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EFFECT OF BIOCHAR AND PIG MANURE ON PERFORMANCE OF RICEBEAN [*Vigna umbellata* (THUNB) Ohwi and Ohashi] AND SOIL PROPERTIES IN DYSTRUDEPTS

Thesis

submitted to

NAGALAND UNIVERSITY

in partial fulfillment of requirements for the Degree

of

Doctor of Philosophy

in

AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

by

YABI GADI

Admn. No. Ph – 266/18 Regn. No. Ph.D./ACSS/00214

Department of Agricultural Chemistry and Soil Science

School of Agricultural Sciences and Rural Development,

Nagaland University, Medziphema Campus – 797 106

Nagaland

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Nagaland

2023

DECLARATION

I, Miss. Yabi Gadi, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other university/institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science

Date:
Place: **(YABI GADI)**

(Y. K. Sharma)
Supervisor

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences and Rural Development
Medziphema – 797 106, Nagaland

Dr. Y.K. Sharma
Professor
Department of Agricultural Chemistry and Soil Science

CERTIFICATE – I

This is to certify that the thesis entitled **"Effect of biochar and pig manure on performance of ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] and soil properties in Dystrudepts"** submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science is the record of research work carried out by Ms. Yabi Gadi, Registration No. Ph.D./ACSS/00214 under my personal supervision and guidance.

The results of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

Date :
Place : Medziphema

(Dr. Y. K. Sharma)
Supervisor

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences and Rural Development
Medziphema – 797 106, Nagaland

CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

This is to certify that the thesis entitled **"**Effect of biochar and pig manure on performance of ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] and soil properties in Dystrudepts**"** submitted by Miss Yabi Gadi, Admission No. 266/18 Registration No. Ph.D./ACSS/00214 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science has been examined by the Advisory Board and External examiner on ……………….............

The performance of the student has been found **Satisfactory/Unsatisfactory.**

Member	Signature
1. Prof. Y. K. Sharma (Supervisor & Chairman)	……………………….
2. ………………………………… (External examiner)	………………………….
3. Dean, SASRD (Pro Vice Chancellor Nominee)	………………………...

Members of Advisory Committee:

1. Prof. A. K. Singh	………………………….
2. Prof. P. K. Singh	………………………….
3. Dr. A. P. Singh	………………………….
4. Prof. M. Dutta	…………………………

Head
Dept. of Agricultural Chemistry
and Soil Science

Dean
School of Agricultural
Sciences and Rural Development

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Date (YABI GADI)

Place:

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LIST OF ABBREVIATIONS

%	Percent
ANOVA	Analysis of variance
@	At the rate
^{0}C	Degree centigrade
Al^{3+}	Aluminium
WB	Wood biochar
BB	Bamboo biochar
PM	Pig manure
CD	Critical Difference
cm	Centimetre
dSm^{-1}	Decisiemens per meter
DAS	Days after sowing
DF	Degree of freedom
et al.	*et allia* (and others/co-workers)
Fig.	Figure
Cmol	Centimol
g	Gram
ha	Hectare
i.e.	that is
Ex. Ca^{2+}	Exchangeable calcium
Ex. Mg^{2+}	Exchangeable magnesium
m	Metre
H^{+}	Hydrogen
DHA	Dehydrogenase activity
TPF	Triphenyl formazan
mt	Million tonnes
MT	Metric tonne
Max.	Maximum

Min.	Minimum
MSS	Mean sum of square
No.	Number
MBC	Microbial biomass carbon
NPK	Nitrogen, Phosphorus, Potassium
NS	Non significant
NU	Nagaland University
P	Phosphorus
q ha^{-1}	Quintal per hectare
RDF	Recommended dose of fertilizer
SEm±	Standard mean error
SS	Sum of square
t	tonne
viz.	Namely

ABSTRACT

The present study entitled "Effect of Biochar and Pig Manure on Performance of Ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] and Soil Properties in Dystrudepts" was conducted in the experimental farm of the Department of Agricultural Chemistry and Soil Science, School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema during the *Kharif* seasons in the year 2019 and 2020. The experiment was laid out in randomized block design with 11 treatments each replicated thrice. The treatments comprises of T_1: control, T_2: RDF @ (20 kg N, 40 kg P_2O_5 and 30 kg K_2O ha^{-1}), T_3: RDF + 2.5 t ha^{-1} wood biochar, T_4: RDF + 5.0 t ha^{-1} wood biochar, T_5: RDF +2.5 t ha^{-1} bamboo biochar, T_6: RDF + 5.0 t ha^{-1} bamboo biochar, T_7: RDF + 2.0 t ha^{-1} pig manure, T_8: RDF + 2.0 t ha^{-1} pig manure + 2.5 t ha^{-1} wood biochar, T_9: RDF + 2.0 t ha^{-1} pig manure + 5.0 t ha^{-1} wood biochar, T_{10}: RDF + 2.0 t ha^{-1} pig manure + 2.5 t ha^{-1} bamboo biochar, T_{11}: RDF + 2.0 t ha^{-1} pig manure + 5.0 t ha^{-1} bamboo biochar. It was observed that application of fertilizer, biochar and pig manure significantly enhanced the plant height, number of branches plant^{-1}, pod plant^{-1}, pod length, seed pod^{-1}, seed and stover yield of ricebean. Ricebean responded exceedingly well to the combined application of RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB (T_9) in terms of growth, yield attributes, quality and nutrient uptake. The seed and stover yield was augmented by 81.06% and 56.24% over control and 38.72% and 33.93% over RDF (T_2) due to application of treatment T_9. Application of biochar and pig manure significantly enhanced the soil pH, cation exchange capacity, base saturation, available nutrients content, exchangeable calcium and magnesium of post harvest soil, while it reduced the exchangeable aluminium, exchangeable hydrogen, exchangeable acidity and total potential acidity of the soil. In terms of soil biological properties the result further revealed that combined application of RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB enhanced dehydrogenase activity and alkaline phosphate activity of the soil. Application of treatment T_8 (RDF + 2.0 t ha^{-1} pig manure + 2.5 t ha^{-1} WB) enhanced the microbial biomass carbon by 91.16% and acid phosphatase activity by 25.97% over control. Thus, results suggested that application of 5.0 t wood biochar ha^{-1} and 2.0 t pig manure ha^{-1} along with recommended dose of fertilizer has the potential to boost the yield of ricebean and maintenance of soil health. Biochar could play important basis for the further development of sustainable agricultural production systems, because its production can be scaled down for smaller communities closer to biomass sources.

Key words: Ricebean, biochar, pig manure, yield, nutrient uptake, soil properties

CHAPTER I

INTRODUCTION

INTRODUCTION

India is the major pulse growing country of the world accounting roughly for one-third of the total world area under pulses and one-fourth of the total world production. Pulse crops also called grain legumes, have been valued as food, fodder and feed and have remained as a mainstay of Indian agricultural for centuries. This signifies the importance of pulses in food and nutrition security for Indian population. Legumes are also known for their protein content and are easily digestible. They are not only used for food purposes but also for helping and restoring soil fertility and health through symbiotic nitrogen fixation, thus providing sustainability of agriculture to the people. India grows nearly 29 million hectare of pulse with the annual production of 25.12 million tones and average productivity of 885 kg ha^{-1} (Agricultural Statistics at a Glance, 2021)

Ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] is a native of South and South East Asia. It is also known as red bean, oriental bean and climbing mountain bean. It is a warm season annual vine legume with yellow flowers and small edible beans. In India, it is mainly confined to the tribal regions of North Eastern Region and hilly tracts of Eastern and Western Ghats (Arora *et al.*, 1980). Ricebean is considered as “underutilized or unexploited crop” or “minor pulse” that has received attention over the past years owing to its wider adaptability, nutrional value, resistance to pest and diseases, storage quality and rich genetic diversity. The seed contains 24% protein, 0.49% fat and 5% fibre which are also rich in methionine and tryptophan as well as vitamins (thiamine, niacin and riboflavin). This crop has immense potential due to its high nutritional quality, high grain yield and multipurpose usage as food, animal feed, cover crop, green manure (Tomooka *et al*., 2002).

