61.40c	54.62b
Wheat residue	35.8	40.61ab	52.41bc	49.48ab	52.25b	63.58c
Soybean biochar	35.8	36.96a	43.30a	40.75a	38.04a	29.23a
Soybean residue	35.8	36.96a	64.20d	47.54ab	36.67a	23.64a
Palampur Soil			**Incubation time (days)**			
Treatment	0	7	15	30	45	90
Control	30.5	40.00a	45.88a	33.77a	31.44a	25.97b
Maize biochar	30.5	38.50a	43.36a	34.67b	46.49ab	23.48b
Maize residue	30.5	40.00a	38.30a	37.38ab	37.19a	27.03b
Rice biochar	30.5	60.49b	62.01b	63.49d	65.09c	56.20d
Rice residue	30.5	44.50a	44.37a	42.30ab	34.09a	23.02b
Wheat biochar	30.5	36.50a	49.41a	50.89c	43.83ab	34.86c
Wheat residue	30.5	44.00a	46.89a	43.68bc	51.80b	26.68b
Soybean biochar	30.5	43.50a	44.87a	41.40ab	31.44a	14.66a
Soybean residue	30.5	41.50a	42.86a	44.58bc	34.09a	26.32b

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments

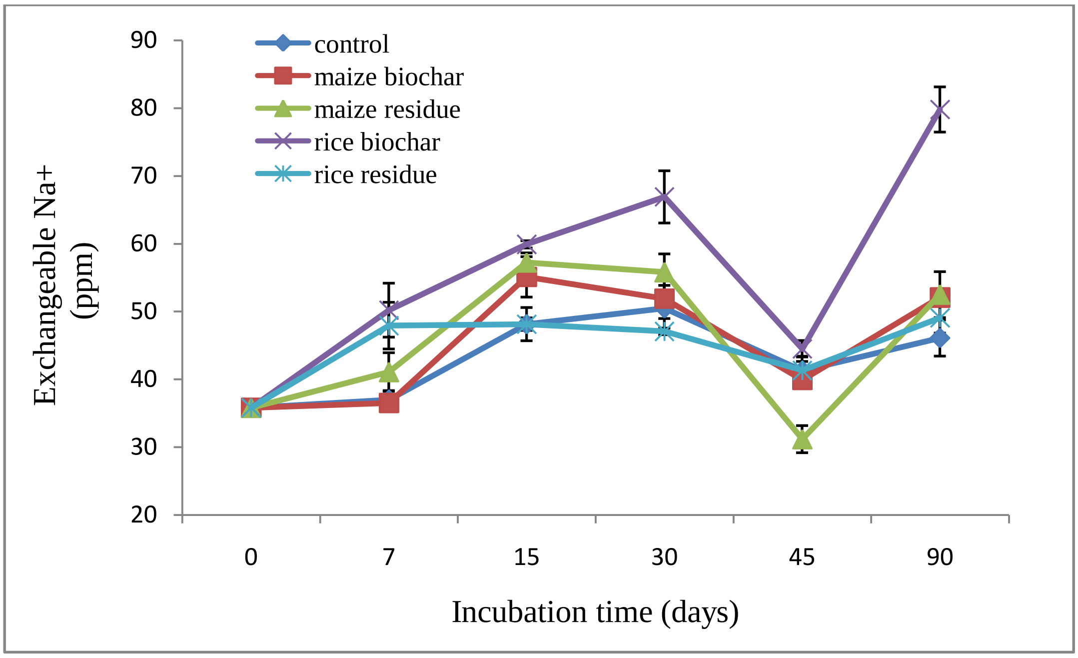

Fig. 4.25 Changes in soil exchangeable Na^+ concentration at Ranchi as affected by incorporation of residue and biochar of maize and rice

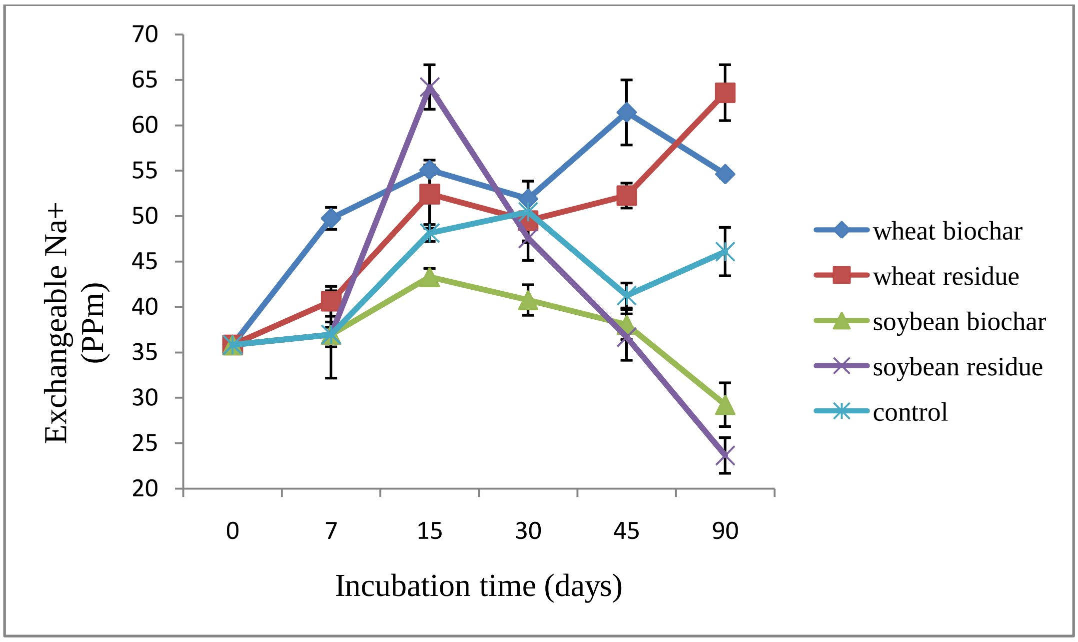

Fig. 4.26 Changes in soil exchangeable Na^+ concentration at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