In India, ricebean crop is used as minor *kharif* pulse crop having the qualities of resistance to drought, prevent soil erosion, improve soil fertility by nitrogen fixing ability, synchronizing habit of pod maturity, resistance to attack of storage pests and high percentage of seed viability. Ricebean is also a lean period crop supporting the farmers with continuous fodder supply to animals all round the growing season (Janjal and Mehta, 2019). In the NER of India, it is predominantly grown under the rainfed condition in mixed farming system under shifting cultivation. The dried seeds are usually eaten boiled or as pulse. Young immature pods are used as vegetables. It is also grown as a green manure and an excellent cover crop. Unlike other pulses, ricebeans are not easily processed into daal, due to their fibrous mucilage that prevents hulling and separation of the cotyledons (Rajerison, 2006).

In Nagaland, low pH and high Al^{3+} concentration leading to Al toxicity are two main factors limiting legume plant growth. Low pH and high Al^{3+} concentration also reduce plant nutrients uptake, root growth, and shoot biomass (Haynes and Ludecke, 1981). It has been shown that adding organic amendments to acid soils, such as biochar and biosolids can enhance the soil fertility similar to lime application (Sarma *et al*., 2017). Therefore, incorporation of biochar into acid soil could also help to mitigate soil Al toxicity by decreasing soil exchangeable acidity, increasing soil exchangeable base cations, and thereby improving soil fertility. Biochar is the carbon-rich product produced by thermal decomposition of biomass under limited supply of oxygen called pyrolysis and at relatively low temperatures (<700°C) (Lehmann and Joseph, 2009). Biomass is categorized into woody and non- woody biomass. The woody biomass primarily comprises of forestry and tress residue while non- woody biomass consist of agricultural and crop residue, animal waste and industrial solid waste (Jafri *et al*., 2018).

It can be used not only as a renewable fuel, but also as a way of improving soil fertility. Biochar exhibit high biodegrability, high contents of total and organic carbon, as well as optimal concentrations of micro and macro elements such as potassium, sodium, magnesium, calcium, copper, zinc, iron etc. In acid soils, biochar addition could increase cation exchange capacity (CEC) and P content, and reduce the availability of toxic metals, improving plant productivity (Chintala *et al*., 2014). The ameliorating effect of biochar on soil pH is proportional to the lime application rate especially in highly weathered acidic soils. The pH increased in various soils up to 1.2 pH units from pH 5.4 to 6.6 on addition of biochar. Increased pH and cation exchange capacity (CEC) resulted in the improvement of nutrient retention and crop growth from biochar amendment. In addition, biochar amendment increases legume growth and yield through increased biological nitrogen fixation (BNF) (Nishio, 1996; Rondon *et al*. 2007; Mia *et al*. 2014). Biochar generally increases carbon sequestration in soil (Sohi *et al*., 2010) while significantly reducing the ammonia and carbon dioxide emission, improves water retention and lower soil compactness.

Biochar has been shown not only to improve soil physico-chemical properties but also it can affect soil microbial enzymatic activities (Ameloot *et al*., 2013), which might be positively correlated with the increase of soil C/N ratio in bio charadded soils (Jiang *et al*., 2016). Biochar can stimulate the growth of rhizosphere microorganisms and mycorrhizal fungi (Derkouska *et al*., 2017). These bacteria and fungi helps in promoting plant growth (Compant *et al*., 2010). Biochar application has been demonstrated to influence the biomass carbon and enzymatic dynamics with organic carbon availability as biochar has noteworthy quantity of dissolved organic carbon (Barman *et al*., 2016). Microbiological activity of soil directly influences the soil quality in general and soil fertility in particular. In summary, changes in microbial community composition or activity induced by biochar may affect the nutrient cycles and plant growth, as well as the cycling of organic matter (Wardle *et al*. 2008; Kuzyakov *et al*. 2009). Biochar provides great opportunities to turn the so called green revolution into sustainable agro ecosystem practice. Good returns on ever more expensive inputs such as fertilizers rely on appropriate levels of soil organic matter, which can be secured by biochar addition as soil management option for the long term. However, the main mechanism underlying the enhancement of nutrients availability with biochar application deserve further determination in order to improve the qualities of agriculture soils.

Application of pig manure to crop land is one of the most obvious methods of recycling plant nutrients. The use of animal waste as manure is a rational alternative and of great interest in terms of environmental, social and agronomic traits. Plant nutrients are removed from the soil in the harvested product fed to the animals and returned to the soil as manure. The availability of plant nutrients from pig manure depends on the composition of the manure and on other factors such as management practices and soil characteristics. Applying pig manure (solid and liquid) as fertilizer in agricultural areas has been reported to significantly improve soil fertility, soil productivity and soil quality (Hountin *et al*., 2000).

In Nagaland, ricebean is commonly known as *Naga daal*, which is mainly grown as one major pulse crop with an area of 4970 ha and production of 5730 metric ton (Statistical Handbook of Nagaland, 2021). It is one of the predominant crops grown under rainfed condition. This crop persists because of their adaptation to special niches in low-input production systems, specific taste and social importance, supply essential nutrients and soil quality improvements. The isolated proteins, starch and fibers from legume seeds have good physico-chemical and health protecting properties. However most of the people particularly in Nagaland are unaware of the nutritional components and importance of legumes for which awareness should be initiated and cultivation in large scale should be encouraged which will also be a way of providing food security.

Keeping above facts in view, present investigation entitled "Effect of Biochar and Pig Manure on Performance of Ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] and Soil Properties in Dystrudepts" was undertaken with the following objectives:

1. To study the effect of biochar and pig manure on growth, yield and nutrient uptake of ricebean
2. To study the effect of biochar and pig manure on soil properties

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The information pertaining to the present investigation entitled "Effect of biochar and pig manure on performance of ricebean [*Vigna umbellata* (thunb) ohwi and ohashi] and soil properties in Dystrudepts" have been presented in this chapter. Related study conducted in India and abroad are reviewed in chapter and presented under following headings.

2.1 EFFECT OF BIOCHAR

2.1.1 Effect on growth and yield

Glaser *et al*. (2001) reviewed a number of early studies conducted during 1980s and 1990s. These tended to show marked impacts of low charcoal additions (0.5 t ha^{-1}) on various plant species. Higher rates seemed to inhibit plant growth. In later experiments, combination of higher biochar application rates along with NPK fertilizer increased crop yield on tropical Amazonian soils and semi-arid soils in Australia.

Lehmann *et al*. (2003a) observed that charcoal additions significantly increased plant growth and nutrition. Leaching of applied fertilizer N was significantly reduced by charcoal, and Ca and Mg leaching was delayed.

Yamato *et al*. (2006) investigated the plant growth and yield responses of maize, cowpea and peanut to the applications of charred bark of *Acacia mangium* at the rate of 37 t ha^{-1} at sites with less fertile soil. The result showed increase in growth and yield on the less fertile soil when applied with fertilizer, which could be due to the increase in N and P availability, mycorrhizal fungi colonization and reduction of exchangeable Al^{3+}.

Van Zwieten *et al*. (2007) reported a nearly 30 to 40% increase in wheat height when biochar produced from paper mill sludge was applied at a rate of 10 t ha^{-1} to an acidic soil but not to a neutral soil.

Rondon *et al*. (2007) observed that bean yield increased by 46% and biomass production by 39% over the control at 60 g kg^{-1} biochar. However, biomass production and total N uptake decreased when biochar dose was increased to 90 g kg^{-1} from 60 g kg^{-1} of soil. N uptake by N-fixing beans decreased by 14%, 17% and 50%, when biochar was applied at the rate of 30, 60 and 90 g kg^{-1} of soil, respectively. Results demonstrate the potential of biochar application to improve N input into agro ecosystem while pointing out the needs for long term field studies to better understand the effects of biochar on biological nitrogen fixation.

Steiner *et al*. (2007a) reported that application of organic fertilizers and charcoal increase nutrient stocks in the rooting zone of crops, reduce nutrient leaching and thus improve crop production on acid and highly weathered tropical soils. Charcoal significantly improved plant growth and doubled grain production if fertilized with NPK in comparison to the NPK-fertilizer without charcoal.

Winsley (2007) reported that even low rates of biochar application can significantly increase crop productivity.

Steiner *et al*. (2008a) reported that addition of biochar to soil @ 5 t ha^{-1} reduced the fertilizer needs by 7 percent. The effects of biochar application are seen more clearly in highly degraded acidic or nutrient depleted soils.

Thies and Rillig (2009) reported positive effects of biochar application on plant growth and yield, soil physical and chemical properties, soil microbial activities, and potential reductions of soil GHG emissions.

Asai *et al*. (2009) investigated the effect of biochar application on grain yields of upland rice (*Oryza sativa* L.) in Northern Laos and reported that biochar application resulted in higher yields at sites with low P availability and improved the response to N and P chemical fertilizer treatment. These results suggest that biochar application has the potential to improve soil productivity of upland rice production in Laos, but the effect of biochar application is highly dependent on soil fertility and fertilizer management.

Van Zweiten *et al*. (2009) reported that fertilizer application caused a significant increase in biomass in soybean and radish in ferrosol. The calcarosol amended with fertilizer and biochar, however gave varied crop responses, increased soybean biomass, but reduced wheat and radish biomass. No significant effects of biochar were shown in the absence of fertilizer for wheat and soybean, while radish biomass increased significantly.

Bakht *et al*. (2009) narrated that application of N fertilizer and involvement of legumes in crop rotation greatly improves the N economy of the cropping system and enhances crop productivity in low N soils.

Major *et al*. (2010) observed that a 4-year field trial with wood-based biochar (8 and 20 t ha^{-1}) on yield of maize and soybean (in rotation) in Columbian tropical region showed no increase in the maize yield during the first year. However, second, third and fourth year reported an increase of 20, 30, and 140%, respectively, indicating a long-term effect of biochar on the crop yield.

De Gryze *et al*. (2010) found out that application of biochar along with inorganic fertilizer made it possible to improve the crop growth and productivity.

Haefele *et al*. (2011) evaluated a four-season field trial in Philippines and Thailand (tropical climate) using rice-husk biochar on dry, poor, non-acidic soil and observed improved yields ranging from 16–35% due to the enhanced water retention and increased availability of K and P.

Mc Elligott (2011) reported that when biochar is applied in combination of a complete fertilizer, biomass increased significantly relative to un-fertilized control treatments suggesting improved fertilizer use efficiency or retention.

Jeffery *et al*. (2011) observed that high crop yields were obtained by amending the soil with biochar produced from wood, paper pulp, wood chips and poultry litter.

Dharmakeerthi *et al*. (2012) found that application of biochar alone has a significant positive effect on above ground dry matter accumulation of the rootstock seedling (81% over the absolute control) while it had no effect on the scion growth. Combined application of 2% biochar with N and Mg significantly increased the above ground dry matter accumulation over sole application of biochar.

Suppadit *et al*. (2012) studied the effect of quail litter biochar on soybean yield attributes and yield in pot experiment in sandy soil and reported significant yield increase with biochar application. The highest number of nodes per plant and the tallest plant were obtained from 98.4g quail litter biochar per pot mixture.

Srinivasarao *et al*. (2013) reported that the addition of biochar to soil have improved the crop yields either due to biochar is rich in plant nutrients and improvement in soil physical, chemical and biological properties due to application of biochar.

Mia *et al*. (2014) reported that biochar amendment increased legume growth and yield through increased biological nitrogen fixation (BNF).

Bandara *et al*. (2015) suggested that the addition of wood biochar to soil improves plant growth by mitigating heavy metal toxicity and enhancing soil enzymatic activities.

Yooyen *et al*. (2015) conducted an experiment using four different levels of biochar with three replicates in completely randomized block design. The result showed that growth and yields of soybean, including stem height, number of nodes, dry matter of stems, dry matter of leaves, dry matter of pods, and dry matter of seeds of biochar treatments show statistically significant differences.

Naomi *et al*. (2015) observed that acidic soil amended with biochar produced from waste basal portions of bamboo was tested by growing mungbean in a randomized complete block design experiment showed that plants grown in soil amended with 8.5 and 15.75% biochar started flowering, pod filling and maturing 6 to 7 days earlier than those grown in un-amended soil. After 60 days, plants in the biochar amended soil were significantly taller by about 27% and their pod production was 102% higher than those without biochar.

Agboola and Moses (2015) reported that biochar and cowdung increased growth and yield of soybean while nodulation decreased. Soil pH, organic carbon, soil nitrogen, calcium, magnesium, potassium, sodium and CEC significantly increased; available phosphorus insignificantly increased, while exchangeable acidity decreased significantly. Soybean responded well to the application of combined biochar and cowdung. These results showed the potential role of combined biochar and cowdung in improving soil fertility and soybean yields.

Gebremedhin *et al*. (2015) reported that biochar significantly increased grain and straw yields of wheat by 15.7% and 16.5% respectively over control. Moreover, the root biomass was significantly increased by 20%. Hence, the biochar produced from *Prosopis juliflora* could be used for wheat productivity improvement.

Zhu *et al*. (2015) investigated five typical agricultural soils in China amended with two biochars. Four treatments were designed: the soil itself as a control, the soil amended with 1% biochar, the soil with fertilizer NPK, and the soil with added biochar and fertilizer. The result showed that biochar amendment increased the maize biomass, yield and the N use efficiency in the red soil.

Agegnehu *et al*. (2015) narrated that plant growth and yield increases with biochar additions. It may have been attributed due to optimization of the availability of plant nutrients, increase in soil microbial biomass and activity and reduction of exchangeable Al^{3+}.

Berek and Hue (2016) reported that biochar contains alkaline substances (carbonates and organic anions from acidic functional groups) and has high pH and thus can be used as alternative amendment for the correction of soil acidity. This is the main reason why incorporation of biochar increases crop yields, which is more evident in acidic soils in tropical and subtropical regions than in temperate regions.

Raboin *et al*. (2016) observed significant increase in maize and common bean (in rotation) yield was observed on application of eucalyptus-based biochar at 10 to 50 t ha^{-1} in acidic soils in Madagascar (humid tropical climate) owing to increased soil pH and lower exchangeable aluminium.

Singh *et al*. (2016) reported that combined application of rice husk biochar (3.6 g kg^{-1} of soil) along with PGPR produced significantly higher rice yield in alluvial soils over uninoculated conditions.

Bhattacharjya *et al*. (2016) reported that application of lantana biochar and pine needle biochar (dose equivalent to 2.5 and 4 ton C ha^{-1}) increased the grain yield of wheat significantly by 6.2% to 24.2% over control in Mollisol.

Jalal *et al*. (2016) conducted a field experiment at the research farm of the University of Agriculture Peshawar. Wheat-maize-wheat cropping pattern was followed with the adjustment of legumes in summer gap (land available after wheat harvest till maize sowing). Legumes *i.e*., mung bean, cowpea and sesbania with a fallow were adjusted in the summer gap with and without biochar application. Biochar was applied at the rate of 0 and 50 t ha^{-1} with four N levels of 0, 60, 90 and 120 kg ha^{-1} to subsequent wheat crop. Biohcar application and plots previously sown with legumes improved thousand grain weight of wheat crop.

Abdul *et al*. (2016) evaluated the sole impact of biochar on yield and yield components of mung bean crop and found that early flowering and maturity was recorded in biochar treated plots as compared to control. The biochar levels significantly improved pods $plant^{-1}$, pods length, grains pod^{-1}, 100 grains weight, biological yield, grain yield and harvest index. Hence it was concluded from the experiment that the application of biochar at the rate of 25 tons ha^{-1} is beneficial for improving mungbean grain yield.

Wang *et al*. (2016) examined the effects of biochar and compost, applied separately or in combination, on plant growth of mung bean (*Vigna radiata*) and soil properties. Results showed that biochar and compost produced positive impacts on both the plants and the soil. Addition of biochar-compost lowered the soil bulk density relative to the control. In short, synergic effects of biochar and compost were documented in promoting plant growth, biomass accumulation, and yield and in improving soil properties.