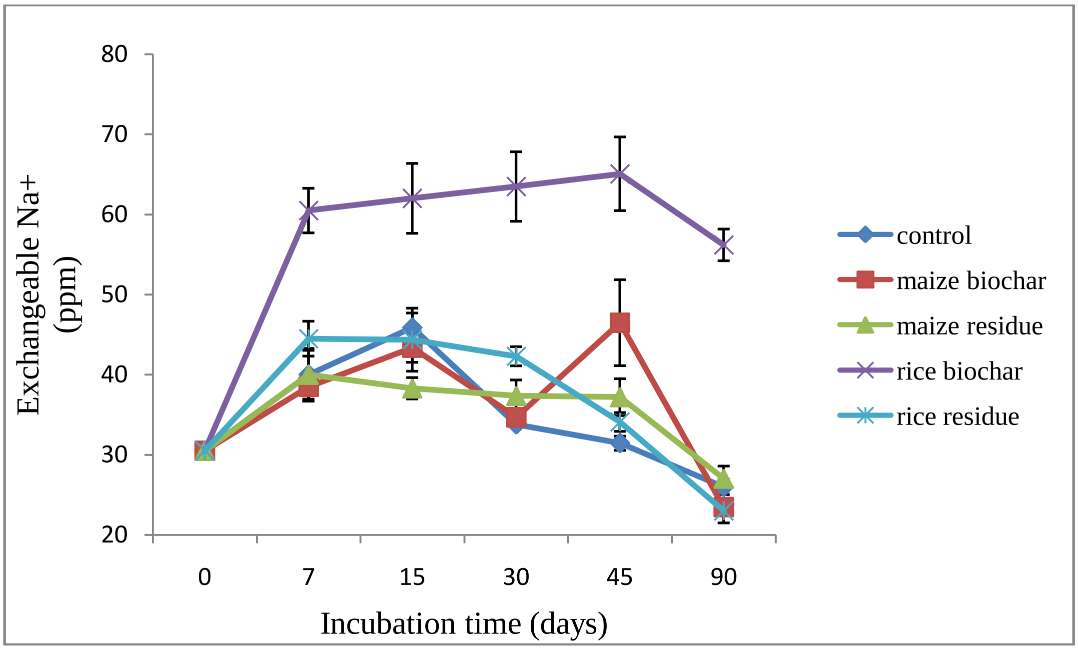

Fig. 4.27 Changes in soil exchangeable Na^{+}concentration at Palampur as affected by incorporation of residue and biochar of maize and rice

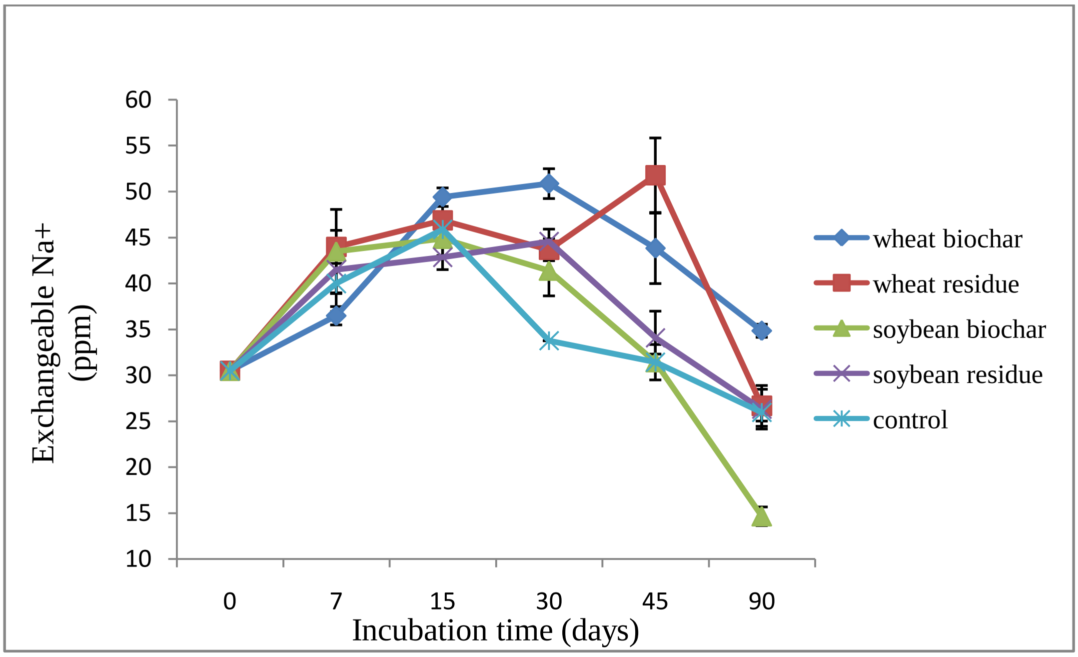

Fig. 4.28 Changes in soil exchangeable Na^{+}concentration at Palampur as affected by incorporation of residue and biochar of wheat and soybean

4.4 Exchangeable Al content

The cause of soil acidity is mainly due to exchangeable Al, while exchangeable H contributes less to exchange acidity.When the soil pH drops below 5, Al^{3+} is solubilized into the soil solution and this is the most important rhizotoxic Al species.The impact of the addition of rice, wheat, soybean, maizebiochar and its crop residues in soil exchangeable Al concentration during the incubation period is shown in table 4.7. Exchangeable Al is the major contributor of exchangeable acidity of *Alfisol* (Yu, 1997; Yuan and Xu, 2011). Application of wheat, soybean, rice, maize biochar and its crop residues significantly (P<0.06) reduced the concentration of exchangeable Al during the incubation period (Table 4.7 and Fig. 4.29, 4.30, 4.31, 4.32). In Ranchi soil, the exchangeable Al^{3+} concentration was significantly differed among different treatments during the incubation periods, However the difference among treatments in 45 days was not significant. Application of wheat, soybean, rice and maize biochar and its crop residues significantly differed the concentration of exchangeable Al^{3+} in Palampur acid soil. It is consistent with the findings of other workers (Steiner *et al.*, 2007; Novak *et al.*, 2009 and Yuan and Xu, 2011). Van Zwieten *et al*., (2010) also reported that an increase in soil pH from 4.2 to between 5.4 and 5.9 with the application of 1% (w/w) papermill biochar in a ferrosol; resulted in a concomitant reduction in exchangeable Al from 2 to <0.1 cmol(p)/kg. The addition of soybean biochar and soybean residue in Palampur acid soil and rice residue in Ranchi acid soil decreased Al concentration compared with other treatments. It indicates that Al toxicity decreased due to its complexation to high-molecular-weight organic compounds (Alleoni *et al.*, 2010) present in the biochar.

Table 4.7:Effect of maize, rice, wheat and soybean biochar and its crop residues on exchangeable Al^{3+} concentration (ppm) during incubation period

Ranchi Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	0.45	0.08b	0.30bc	0.33ab	0.26a	0.48e
Maize biochar	0.45	0.00a	0.18b	0.33ab	0.21a	0.33c
Maize residue	0.45	0.00a	0.21bc	0.62ab	0.23a	0.22abc
Rice biochar	0.45	0.00a	0.21bc	0.73b	0.31a	0.29bc
Rice residue	0.45	0.33d	0.18b	0.35ab	0.18a	0.17ab
Wheat biochar	0.45	0.00a	0.00a	0.30a	0.21a	0.26abc
Wheat residue	0.45	0.00a	0.24bc	0.24a	0.21a	0.29abc
Soybean biochar	0.45	0.23c	0.27bc	0.54ad	0.23a	0.12a
Soybean residue	0.45	0.08b	0.33c	0.43ab	0.28a	0.24abc
Palampur Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	2.99	2.24e	2.99d	1.99cd	1.76c	2.03f
Maize biochar	2.99	2.32e	2.88d	1.74c	2.63d	2.17f
Maize residue	2.99	1.68d	2.34c	2.14d	2.01c	1.83e
Rice biochar	2.99	0.62b	0.99b	0.96b	0.69ab	0.70b
Rice residue	2.99	0.50ab	0.90b	2.04b	1.74c	0.86c
Wheat biochar	2.99	0.98c	1.38b	1.03cd	0.89b	1.26c
Wheat residue	2.99	1.93d	2.68cd	2.45e	1.93c	1.45d
Soybean biochar	2.99	0.25a	0.37a	0.35a	0.40a	0.24a
Soybean residue	2.99	0.78bc	0.42a	0.43a	0.45a	0.22a