Arif *et al*. (2017) conducted a two-year maize-wheat rotation field experiments to test the effects of biochar on crop productivity, soil properties and phosphorous use efficiency (PUE) when applied with organic P sources as either farmyard manure (FYM) or poultry manure (PM) and diammonium phosphate (DAP) chemical fertilizer. Analysis of the two-year data revealed that biochar and P sources significantly and positively changed crop and soil quality attributes. Application of biochar significantly increased biological and grain yields of maize and wheat, soil organic carbon (SOC), and available nitrogen (N) and P contents without any negative effects on soil pH and electrical conductivity (EC).

Berihun *et al*. (2017) studied the effect of types and rates of biochar on growth, yield, and yield component of garden pea and found that maximum germination percentage of garden pea seeds (95.23%) was recorded at 18 t ha^{-1} of Lantana biochar. The shoot length was significantly affected at 15 days and 30 days of biochar application. Moreover, fresh shoot weight and dry root biomass, number of seeds per pod, and grain yield of garden pea were significantly affected. Of the substrate and application rate applied, *Lantana camara* 12 t ha^{-1} and *Lantana camara* 18 t ha^{-1} significantly increased yield of garden pea.

Zahir *et al*. (2017) observed that biochar application at the rate of 25 ton ha^{-1} resulted in higher seed yield of mungbean (639 kg ha^{-1}) as compared to control (579 kg ha^{-1}) and 50 ton ha^{-1} (626 kg ha^{-1}).

Hussain *et al*. (2017) reported that application of biochar at the rate of 25 t ha^{-1} in combination with FYM and mineral nitrogen at the rate of 10 t ha^{-1} and 30 kg, respectively is recommended for improving mungbean plant growth and productivity.

Isley *et al*. (2017) assessed the effect of biochar prepared from wastes filtration materials on the growth and production of common bean (*Phaseolus vulgaris* L.) with three different biochar from organic wastes (rice husk, sawdust, and sorghum silage) using as filtration material for swine biofertilizer. In each experiment the treatments consisted of the addition of five different biochar concentrations (0%, 2.5%, 5%, 7.5%, and 10% v/v), these results indicated that biochar contributed significantly to the growth and production of common bean plants

Meena *et al*. (2017) observed that application of graded level of biochar, carpet waste FYM and PGPR was found to significantly enhance the straw and grain yield of mungbean and found 60.17% higher over the treatment control. Grain and straw yield of mungbean significantly increased with the application of graded level biochar, carpet waste FYM and PGPR.

Macil *et al*. (2017) studied response of photosynthesis, chlorophyll content (CC), stomatal conductance (SC) and intercepted radiation (IR) of chickpea to biochar (0, 5 10 and 20 t ha^{-1}) and found that plant height increased only at 70 days after emergence. However biochar did not affect photosynthesis in either season. Therefore the use of biochar may be beneficial in chickpea cropping systems characterized by poor soils and dry winter seasons.

Rafael *et al*. (2018) found out that biochar application promoted plant-root interactions with symbiotic bacteria by increasing the root nodulation. In addition, dry pod, root and nodules yields increased by at least 776, 1342, and 344% in treatments BC1+1/2NPK, BC2+1/2NPK and BC3+NPK compared with the control, respectively. The increase of cowpea yield with the application of biochar is associated with the improvement of soil physical, chemical and biochemical properties.

Taiwo *et al*. (2018) studied the effect of Plant Growth Promoting Rhizobacteria (PGPR) on cowpea (*Vigna unguiculata*) using biochar as a carrier. The nodulation and plant heights of cowpea plants increased with the application of biofertilizer + biochar and showed about 13% and 53% increase in plant height and number of leaves respectively, over the control for the field experiment.

Pandit *et al*. (2018) observed no considerable effect on crops yield in the first year for maize and mustard (in rotation) in acidic silty loam in Rasuwa, Nepal. However, 50, 47, and 93% increase in maize and 96, 128, and 134% increase in mustard yield at 15, 25, and 40 t ha^{-1} biochar application rates was observed during the second year. Yields of both maize and mustard correlated strongly with plant available P, K, total organic carbon percent, pH and CEC, and improved with increasing biochar application rate.

Glaser and Lehr (2019) reported that addition of biochar significantly increased the plant P availability significantly for its growth and development to acid and neutral soil.

Situmeang *et al*. (2019) investigated the effect of biochar and phonska fertilizer as well as its interaction on the growth and yield of corn crops. The results showed that the dose of biochar 10 t ha^{-1} gave the highest dry weight of seed per hectare of 8.12 tons, an increase of 32.77%.

Garamu *et al*. (2019) studied the effect of different source and rates of biochar application on the yield, and yield component of mung bean. The results indicated that at 10 t ha^{-1} rates of biochar application gave the highest seed yield. In contrast, the lowest seed yield (513.4 kg ha^{-1}) was recorded from control treatment.

Luhua *et al*. (2019) conducted pot experiment using ricebean on sandy yellow soil with pH of 5.5. The experiment included three lime rates (0, 0.75 and 1.5 g kg^{-1}) and three biochar rates (0, 5 and 10 g kg^{-1}). The results indicated that both lime and biochar could reduce soil exchange Al concentration, increase soil pH and the contents of soil microbial biomass carbon and microbial biomass nitrogen, and enhance urease and dehydrogenase activities, benefiting root growth and nodulation in acid soils.

Arunkumar and Thippeshappa (2020) observed that growth and yield attributing characters of green gram *viz*., plant height and number of leaves per plant, number of pods bearing auxiliary branches per plant, pod length, number of pods per plant, and number of seeds per pod were significantly influenced by residual effect of applied biochar and FYM with RDF at different growth stages.

Yeobah *et al*. (2020) narrated that biochar produced from pyrolysis of organic materials has been found to improve plant growth. The results showed that the spot and ring methods of application significantly enhanced height, girth, nodule number and dry weight, shoot biomass and grain yield of cow pea as well as nitrogen and phosphorus contents in shoots and grains when compared with the broadcast method and control.

Yin *et al*. (2021) assessed the effect of wood waste biochar (WB) on the growth and biological nitrogen fixation of wild soybean (*Glycine max* subsp. soja Siebold & Zucc.), a legume with high economic values and salt tolerance in coastal soil, were explored using a 42-day pot experiment. With the optimal rate of WB addition (1.5%, w/w), the biomass and plant height of wild soybean increased by 55.9% and 28.3%, respectively. Further, it enhanced the photosynthesis (chlorophyll content) and biological nitrogen fixation (nodule number) of the wild soybean.

2.1.2 Effect on nutrient composition and uptake

Wardle *et al*. (1998) narrated that charcoal addition enhanced seedling shoot to root ratios further leading to greater N uptake.

Chowdhury *et al*. (2000) reported that compost amendment enhanced available S, thereby enabling S uptake in plants.

Lehmann *et al*. (2002) elucidate that nitrogen uptake was significantly decreased by charcoal additions, which was an effect of poor N nutrition. Phosphorus nutrition and uptake increased when biochar was added. Biochar addition improved foliar K uptake. Uptake of Ca, Zn and Cu by the plants increased with higher biochar addition. Leaching of applied fertilizer and N was significantly reduced by biochar addition.

Glaser *et al*. (2002a) reported that biochar amendments can reduce the bulk density in soils leading to increase root penetration that allows the uptake of nutrients from soil solution.

Lehmann *et al.* (2003b) revealed that increasing biochar application rates increase the P concentration and uptake in plants. In addition, an increase in grain yield has also been recorded from after addition of biochar to rice fields with low available P.

Oguntunde *et al*. (2004) studied the effects of heating and charcoal residue on maize yield, soil texture and soil chemical properties. The results showed an increased nutrient availability and uptake due to charcoal residues in the kiln sites. The improved nutrient contents particularly resulted in a significant maize yield.

Chan *et al*. (2007) reported that available K in biochar is typically high leading to increased K uptake as a result of biochar application.

Warnock *et al.* (2007) reviewed that biomass-derived black carbon (biochar) affects microbial populations and soil biogeochemistry, thereby improving nutrient concentration and uptake. Many of the pores within a biochar particle are large enough to accommodate soil microorganisms including most bacteria and many fungi.