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments

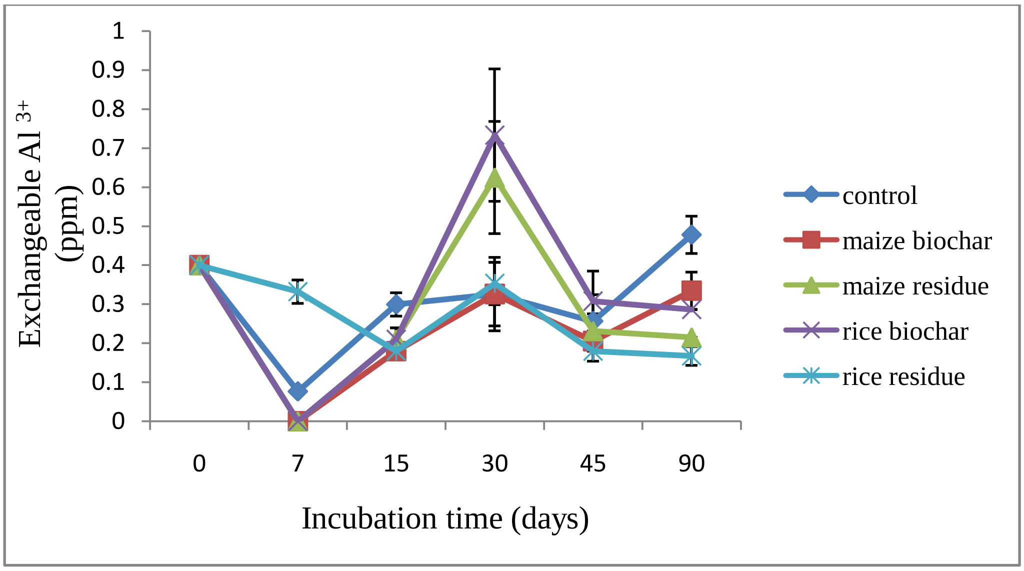

Fig. 4.29 Changes in soil exchangeable Al^{3+} concentration at Ranchi as affected by incorporation of residue and biochar of maize and rice

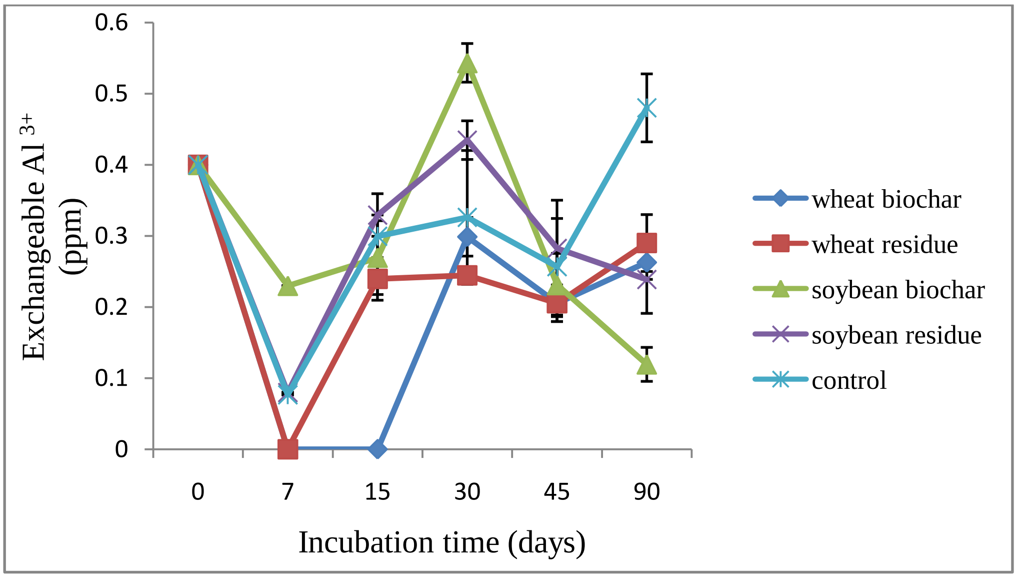

Fig. 4.30 Changes in soil exchangeable Al^{3+} concentration at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

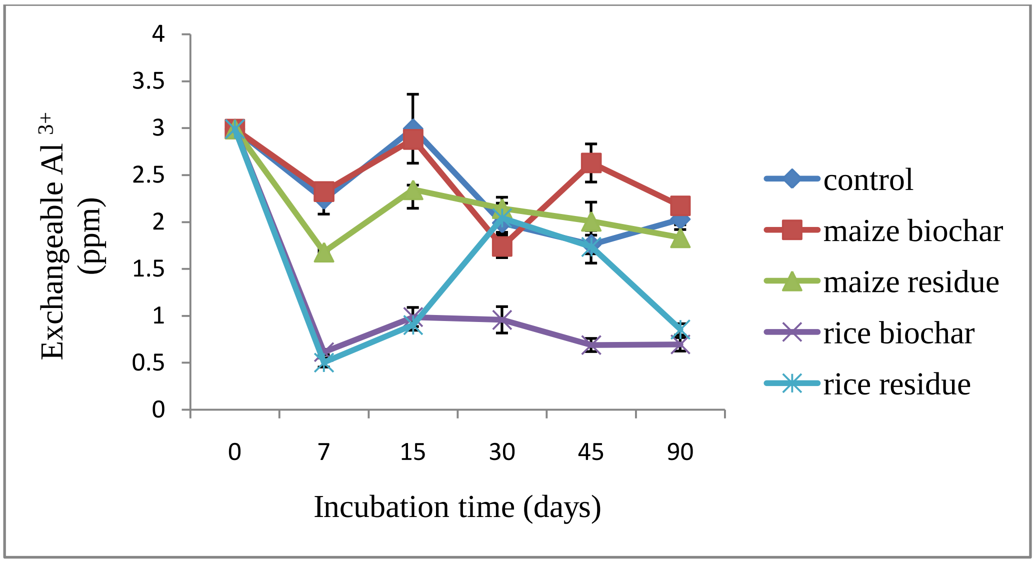

Fig. 4.31 Changes in soil exchangeable Al^{3+} concentration at Palampur as affected by incorporation of residue and biochar of maize and rice