Steiner *et al*. (2008b) reported that application of poultry litter biochar without N fertilizer had resulted in increase yield of radish from 42 to 96% in comparison with control, indicating the enhanced N availability and uptake.

Khan *et al*. (2008) evaluated the effect of rhizobial inoculation and NPK fertilizer combinations on two mungbean genotypes NM-92 and NCM-209, nodulation, nitrogen fixation, growth and yield. The results of the study showed that interaction of genotype with NPK fertilizer improved the N content of shoots, number of seeds per pods and N content of soil after harvest.

De Luca *et al*. (2009) observed that applying biochar to forest soils along with natural or synthetic fertilizers has been found to increase the bioavailability and plant uptake of nitrogen and phosphorus, alkaline metals and some trace metals.

Novak *et al*. (2009) reported that biochar additions to the soil caused significant improvements in plant nutrient uptake (especially Ca, P, Zn, and Mn). Biochar additions to the soil increased soil pH, soil organic carbon, Ca, K, Mn, P and decreased exchangeable acidity.

Major *et al*. (2010) observed a very high rate of nutrient uptake by maize grown in infertile acidic soils under field conditions after a single biochar application.

Laird *et al*. (2010) reported that biochar may affect nutrients through the reduction in leaching losses thus improving the retention of nutrients, such as K in plants.

Uzoma *et al*. (2011) investigated the effect of cow manure biochar on maize yield, nutrient uptake and physico-chemical properties of a dry land sandy soil. Results of the study indicated that application of cow manure biochar at 15 and 20 t ha^{-1} significantly improved maize yield and nutrient uptake.

Major *et al*. (2011) conducted a field experiment by applying 20 t ha^{-1} biochar (BC) to a Colombian savanna Oxisol. Result showed that biochar additions increases plant nutrient uptake but reductions in inorganic N and K leaching were lower than measured increases in plant uptake.

Nigussie *et al*. (2012) investigated the effect of biochar application on the selected properties of chromium polluted soils and uptake of lettuces grown in polluted soils. The study showed a significant increase in nutrient uptake of nitrogen, phosphorous and potassium by addition of biochar.

Rajkovich *et al*. (2012) observed that N uptake of corn plants was increased by 15% after biochar application with recommended fertilizers.

Zheng *et al*. (2013) narrated that biochar addition stimulated maize growth, both above and below ground. Biochar also increased N utilization efficiency (NUE) of maize but decreased N accumulation efficiency (NAE), indicating that biochar addition may improve N concentration in maize crop.

Milla *et al*. (2013) conducted a field experiment to investigate the effect of rice husk biochar (RHB) and wood biochar (WB) on the growth rate of water spinach in a field experiment. The result showed that rice husk biochar could act as a soil conditioner, enhancing water spinach growth by supplying and retaining nutrients, leading to better root growth and nutrient uptake and thus improving the soil's physical and biological properties.

Schulz *et al*. (2013) studied about the optimum biochar, compost amounts and mixture ratios with respect to plant response and soil fertility. Results showed that nutrient uptake and biomass production was increased with rising biochar and compost amounts.

Dhage *et al*. (2014) indicated that grain and straw yield, uptake of phosphorus and sulphur increased in soybean with increase in the rate of application of P and S along with biochar in various combinations.

Oram *et al*. (2014) reported enhanced concentrations of nutrient uptake in legume biomass after addition of grass-derived biochar.

Fox *et al*. (2014) investigated the role of S and P-mobilizing bacteria in plant growth promotion in biochar-amended soil. These findings suggest that biochar amendment enhances microbially mediated nutrient mobilization of S and P resulting in improved plant growth and nutrient uptake.

Mia *et al*. (2014) reported that legume plant N concentrations increased significantly when biochar was applied at a rate of 120 t ha^{-1}.

Vaccari *et al*. (2015) reported that biochar treatments at the rate of 14 t ha^{-1} significantly increased the concentration of K in tomato leaves.

Inal *et al*. (2015) evaluated the effects of processed poultry manure (0, 5, 10 and 20 g kg^{-1}) and its biochar (0, 2.5, 5, 10 and 20 g kg^{-1}) on soil chemical properties of a calcareous soil and growth of bean (*Phaseolus vulgaris*) and maize (*Zea mays*) plants. Result of this study revealed that poultry manure and biochar applications increased the growth of maize and bean plants. Poultry manure and biochar resulted in increased concentrations of N, P, K, Ca, Fe, Zn, Cu and Mn in bean plants.

Sean and Nigel (2015) reviewed that biochar play an important role in a wide variety of forest restoration efforts, helping in improving nutrient concentration of forest specifically as a replacement product for other forms of organic matter and liming agents.

Kleber *et al.* (2015) studied about the indirect nutrient value of biochar and its ability to retain nutrients in the soil and, therefore, to reduce leaching losses, resulting in increased nutrient uptake by plants and higher production.

Senbayram *et al*. (2015) reported that application of high rates of K or ammonium ($NH4^{+}$) fertilizer often enhances the risk of Mg deficiency. High concentrations of these cations in the soil solution interfere with Mg uptake by plants (called nutrient antagonism).

Gao and De Luca (2016) reported that biochar addition enhanced plant growth, nutrient uptake and crop yield. Biochar itself can serve as a source of nutrients and its structure and surface chemistry can enhance the capacity to hold nutrient ions thus increase availability.

Naeem *et al*. (2016) elucidate that application of two maize biochar @ 10 g kg^{-1} of soil significantly increased P and K uptake in shoot as well as in root compared to control.

Zahefidar and Najafian (2016) found that application of biochar @ 1.5% and 3% weight of soil significantly increased the N, P, K uptake of *Ocimum basilicum*.

Li *et al*. (2016) reported at application of two maize straw biochar @10 g kg^{-1} of soil significantly increased N and K uptake in spinach plant.

Bhattacharjya *et al*. (2016) reported that residual effect of pine needle biochar and lantana biochar (doses equivalent to 5 ton C ha^{-1}) was significant and resulted in increased N, P and K uptake in wheat grain after rice in pot experiment.

Cheng *et al*. (2016) reported that chicken litter biochar addition at the rate of 20 t ha^{-1} significantly increased N, P and K uptake in leaves and stem of maize plants over control in two years field experiment.

Syuhada *et al*. (2016) investigated the impact of biochar amendment on chemical properties and corn nutrient uptake in a sandy Podzol soil. The result showed that corn N and K uptakes were significantly increased by the addition of biochar.

Eazhilkrishna *et al*. (2017) conducted a field experiment to study the effect of nutrient enriched biochar from sugar industry wastes on yield of hybrid maize (NK6240) on Typic Rhodustalf (Alfisol) of Tamil Nadu. The results of the field experiment revealed that the grain yield (5677 kg ha^{-1}) and stover yield (9504 kg ha^{-1}) significantly increased up to 125% RDF through nutrient enriched biochar (T4) which is 23% higher than the yield of nutrients supplied through 100% RDF through inorganic fertilizers (T7). Since the nutrient supplied through NEB is released in a phased manner, it enhanced the uptake of nutrients and there by enhanced the yield of hybrid maize.

Muhammad *et al*. (2017) found that integration of biochar and legumes significantly enhanced plant height, nitrogen concentration and grain yield of maize.

Rietra *et al*. (2017) reviewed that biochar interaction with plant nutrients can yield antagonistic or synergistic outcomes that influence nutrient use efficiency and nutrient uptake.

Jeffery *et al*. (2017) reported that application of biochars can also improve the fertility of acidic soils and increase crop productivity and nutrient uptake.

Zhang *et al*. (2017) observed that sulphur enriched biochar amendment significantly increased corn plant uptake of S and other macro nutrients such as (N, P, K, Ca, and Mg) and micro-nutrients (Zn, Mn and B).

Miranda *et al*. (2017) conducted a green house experiment on effects of biochar and nitrogen application on yields of upland rice and cowpea. The results showed that biochar addition decreased the calcium and magnesium concentrations in upland rice and cowpea.

Joseph *et al*. (2018) found that combined application of biochar with manures, composts, or other organic material can improve NUE as a result of slower leaching rates.

Rafael *et al*. (2018) found that biochar in combination with NPK fertilizers improved soil chemistry and enzymatic activities, allowing reduced fertilizer application while there was a significant effect of treatment on plant nutrient uptake by cowpea.

Adekiya *et al*. (2019) conducted a field experiment to evaluate the effects of biochar and poultry manure on soil properties, leaf nutrient concentrations and root yield of radish. Results showed that application of biochar increased soil pH and concentrations of organic matter, N, P, K, Ca and Mg, as well as nutrient concentrations, uptake and yield of radish.

Sun *et al*. (2019) observed that application of biochar at rates between 5 and 20 Mg ha^{-1} increased wheat NUE between 5.2 and 37.9% and grain yield between 2.9 and 19.4%. However, biochar rates >30 Mg ha^{-1} had a negative impact on NUE and grain yield.

Alexandre *et al*. (2019) conducted green house experiment in upland rice and cowpea and observed an increase in the amounts of K and P nutrient content and reduction in levels of Ca and Mg after application of biochar.

Meena *et al*. (2020) reported that application of biochar along with soil test value based fertilizer (STV) + FYM + $ZnSO_4$ influenced the productivity of rice and cowpea of 104.82 q ha^{-1} and 2474.77 kg ha^{-1} , respectively and the uptake of nitrogen, phosphorus and potassium by rice (107.72, 28.16 and 69.34 kg ha^{-1} respectively), and cowpea (68.06, 5.86 and 38.67 kg ha^{-1} respectively) which was found on par with application of biochar along with RDF + FYM + $ZnSO_4$.

Baigorri *et al*. (2020) studied the effects of granulated fertilizers incorporating biochar at different concentrations, as well as of biochar used as an amendment, on plant growth and mineral nutrition. The results showed that biochar enhanced foliar P, Ca and N content, as well as growth in acidic soil.

Gamal *et al*. (2020) studied the influence of sulphur and biochar on soil properties, productivity of wheat and soybean yields in soils having different texture classes. Results indicated that application of sulphur and biochar increased the grain and straw yields as well as N, P, K and S concentration and improved the nutrient uptake of wheat and soybean.

Apori *et al*. (2020) reported that the combined application of biochar and NPK plots in cucumber crop obtained higher nutrients composition than the sole application of biochar and manure addition.

Egamberdieva *et al*. (2020) observed that P and K uptake of broad bean under drought conditions increased by 14% and 23% fewer than 2% MBC amendment, and by 23% and 34% under 4% MBC amendment as compared to plants grown without biochar application, respectively.

Kumar *et al*. (2021) investigated the effect of different sustainable production of rice and revealed that integration of biochar with mineral fertilizers improves soil organic carbon at the harvest of paddy by 44-54% and resulting in higher plant nutrient uptake.

Egamberdieva *et al*. (2021) reported that biochar application increased N uptake of soybean plants in all soil treatments with N or P supply, compared with *B. japonicum* inoculated and uninoculated plants.

Cui *et al*. (2021) also found that biochar promotes root growth by increasing soil K availability.

2.1.3 Effect on physicochemical properties of soils

Haynes and Mokoloblate (2001) narrated that organic residues such as biochar releases P which can become adsorbed to oxide surfaces. This will, in turn, reduce the extent of adsorption of subsequently added P thus increasing P availability in soil.

Glaser *et al*. (2002b) observed increasing trend of bio-available P and base cations in biochar applied soils. Biochar application boosts up the soil fertility and improves soil quality by raising soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity and retaining nutrients in soil.

Briggs *et al*. (2005) found that after adding biochar to the soil, the Munsell color value increased with the increase of biochar content, while low water content the biochar will significantly increase the temperature of the soil. From the perspective of improving the physical properties of the soil, proper application of biochar can produce good effects on agricultural soil.

Troeh and Thompson (2005) observed that biochar improved the chemical characteristics of the soil and is used as a soil fertilizer due to its high content of nutrients to plants.

Cheng *et al*. (2006) investigated the relative importance of either biotic or abiotic oxidation of biomass derived black carbon (BC) and characterize the surface properties and charge characteristics of oxidized BC. Black carbon incubated at both 30ºC and 70ºC without microbial activity showed a decrease in pH, as well as an increase in cation exchange capacity and in oxygen content respectively.

Liang *et al.* (2006) found that Black Carbon (BC) may significantly affect nutrient retention and play a key role in a wide range of biogeochemical processes in soils, especially for nutrient cycling. Additionally, a high specific surface area was attributable to the presence of BC, which may contribute to the high CEC found in soils that are rich in BC.

Yamato *et al*. (2006) reported that application of bark charcoal induced changes in soil chemical properties by increasing the pH value, total N and available P_2O_5 contents, cation exchange capacity, amounts of exchangeable cations and base saturation, and by decreasing the content of exchangeable Al^{3+}.

Naramabuye and Haynes (2006) conducted a laboratory incubation experiment to investigate the effect of the addition of two rates of a range of organic amendments to an acid soil. The result showed that soil pH was increased and exchangeable Al plus total and monomeric Al in solution was decreased by addition of all the organic amendments.

Fageria and Baligar (2008) observed that application of biochar to soil may improve nutrient supply to plants. Soil reaction (pH) is an important characteristic of soils in terms of nutrient availability and plant growth. Most plants have a preferred pH range where maximum growth and production can be attained. Plant growth, fertilizer application and crop harvesting acidify soils depending on the source of fertilizer, the differential uptake and distribution of positively and negatively charged ion.

Sohi *et al*. (2009) narrated that biochar can alters soil properties, enhances sorption of inorganic and organic compounds, thereby encourages microbial activity providing a medium for adsorption of plant nutrients and soil biota for microbes.

Cheng and Lehmann (2009) reported that the aged biochar were shown to have higher oxygen concentrations, surface acidity, and negative surface charge, CEC.

Rodriguez *et al*. (2009) carried out an experiment to measure changes in soil fertility as a function of the growth of maize plants over a 30-40 day period following seeding. The result showed that biochar increased green biomass growth of the maize on the fertile soil and soil pH was increased from 4-4.5 to 6.0-6.5 due to addition of biochar.

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

Novak *et al*. (2009) determined the impact of pecan shell based biochar additions on soil fertility characteristics and water leachate and reported that biochar addition increased soil pH, soil organic carbon, Ca, K, Mg, P and decreased exchangeable acidity.

Sohi *et al*. (2010) narrated that the function of biochar arises from specific surface area, which increases with temperature through the formation of micropores and the abundance of carboxyl groups on those surfaces. Both mineral and organic fractions of soil contribute to phosphorus and cation exchange capacity (CEC) in soil.

Masulili Agusalim *et al*. (2010) studied the characteristics of biochar made from rice husk and its potential as a soil amendment in acid soils. The result showed that application of biochar decreased soil bulk density, soil strength, exchangeable Al, and soluble Fe and increased porosity, available soil water content, C-organic, soil pH, available P, K, CEC, and Ca.

Afeng *et al*. (2010) reported that wheat straw biochar improved SOC (soil organic carbon) by 57%, total N content was enhanced by 28% in the 40 t ha^{-1} without N fertilization.

Gaskin *et al*. (2010) observed that biochar typically increases pH of acidic soils due to the liming capacity of associated carbonate salts retained in the ash component of biochar. This can improve the availability of some nutrients, which is commonly thought to be responsible for positive plant growth responses to biochar amendments.

Yuan and Xu (2011) reported that addition of biochar increased exchangeable base cations, effective cation exchange capacity, and base saturation, whereas soil exchangeable Al and exchangeable acidity decreased.

Mankasingh (2011) investigated the potential of biochar to improve soil fertility and moisture content. The results suggest that an application rate of 6.6 metric tonnes ha^{-1} cassia biochar from different biomass feedstock contained >20% C and were high in macro and micronutrients.

Yu *et al*. (2011) found that wood-based biochars and straw biochar is more effective and desirable for improving soil fertility.