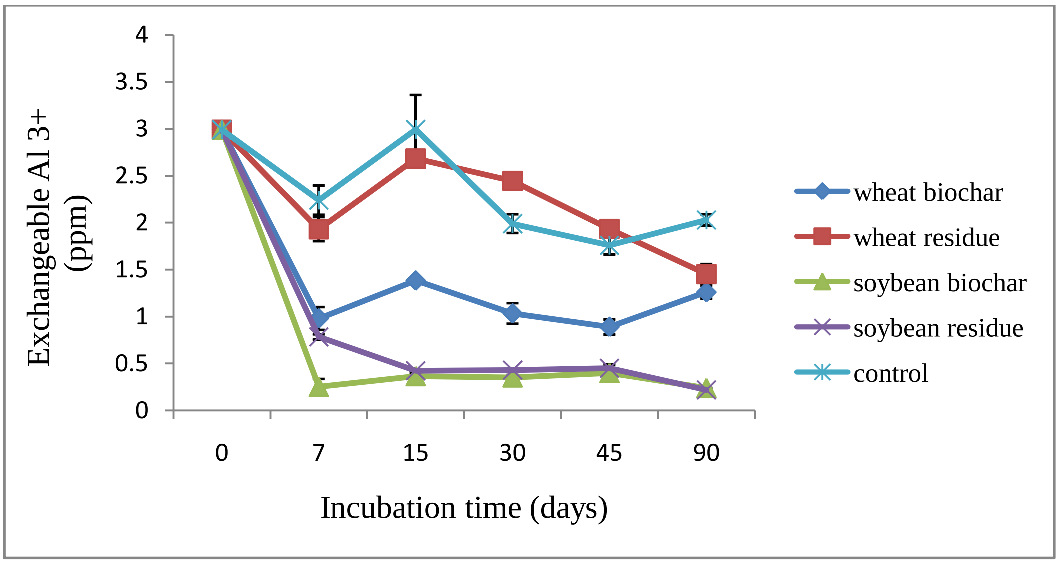

Fig. 4.32 Changes in soil exchangeable Al^{3+} concentration at Palampur as affected by incorporation of residue and biochar of wheat and soybean

4.5Available P

Application of biocharand crop residues significantly (P<0.05) affected the P availability in high P soils of Palampur and Ranchi (Table 4.8 and Fig. 4.33, 4.34, 4.35 and 4.36). Acid soils are generally deficient in available P. The initial P status of incubated soil of Palampur and Ranchi were 15.5 ppm and 19.5 ppm, respectively. Application of biochar and crop residues significantly increased the availability of P comparedwith control. The increase in soil available P induced by maize and soybean biochar was much greater than other treatments. In general application of soybean biochar proved to be the best in increasing the available P status of soil (fig.4.34 and 4.36). There were more than 2-3 folds of increase in P concentration in soil till 45 days of incubation. Thereafter, a decreasing trend was observed at termination of incubation study. Similar trend was recorded in Palampur soil also.

Table 4.8:Effect of maize, rice, wheat and soybean biochar and its crop residues on available P during incubation period

Ranchi Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	19.5	21.58a	28.08ab	15.35a	13.38a	9.96a
Maize biochar	19.5	41.18d	42.97c	34.18de	22.55cd	22.27d
Maize residue	19.5	27.56abc	29.63ab	29.01cd	25.25d	19.69cd
Rice biochar	19.5	33.03c	36.79bc	34.90de	17.88abc	13.25ab
Rice residue	19.5	23.86a	19.01a	18.65ab	18.70abc	11.05a
Wheat biochar	19.5	31.35bc	37.11bc	21.25abc	19.43bc	14.10ab
Wheat residue	19.5	23.89a	23.40a	17.95ab	17.00abc	12.78ab
Soybean biochar	19.5	41.75d	43.83c	40.77e	25.78d	22.40d
Soybean residue	19.5	26.12ab	19.31a	25.15bc	15.24ab	16.90bc
Palampur Soil	**Incubation time (days)**					
Treatment	0	7	15	30	45	90
Control	15.59	22.95a	21.13a	13.06a	13.06a	12.65a
Maize biochar	15.59	52.12e	47.37d	37.15e	35.93d	29.40c
Maize residue	15.59	32.72bc	26.77a	21.64b	23.25bc	16.01a
Rice biochar	15.59	35.77c	36.50b	27.76c	27.05bc	24.81b
Rice residue	15.59	27.50ab	27.15a	21.91b	19.48b	14.74a
Wheat biochar	15.59	37.67c	35.22b	30.69d	27.21bc	21.15b
Wheat residue	15.59	24.02a	25.13a	19.52b	22.54bc	13.73a
Soybean biochar	15.59	43.60d	41.75c	40.03f	29.13c	23.07b
Soybean residue	15.59	25.97ab	24.98a	22.83b	21.83bc	15.72a

*Similar letter denotes that there is no variation in treatment, where as different letters shows significant variation amongst the treatments

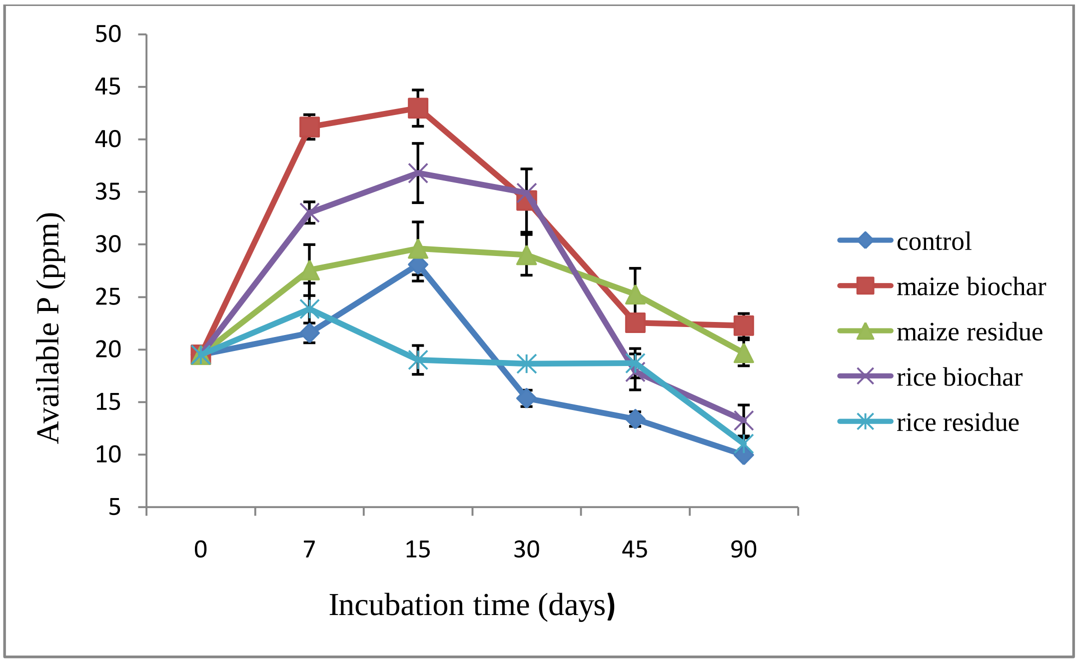

Fig. 4.33 Changes in soil available P concentration at Ranchi as affected by incorporation of residue and biochar of maize and rice