Yuan *et al*. (2011) found that carbonates were the major alkaline components in the biochars generated at the high temperature. The data of FTIR–PAS and zeta potentials indicated that the functional groups such as –COO (–COOH) and –O (–OH) contained by the biochars contributed greatly to the alkalinity of the biochar samples tested, especially for those generated at the lower temperature. These functional groups were also responsible for the negative charges of the biochars.

Eastman (2011) reported that after applying 25 g kg^{-1} of biochar in silt soil, the soil bulk density decreased by 0.19 g cm^{-3} and after adding 5% of biochar, the water permeability and water retention of the soil are improved. Compared with perlite and vermiculite, its effect on soil compaction is more obvious.

Petter *et al*. (2012) evaluated the effect of biochar made from Eucalyptus on soil fertility, and on the yield and development of upland rice. The result showed that biochar positively affected soil fertility such as total organic carbon (TOC), Ca, P, and pH at 0–10 cm soil depth, and it was the only factor with significant effect on yield.

Dempster *et al*. (2012) found that plant tissue K concentration and soil P and K increased following biochar application.

Schulz and Glasner (2012) conducted study to test the biochar effects on soil quality and plant growth by addition of mineral and organic fertilizers. Biochar addition to mineral fertilizer significantly increased plant growth and increased the plant available K content and TOC as compared to mineral fertilizer alone. Combination of biochar with compost showed the best plant growth.

Carvalho (2013) reported that wood biochar application coupled with N fertilization showed an increase in soil pH, K, Ca, Mg, CEC, Mn and nitrate while decreasing Al content and potential acidity of soils.

Biederman and Harpole (2013) reported that applications of biochar to soil have shown obvious increases in total SOC and N concentrations, the availability of major cations and P, CEC and pH.

Jien and Wang (2013) evaluated the influences of biochar made from the waste wood of *Leucaena leucocephala* on the physicochemical properties of long-term cultivated, acidic Ultisol. Results indicate that applying biochar improved the physicochemical properties of the highly weathered soils, including significant increases in soil pH from 3.9 to 5.1, cation exchange capacity from 7.41 to 10.8 $cmol(p^{+})kg^{-1}$, base cation percentage from 6.40 to 26.0%.

Liu *et al*. (2013) observed that both bamboo biochar and rice straw biochar (RB) significantly increased soil pH and soil organic carbon compared to control, whereas their effects on total N were either very small or non-significant. Application of rice straw biochar significantly increased soil available P and K in both years, and increases relative to control.

Wang *et al*. (2014) assessed the incubation experiment of rice husk biochar (RHB) and acid soil in a controlled cabinet to test the effect of biochar on soil available elements. The levels of soil pH, K, Ca, Mg, Na and total C and N increased while the Al and Pb contents decreased. Total carbon and potassium increased by 72% and by 6.7 fold respectively over the control at 4% of rice husk biochar adding level.

Liu Fang *et al*. (2014) added biochar to the soil, and the content of available phosphorus, available nitrogen and available potassium in the soil increased, which significantly improved the soil nutrient status.

Chintala *et al*. (2014) investigated the effect of biochar addition on the chemical properties of acidic soil such as soil pH, electrical conductivity (EC), cation exchange capacity (CEC), and exchangeable acidity to determine the liming potential of biochars. The result showed that application of corn stover biochar had shown a relatively larger increase in soil pH than switchgrass biochar at all application rates. The ameliorating effect of biochars on chemical properties of acidic soil was consistent with their chemical composition.

Alburquerque *et al*. (2014) reported that addition of biochar, especially at high application rates, decreased soil bulk density and increased dissolved organic C, available P, S and decreased soil nitrate concentration. Therefore, biochar can improve soil properties and increase crop production with a consequent benefit to agriculture.

Abewa *et al*. (2014) reported that application of biochar increased soil pH, CEC, available P and organic carbon and significantly increased yield.

Glaser *et al*. (2014) observed that biochar from green cuttings increased CEC, exchangeable K, total N, available P at biochar addition of 1 t ha^{-1}, 10 t ha^{-1}

and 40 t ha^{-1} also increased the water holding capacity of the sandy soil by 6% and 25%.

Liang *et al*. (2014) reported that biochar promoted decreased soil bulk density, increased exchangeable K and water holding capacity at 90 t ha^{-1}

Mukherjee *et al*. (2014) found out that oak wood biochar reduced soil bulk density by 13% and increased soil-C by 7%.

Havlin (2014) reported that compressed soils have a low pore space and lower oxygen diffusivity resulting in anaerobic conditions that decreases plant growth considerably. A reduction of 45 and 14% was observed in the yield of soybean and corn, respectively, when cultivated in compacted soils compared to normal soil. Biochar application can reduce these effects and enhance the physical properties of nutrient-depleted or degraded soils.

De Luca (2015) reported that biochar additions to soils have recorded changes in the soil environment that could increase soil S bio-availability. Biochar additions to mineral soils may also directly or indirectly affect S sorption reactions and S reduction.

Agegnehu *et al*. (2015) found that application of compost along with biochar and fertiliser significantly increased plant growth, soil nutrient status especially P, K, Ca and Mg and plant nutrient content, with shoot biomass.

Chang *et al*. (2016) focuses on the influences of peanut biochar application on N mineralization in abandoned orchard soil during a 46-day incubation. The treatments contained control, 1% biochar (BC), and 3% biochar (BC). Results showed that peanut biochar increased soil pH, CEC and EC, but decreased soil urease activities significantly.

Glab *et al.* (2016) indicated that biochar application significantly improved the physical properties of the sandy soil. It was found that the basic soil physical parameters, such as bulk density and total porosity, were not only dependent on the rate but also on the size of the biochar. Small particles of biochar reduced the volume of soil pores in diameter below 0.5 µm but increased the volume of larger pores with a diameter 0.5–500 µm.

Mandal *et al*. (2016) reported that char materials can potentially sequester C in soil, reduce nitrogen (N) loss from soil in terms of N_2O emission and ammonia (NH_3) volatilization, improve nutrient retention capacity of soils and reduce runoff and leaching losses, improve plant growth by supplying nutrients to the roots and microbes directly from the source, or indirectly by their ability to absorb and retain nutrients.

Andrian *et al*. (2016) reported that biochar, compost, co-composted biochar as organic amendments improved soil properties including soil water content.

Bayu *et al*. (2016) showed that the addition of biochar improved pH, electric conductivity (EC), cation exchange capacity (CEC), organic carbon (OC), organic matter (OM), total nitrogen (TN), exchangeable cations and available phosphorous of the soil.

Liu *et al*. (2016) conducted field experiments in Zhejiang Province, China, and the results showed that bamboo biochar and straw biochar had little effect on soil pH. Rice straw biochar could increase soil pH by 0.18, and bamboo biochar could increase soil pH by 0.15.

Pandian *et al*. (2016) evaluated the effect of biochar and organic soil amendments on soil physicochemical and microbial load, carbon sequestration potential, nutrient uptake and yield of groundnut in acidic red soil under rainfed condition. The results suggested that application of biochar to acidic red soil favoured good soil physical, chemical and biological environment, and these positive changes influenced growth and yield attributes and enhanced pod yield 29% over control.

Suliman *et al*. (2017) found that biochar as a soil amendment may improve the physicochemical properties of degraded or nutrient-depleted soils. The ability of biochar to retain soil water is a function of the combination of its porosity and surface functionality. Biochar increases porosity due to its particularly porous internal structure and increased soil porosity increases the surface area of soil so that water is better able to penetrate, thereby decreasing the soil bulk density, increases total pore volume and water holding capacity.

Miranda *et al*. (2017) evaluated the effects of biochar and nitrogen application on yields of upland rice and cowpea. Biochar promoted increased soil pH, potassium content, and exchangeable sodium percentage and decreased calcium and magnesium.

Zee *et al*. (2017) conducted a field study to investigate the effects of biochar on plant growth. Biochar appears to be an effective method of supplying available phosphorus (P), potassium (K), and increasing soil pH, while there was no effect on nitrogen availability.

Gao *et al*. (2017) enumerated several biochar feedstocks, including peanut hull, switchgrass, bamboo, bagasse, maize stover, stalks, pepperwood, filter cake, pecan shells, acacia whole-tree, mixed wood, and sewage sludge, that were reported as effective at decreasing NO_3 , NH^{4+}, phosphate (PO_4^{3-}), K^+ , Ca^{2+}, Mg^{2+}, and Zn leaching.