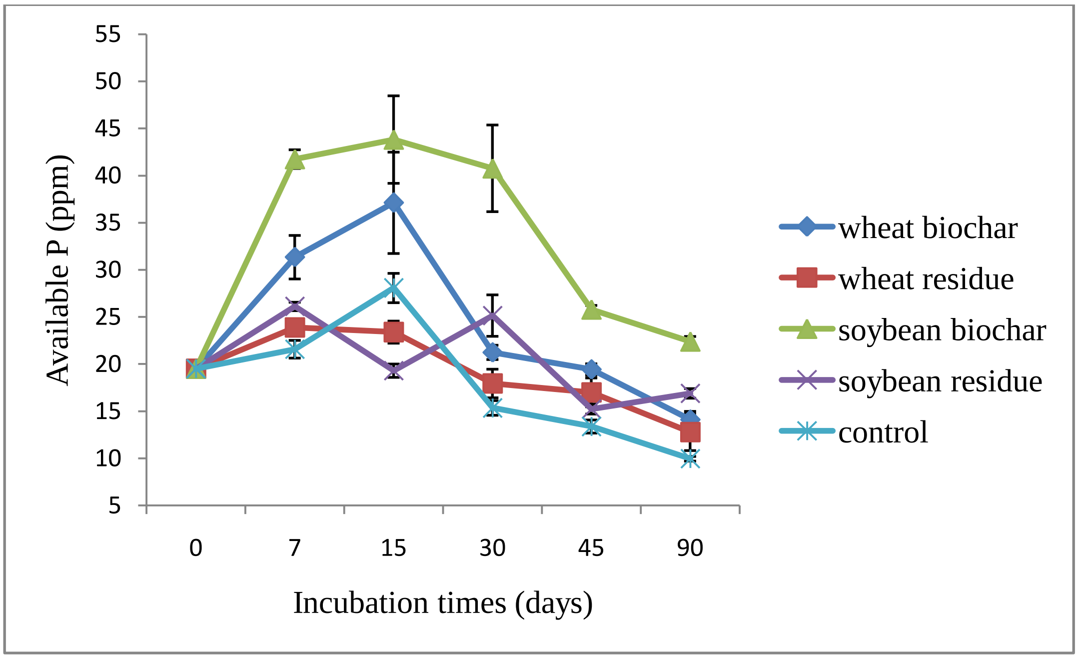

Fig. 4.34 Changes in soil available P concentration at Ranchi as affected by incorporation of residue and biochar of wheat and soybean

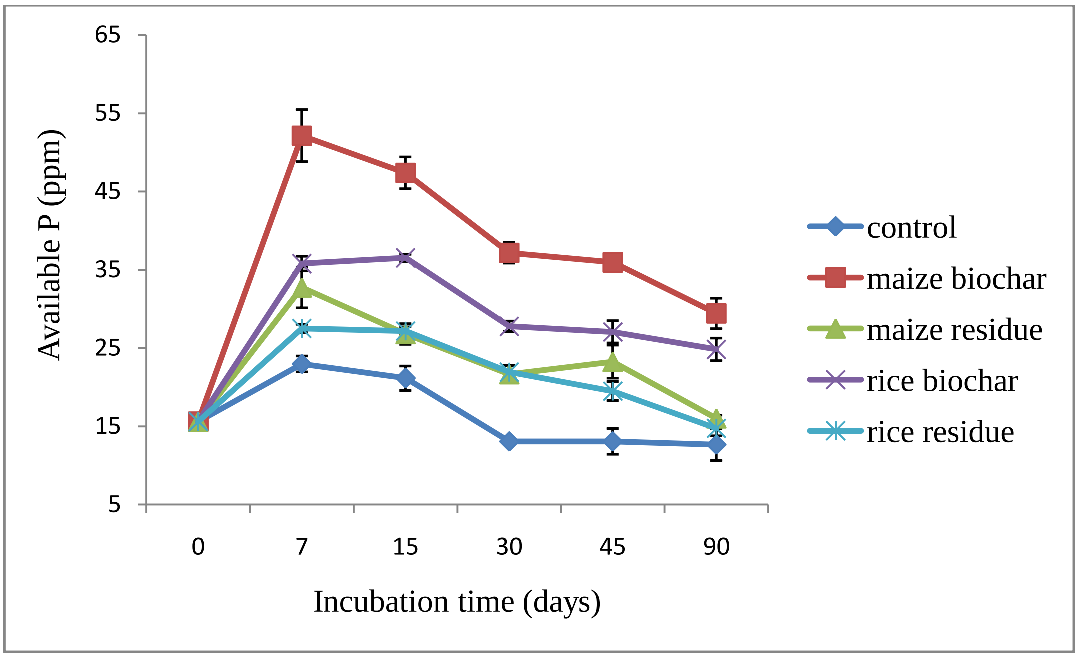

Fig. 4.35 Changes in soil available P concentration at Palampur as affected by incorporation of residue and biochar of maize and rice

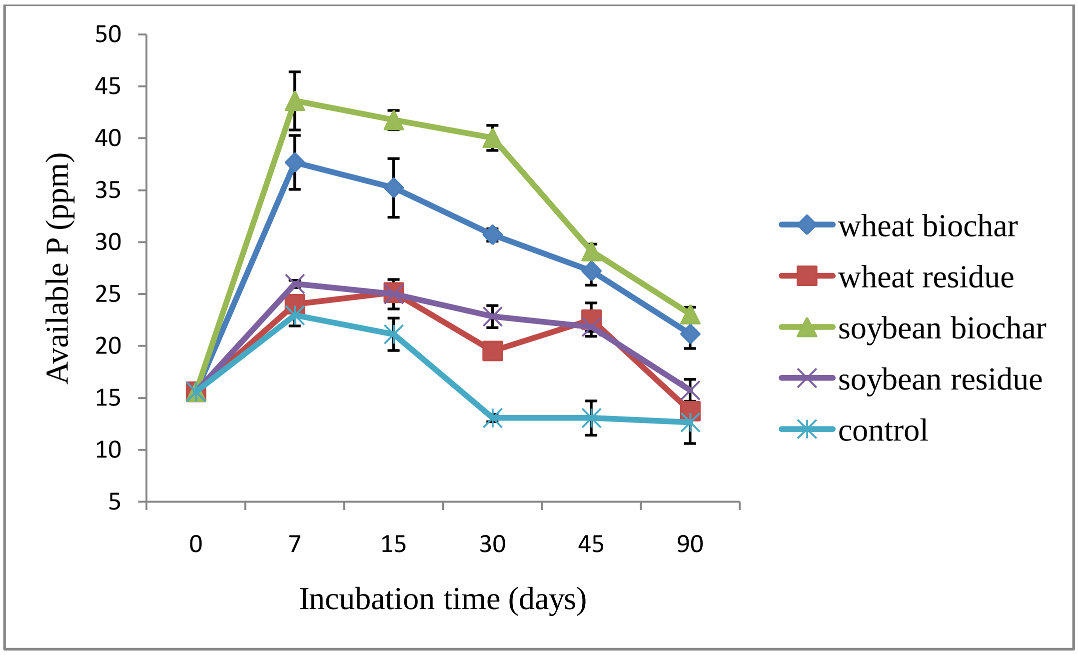

Fig. 4.36 Changes in soil available P concentration at Palampur as affected by incorporation of residue and biochar of wheat and soybean

4.6 Effect of NPK, FYM and different levels of biochar (BC) on barley dry matter yield (g/pot) and Nitrogen content in pot experiment

A pot experiment was conducted by taking Barley as a test crop at Indian Institute of Soil Science Bhopal during *Rabi* season 2014. Soil sample was collected from Ranchi having a pH of 6.2. Two Kg of soil sample was weighed and filled, in each pot.

Fresh weight and air dry weight of barley crop recorded at the time of harvest under NPK, FYM and different levels of biochar is given in table 4.9

Table 4.9: Effect of NPK, FYM 1% and different levels of biochar on dry matter yield of barley plants

Treatment	Fresh weight (60 DAS)	Air dry weight (60DAS)
Control	17.5e	3.15f
NPK	25.4cd	4.44de
NPK+BC 1%	30.5ab	5.10bcd
NPK+BC 2%	30.3ab	3.84ef
NPK+BC 3%	26.7c	3.96ef
BC 1%	23.0d	6.18a
BC 2%	25.2cd	5.94ab
BC 3%	22.3d	4.70cde
FYM 1%	23.2d	3.87ef
FYM 1%+NPK	27.6bc	5.03bcd
NPK+FYM 1%+BC 1%	32.6a	5.32abcd
NPK+FYM 1%+BC 2%	32.4a	5.60abc
NPK+FYM 1%+BC 3%	31.3a	5.93ab
CD 5%	3.36	0.962
CV %	7.42	11.82

*Biochar and FYM doses were on weight basis
*Similar letter denotes that there is no variation in treatments, where as different letters shows significant variation amongst the treatments

Fresh weight and air dry weight of barley plants were significantly increased due to application of NPK, FYMand different levels of biochar. Significantly increase in fresh weight of Barley plant was recorded underNPK+FYM 1% +BC 1% (32.6 g/pot), followed by NPK+FYM 1%+BC 2% (32.4 g/pot), and NPK+FYM 1% +BC 3% (31.3 g/ pot). In case of air dry weight BC 1% (6.18 g/pot) and BC 2% (5.94 g/pot) showed significantly increase in biomass weight over control (3.15 g/pot). Lowest fresh and air dry weight of barley crop was recorded at BC 3% (22.3 g/pot) and NPK+ BC 2% (3.84 g/pot) respectively. The results reconfirm that there was significant increase in biomass yields when acid soils were amended with biochars (Atkinson *et al*., 2010 and Masud *et al.,* 2014).

N content of barley plants at the time of harvest as influenced by NPK, FYM 1% and different levels of biochar is given in table 4.10 and Fig. 4.37

Table 4.10: Effect of NPK, FYM 1% and different levels of biochar on N content of barley plants

Treatment	N Content (%)
Control	1.19f
NPK	1.60cde
NPK + BC 1%	1.83abc
NPK + BC 2%	1.85ab
NPK + BC 3%	1.39ef
BC 1%	1.64bcd
BC 2%	1.28f
BC 3%	1.28f
FYM 1%	1.68bcd
NPK + FYM 1%	2.01a
NPK + FYM 1%+ BC 1%	2.07a
NPK +FYM 1% +BC 2%	1.88ab
NPK + FYM 1% +BC3%	1.53de
CD 5%	0.25
CV	8.89

*Similar letter denotes that there is no variation in treatments, where as different letters shows significant variation amongst the treatments

Nutrient uptake is usually governed by the nutrient concentrations in plant tissues and dry matter yield. There was significant increase in N(%) content of barley plants due to addition of NPK, FYM 1% and different levels of subabul biochar application over control, but increase was more pronounced underNPK + FYM 1% +BC 1% (2.07 %), which was statistically at par with NPK + FYM 1% (2.01 %). The enhancement of N uptake by plants due to the application of biochars has been reported in previous studies also (Chan *et al*., 2008; Van Zwieten *et al*., 2010). N content was equal and lower at higher rate of biochar application (2 & 3%).

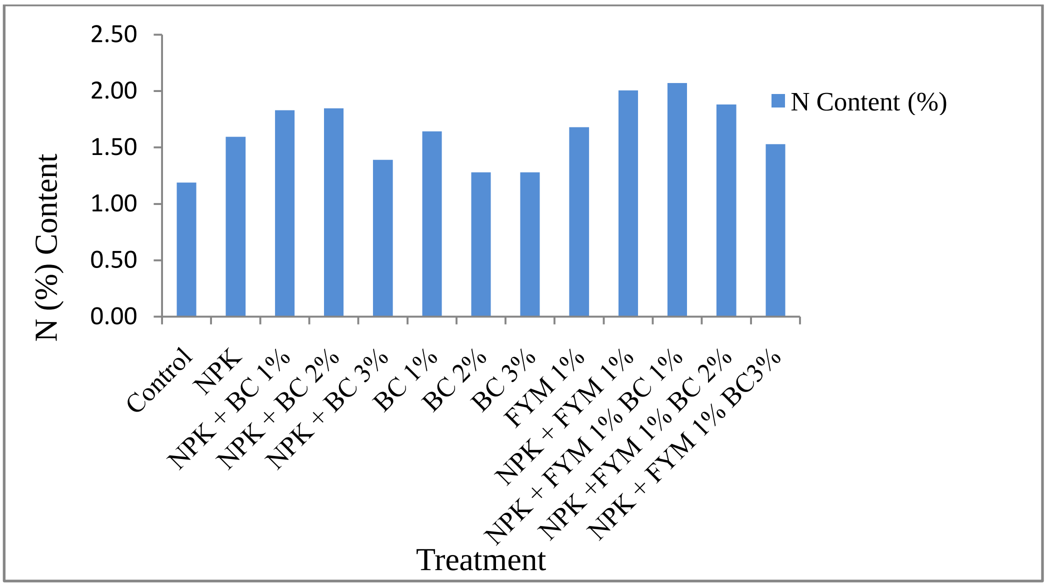

Fig. 4.37: Effect of NPK, FYM 1% and different levels of biochar on N content of barley plants

4.7 Percentage increase/decrease in crop productivity with different liming materials for its efficacy over control

Percentage (%) of fresh weight of barley plants was significantly increased due to incorporation of different liming materials (NPK, FYMand different levels of biochar). Significantly increase in percentage of fresh weight of barley plant was recorded underNPK+FYM 1% +BC 1% (86.61%), followed by NPK+FYM 1%+BC 2% (85.35%) and NPK+FYM 1% +BC 3% (78.97%), so increased their liming efficacy over control.Lowest percentage of fresh weight of barley crop was recorded at BC 3% (28%) and NPK+ BC 2% (0.24%) respectively.

4.8 Effect of different liming materials for their liming efficacy on Nitrogen uptake (g/pot) by barley plants in pot experiment

There was increase in N uptake (g/pot) by barley plants due to addition of different liming material (NPK, FYM 1% and different levels of biochar over control, but increase was more pronounced underNPK + FYM 1% +BC 1% (11.02 g/pot) , followed byNPK + FYM 1% +BC 2% (10.45 g/pot).N uptake by barley plant was lower at NPK + BC 3 % (5.51 g/pot) level.

Table 4.11: Effect of different liming material on barley dry matter yield for its efficacy over control

Treatment	Fresh weight (%)
Control	-
NPK	45.12
NPK + BC 1%	74.49
NPK + BC 2%	73.21
NPK + BC 3%	52.78
BC 1%	31.73
BC 2%	44.05
BC 3%	27.80
FYM 1%	32.49
NPK + FYM 1%	57.88
NPK + FYM 1%+ BC 1%	86.61
NPK +FYM 1% + BC 2%	85.35
NPK + FYM 1%+ BC3%	78.97

Table 4.12 N uptake by barley plants in pot experiment

Treatment	N uptake
Control	3.68
NPK	7.09
NPK + BC 1%	9.35
NPK + BC 2%	7.10
NPK + BC 3%	5.51
BC 1%	10.15
BC 2%	7.60
BC 3%	5.96
FYM 1%	6.50
NPK + FYM 1%	10.09
NPK + FYM 1%+ BC 1%	11.02
NPK +FYM 1%+ BC 2%	10.45
NPK + FYM 1% BC3%	8.92

CHAPTER- V

SUMMARY AND CONCLUSIONS

SUMMARY

Acid soils, which are soils with a pH of 5.5 or lower in 1:1 water extract (USDA 1970), are one of the most important limitations to agricultural production worldwide. Many factors contribute to phytotoxicity of these soils; however, in acid soils with a high mineral content, aluminum (Al) is the major cause of toxicity.Acid weathered soils often require lime and fertilizer application to overcome nutrient deficiencies and metal toxicity to increase soil productivity (Hass *et al*., 2012). In India, approximately one-third (49 M ha) of the cultivated land is affected by soil acidity (Mandal 1997). In acidic soils, crop productivity is mostly constrained by aluminum (Al) and iron (Fe) toxicity, phosphorus (P) deficiency and other acidity-related soil fertility and plant nutritional problems (Patiram 1991; Manoj-Kumar *et al*., 2012). Lime is generally used to amend soil acidity (Adams 1984). Although liming of acid soils can ameliorate soil acidity, this is neither an economic option for poor farmers nor an effective strategy for alleviating subsoil acidity. Recent studies have shown that direct application and incorporation of green manures, animal wastes and crop residues can ameliorate soil acidity (Hue 1992; Berek *et al*., 1995; Xu *et al*., 2006). Decarboxylation during the process of decomposition of added plant residues consumes protons and increases the soil pH (Yan *et al*., 1996; Tang and Yu 1999). However, the reclamation effects of direct incorporation of organic residues in soil do not last long due to rapid mineralization of added residues.Keeping in view the above facts, an investigation entitled **"Evaluation of organic resources for liming efficacy in acid soils"** was carried out. An incubation study was conducted in laboratory at Indian Institute of Soil Science, Bhopal. Two types of acidic soil were taken in this study i.e. Palampur and Ranchi soil. Biochar 2 gram and crop residue 3.5 gram was taken to maintain approximate equivalent amount of C in each soil. Soil moisture level was maintained throughout the study. Soil sample were analyzed at 0, 7, 15, 30, 45 and 90 days after incubation. Based on the result obtained in present investigation following conclusions were drawn.

CONCLUSION

- It was observed from the incubation study that legume crop residue (particularly soybean) and its biochar is one of the most potential amendments for reclamation of acid soil and also transformation of nutrients under acidic soil conditions.The results emanating from Ranchi soil indicated that legume residue could be as effective as biochar for remediation of low soil pH provided the residue rate should be on C equivalent basis of biochar.Liming materials on N and P transformation in soil were evaluated the incorporation of maize, rice, wheat, soybean residues and their biochar effectively decreased soilammoniacal nitrogen (NH_4^+-N),available P and nitrate nitrogen (NO_3^--N) of Palampur and Ranchi soils.
- Liming materials were evaluated for their role in reducing the acidity, the incorporation of maize, rice, wheat, soybean residues and their biochar effectively decreased soil exchangeable Al^{3+} toxicity, and there by increased soil pH and exchangeable base cationsof Palampur and Ranchi soils.
- Crop residues and their biochar evaluation through short-term soil incubations can provide some insight into the short-term effects of these materials that could be used as an amendment for reclamation of acidic soil. The present work provides useful information on maize, rice, wheat, soybean residues and their biochar,and its impact on nutrient transformation and alleviation of soil acidity.
- Significantly increase in fresh weight of Barley plant was recorded when an acid soil was amended with FYM and biochar.

SUGGESTIONS FOR FUTURE RESEARCH WORK

In the light of experience gained during course of investigation and results obtained, it is felt that this kind of study should be given due consideration in future studies.Future work is required to assess the impact biochar and their crop residues on performance of crops under field conditions. The effect of maize, rice, wheat, soybean biochar and their crop residues addition on acid soil reclamation and nutrients transformations needs to be further assessed in field before large-scale applications to agricultural fields.

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Appendices

APPENDIX – A

Table : SEm values of soil pH during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.08	0.08	0.07	0.04	0.04
Maize biochar	0.08	0.13	0.06	0.05	0.07
Maize residue	0.26	0.07	0.20	0.27	0.06
Rice biochar	0.02	0.32	0.24	0.12	0.21
Rice residue	0.05	0.14	0.09	0.10	0.08
Wheat biochar	0.14	0.06	0.09	0.06	0.02
Wheat residue	0.05	0.07	0.13	0.06	0.08
Soybean biochar	0.09	0.07	0.09	0.08	0.17
Soybean residue	0.01	0.07	0.23	0.05	0.24
Palampur Soil	Incubation time (days)				
Treatment					
Control	0.03	0.02	0.08	0.07	0.06
Maize biochar	0.09	0.01	0.02	0.04	0.03
Maize residue	0.07	0.05	0.02	0.09	0.02
Rice biochar	0.24	0.04	0.01	0.01	0.11
Rice residue	0.05	0.00	0.03	0.02	0.06
Wheat biochar	0.09	0.04	0.01	0.02	0.06
Wheat residue	0.16	0.02	0.06	0.05	0.01
Soybean biochar	0.10	0.10	0.05	0.10	0.16
Soybean residue	0.00	0.11	0.11	0.02	0.03

APPENDIX – B

Table : SEm values of EC during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.01	0.00	0.01	0.01	0.01
Maize biochar	0.02	0.01	0.00	0.01	0.01
Maize residue	0.02	0.01	0.02	0.01	0.01
Rice biochar	0.05	0.10	0.04	0.11	0.10
Rice residue	0.02	0.05	0.02	0.01	0.00
Wheat biochar	0.03	0.03	0.02	0.00	0.00
Wheat residue	0.04	0.02	0.01	0.01	0.02
Soybean biochar	0.01	0.02	0.01	0.03	0.03
Soybean residue	0.00	0.01	0.01	0.02	0.03
Palampur Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.00	0.03	0.00	0.01	0.00
Maize biochar	0.02	0.01	0.03	0.00	0.05
Maize residue	0.01	0.00	0.00	0.00	0.01
Rice biochar	0.03	0.01	0.01	0.01	0.03
Rice residue	0.04	0.01	0.01	0.01	0.00
Wheat biochar	0.03	0.03	0.00	0.00	0.00
Wheat residue	0.01	0.02	0.01	0.03	0.03
Soybean biochar	0.02	0.02	0.01	0.01	0.04
Soybean residue	0.01	0.00	0.01	0.01	0.03

APPENDIX – C

Table : SEm values of ammonical nitrogen (NH_4^+- N) concentration during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	1.74	1.89	1.44	2.54	2.29
Maize biochar	0.76	1.05	4.10	1.08	3.55
Maize residue	0.52	0.16	0.56	0.14	2.53
Rice biochar	0.23	1.11	1.88	5.74	1.26
Rice residue	6.68	3.21	2.05	2.65	0.82
Wheat biochar	0.61	5.01	3.52	3.23	6.33
Wheat residue	2.33	0.57	0.44	0.14	0.05
Soybean biochar	0.94	0.64	0.67	5.69	0.77
Soybean residue	1.85	1.35	2.02	5.27	10.00
Palampur Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.78	1.68	2.99	2.65	1.66
Maize biochar	1.14	2.51	3.16	1.85	3.05
Maize residue	0.92	0.95	0.23	0.54	0.26
Rice biochar	1.84	1.91	4.21	0.76	1.84
Rice residue	0.74	7.41	10.30	3.59	0.57
Wheat biochar	5.47	1.35	5.10	4.27	6.31
Wheat residue	1.40	0.31	0.74	0.25	4.40
Soybean biochar	4.69	1.52	4.74	0.90	2.42
Soybean residue	2.03	0.77	12.82	1.63	2.04

APPENDIX – D

Table : SEm values of nitrate nitrogen (NO_3^-- N) concentration during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.19	0.22	0.02	0.32	0.18
Maize biochar	0.07	0.16	0.22	0.12	1.06
Maize residue	0.06	0.19	0.02	0.11	0.05
Rice biochar	0.18	0.23	0.13	0.36	0.06
Rice residue	0.21	0.08	0.33	0.36	0.38
Wheat biochar	0.27	0.32	0.18	0.32	0.15
Wheat residue	0.11	0.09	0.27	0.02	0.05
Soybean biochar	0.10	0.11	0.15	0.90	0.49
Soybean residue	0.06	0.04	0.16	0.29	1.54
Palampur Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.11	0.21	0.05	0.85	0.38
Maize biochar	1.58	0.74	0.75	0.31	3.32
Maize residue	0.01	0.46	0.02	0.20	0.03
Rice biochar	0.26	1.24	1.31	0.44	1.02
Rice residue	0.91	1.99	2.58	0.68	0.17
Wheat biochar	0.13	1.85	2.98	1.18	1.00
Wheat residue	0.18	0.13	0.29	0.18	0.07
Soybean biochar	0.24	3.50	2.72	2.90	3.67
Soybean residue	0.10	0.64	0.16	0.88	0.04

APPENDIX – E

Table : SEm values of Ca^{2+} + Mg^{2+} concentration during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.00	0.10	0.16	0.59	0.47
Maize biochar	0.31	0.28	0.09	0.41	0.52
Maize residue	0.27	0.18	0.25	0.50	0.17
Rice biochar	0.09	0.10	0.49	0.55	0.15
Rice residue	0.09	0.28	0.19	0.48	0.25
Wheat biochar	0.18	0.10	0.58	0.63	0.00
Wheat residue	0.09	0.18	0.10	0.54	0.47
Soybean biochar	0.24	0.42	0.25	0.48	0.17
Soybean residue	0.15	0.18	0.10	0.18	0.29
Palampur Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.39	0.10	0.15	0.23	0.53
Maize biochar	0.20	0.10	0.09	0.00	0.07
Maize residue	0.20	0.17	0.09	0.48	0.21
Rice biochar	0.26	0.17	0.09	0.23	0.28
Rice residue	0.45	0.36	0.15	0.38	0.12
Wheat biochar	0.17	0.26	0.38	0.66	0.44
Wheat residue	0.10	0.26	0.35	0.26	0.42
Soybean biochar	0.10	0.10	0.26	0.09	0.36
Soybean residue	0.20	0.10	0.38	0.09	0.49

APPENDIX – F

Table : SEm values of K concentration during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	10.95	11.61	13.40	7.12	5.64
Maize biochar	52.13	27.34	34.05	25.44	23.39
Maize residue	30.11	30.73	41.95	28.18	19.38
Rice biochar	41.77	19.28	19.08	25.52	42.46
Rice residue	2.28	8.40	5.13	11.01	19.84
Wheat biochar	12.07	56.60	24.93	7.06	1.96
Wheat residue	47.88	33.01	38.07	26.87	33.26
Soybean biochar	0.79	25.76	67.12	30.51	37.25
Soybean residue	20.39	23.76	24.54	40.98	7.83
Palampur Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	1.32	7.92	16.78	11.58	5.13
Maize biochar	35.68	8.25	13.43	33.37	12.08
Maize residue	22.70	21.43	7.08	25.40	7.70
Rice biochar	30.00	13.10	20.94	11.50	18.48
Rice residue	3.12	23.54	31.98	245.62	15.13
Wheat biochar	28.01	34.93	8.12	39.35	9.24
Wheat residue	25.82	26.65	5.75	19.80	18.76
Soybean biochar	25.10	5.45	20.67	13.51	31.60
Soybean residue	8.23	31.90	17.86	23.43	8.02

APPENDIX – G

Table : SEm values of Na^+ concentration during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	1.37	0.93	3.40	1.38	2.66
Maize biochar	0.46	2.98	2.95	0.79	1.13
Maize residue	2.85	1.41	2.70	2.00	3.39
Rice biochar	3.98	0.53	3.85	1.21	3.33
Rice residue	3.44	2.45	0.49	2.10	2.26
Wheat biochar	1.21	0.53	1.94	3.58	0.43
Wheat residue	1.65	3.74	2.22	1.38	3.08
Soybean biochar	4.81	0.93	1.68	1.65	2.40
Soybean residue	0.79	2.45	2.43	2.55	1.96
Palampur Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	3.04	1.82	0.00	0.89	0.94
Maize biochar	1.80	1.82	0.90	5.37	1.07
Maize residue	3.28	1.33	1.96	2.30	1.55
Rice biochar	2.78	4.37	4.34	4.60	1.98
Rice residue	2.18	3.94	1.19	1.17	1.53
Wheat biochar	1.00	1.01	1.62	3.83	0.71
Wheat residue	1.80	2.31	1.19	4.06	2.22
Soybean biochar	4.58	1.82	2.74	1.93	1.02
Soybean residue	2.50	1.33	1.35	2.90	2.16

APPENDIX – H

Table : SEm values of P concentration during incubation period

Ranchi Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	0.94	1.56	0.78	0.69	0.25
Maize biochar	1.17	1.73	3.01	0.67	1.15
Maize residue	2.42	2.51	1.93	2.48	1.24
Rice biochar	1.02	2.82	0.10	1.71	1.47
Rice residue	2.46	1.37	0.06	1.40	0.54
Wheat biochar	2.31	5.38	0.76	0.61	0.89
Wheat residue	0.38	1.17	1.52	1.53	1.95
Soybean biochar	0.99	4.64	4.60	0.45	0.54
Soybean residue	0.45	0.71	2.20	0.53	0.51
Palampur Soil	Incubation time (days)				
Treatment	7	15	30	45	90
Control	1.02	1.56	0.35	1.65	2.03
Maize biochar	3.32	2.03	1.32	0.84	1.95
Maize residue	2.60	1.32	1.08	2.11	0.40
Rice biochar	0.94	0.45	0.67	1.42	1.44
Rice residue	0.52	0.54	0.89	1.21	0.98
Wheat biochar	2.60	2.83	0.60	1.36	1.39
Wheat residue	0.59	0.74	0.41	1.61	0.24
Soybean biochar	2.80	0.93	1.21	0.68	0.66
Soybean residue	0.35	1.42	1.06	0.42	1.06

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