Han Weng *et al*. (2017) reported that biochar accelerates the formation of microaggregates via organo-mineral interactions, resulting in the stabilization and accumulation of SOC and biochar can increase the stable C content of soil.

Trupiano *et al*. (2017) reported that in a soil poor in nutrients the biochar alone could be effectively used to enhance soil fertility and plant growth and biomass yield.

Nair *et al*. (2017) reported that biochar, when applied to soils is reported to enhance soil carbon sequestration and provide other soil productivity benefits such as reduction of bulk density, enhancement of water-holding capacity and nutrient retention, stabilization of soil organic matter, improvement of microbial activities, and heavy-metal sequestration.

Tan *et al*. (2017) reported that biochar directly changes the physical and chemical properties of soil and consequently the microorganism activity.

Mavi *et al*. (2018) reported that electrical conductivity (EC), pH, oxidisable organic carbon (OC), microbial biomass carbon (MBC), dissolved organic carbon (DOC) and available nutrients (NPK) status increased with increasing rates of biochar addition.

Guo *et al*. (2018) found that application of straw, under the condition of single application of biochar, the total amount of exchangeable base ions in the soil was significantly increased. This was because biochar has a loose and porous structure, its surface area is large and the surface is rich in organic functional groups, it can absorb more base ions, thereby increasing the soil base saturation and making the CEC value higher.

Li *et al*. (2018) conducted a study where physiochemical properties of biochar derived from switchgrass, water oak and biosolid at different pyrolysis temperatures were characterized using multiple techniques. The results indicated that cation exchange capacity (CEC) and morphological characteristics (e.g., porosity) were found to be the predominant factors affecting biochar.

Naeem *et al*. (2018) observed that combined application of biochar, compost and inorganic fertilizer significantly increased soil properties such as soil organic carbon (SOC) and available N, P, K status of the soil.

Shetty and Prakash (2020) studied the effect of biochar treatment on alleviation of soil aluminium (Al) toxicity and its role in enhancing plant growth parameters. The result showed that wood biochar at higher dose performed better in reducing soluble and exchangeable Al in comparison to other biochars indicating its higher ameliorating capacity.

Haojie *et al*. (2020) reported that biochar has a loose and porous structure, with large surface area and is rich in organic functional groups, it can adsorb more base ions, thereby increasing the soil base saturation and making the CEC value higher.

Rahim *et al*. (2020) concluded that preceding legumes and previously applied biochar showed a significant carry-over effect on soil fertility status.

Adekiya *et al*. (2020) reported that incorporation of 30 Mg ha^{-1} of hardwood biochar increased the OM by an average 77, 18, and 9%, compared to un-amended control, 10, and 20 Mg ha^{-1} of biochar across two years, respectively.

Adnan *et al*. (2020) corborrated that biochar is emerging as a suitable practice to effectively decrease the usage of synthetic fertilizers and increase NUE.

Peeyush *et al*. (2021) reported that biochar enhanced the physical properties of soil (such as infiltration rate, maximum water holding capacity, aggregate stability, and mean weight diameter) leading to an increased crop yield and maximum monetary returns under subtropical conditions.

Jien *et al*. (2021) investigated that when 4% biochar was incorporated into highly weathered tropical soils (sandy clay loam) in-situ for 1 year revealed that wood-based biochar could reduce soil bulk density by 5% and increase porosity by 5%. When this biochar at 4% was applied with 1% compost, the bulk density further reduced by 16% and porosity increased by 8%. Higher biochar application (6%) with compost (1%) lowered the bulk density and increased porosity even more at 16 and 22%, respectively.

2.1.4 Effect on biological properties of soils

Pietikainen *et al*. (2000) argued that microbial abundance in soil may enhance due to sorption of bacteria on surface of biochar, rendering them less vulnerable to leaching loss. The effect will be more marked on bacterial community compared with fungi due to their small size. Assuming that highly recalcitrant biochar acts more like a mineral constituent for microbes in soil, the non-biochar C status in this soil should diminish due to enhanced microbial activity.

Yamato *et al*. (2006) showed that that bark charcoal application is effective in increasing the yield of crops through the amelioration of the soil chemical properties and the creation of an appropriate environment for root growth and AM fungal colonization, while improving the MBC.

Grossman *et al*. (2010) observed the microbial community composition in soils from the Brazilian Amazon with two contrasting histories; Anthrosols and their adjacent non Anthrosol soils of the same mineralogy. The result showed that the Anthrosols which had consistently higher concentrations of incompletely combusted organic black carbon material (BC) showed higher soil pH, and higher concentrations of P and Ca, higher MBC and MBN compared to their respective adjacent soils.

Kuang Chongting *et al*. (2012) found that as the amount of biochar applied increases, the microbial biomass will also increase. Applying 0.5% and 1% biochar to the soil greatly increased the soil microbial MBC and MBN content.

Rousk *et al*. (2013) narrated that biochar pores may provide physical protection for soil microorganisms. Microbial abundance, diversity and activity are strongly influenced by pH.

Kumar *et al*. (2013) also reported that *parthenium* biochar which is prepared at 300ºC significantly increased dehydrogenase activity when applied at the rate of 5 g to 20 g kg^{-1} of soil and soil microbial biomass carbon was 1.4, 1.7 and 2.1 times higher than control at 1, 3 and 5 g kg^{-1} application dose, in laboratory experiment.

Masto *et al*. (2013) observed that *Eichornia* biochar when applied at the rate of 3 g, 5 g, 10 g and 20 g kg^{-1} of soil, significantly increased the activity of dehydrogenase, catalase and active microbial biomass carbon, but activity of acid phosphatase and alkaline phosphates significantly increased only when biochar was applied at the rate of 10 g and 20 g kg^{-1} of soil.

Ameloot *et al*. (2013) observed in incubation experiment (117 days) that application of two types of biochar (prepared at 350ºC and 700ºC) significantly increased microbial biomass carbon, while the increment in the activity of dehydrogenase was significantly enhanced only in biochar treatments which were produced at 350ºC.

Jaafar *et al*. (2014) found that structural characteristics of biochar provide potential micro-habitats for soil organisms.

Tong *et al*. (2014) reported that applied biochar may provide habitats for growth of soil dwelling microorganisms and protect them against natural predators.

Demise *et al*. (2014) conducted lab incubation study in red soil with oak wood biochar and bamboo biochar (0.5%, 1.0% and 2% of the soil weight) and found that urease activity significantly increased by both types of biochar at all the three application rates but microbial biomass increased only when biochar applied @ 0.5% of the soil weight over control.

Demise and Zhang (2015) found that application of oak wood biochar and bamboo biochar at the rate of 0.5%, 1% and 2% significantly increased urease activity microbial biomass carbon in degraded red soils (pH 4.57) in incubation experiment.

Mierzwa-Hersztek *et al*. (2016) evaluated the effect of the addition of poultry litter and biochar on soil enzymatic activity, soil ecotoxicity and grass crop yield (pasture grass mix). Biochar had more adverse effect on soil enzymatic activity and grass crop yield than non-converted poultry litter, but it significantly reduced soil toxicity.

Bhaduri *et al*. (2016) reported that higher rate of biochar addition showed decreased acid phosphatase activity whereas the urease and fluorescein diacetate hydrolyzing activities in soil were increased.

Gasco *et al*. (2016) observed that addition of pig manure increased dehydrogenase, phosphomonoesterase and phosphodiesterase activities, while biochar prepared at 300 °C resulted on a positive effect on dehydrogenase activity.

Tao *et al*. (2016) found that the combined application of unequal amounts of nitrogen fertilizer and biochar can significantly increase soil MBC and MBN.

Song *et al*. (2017) found that the amount of biochar and the level of nitrogen application have a certain effect on the soil MBC content, but it has little effect on MBN

Venkatesh *et al*. (2018) reported that the optimal biochar combining fertilizer and carbon storage function in soils would activate the microbial community leading to nutrient release and fertilization and would add to the decadal soil carbon pool.

Irfan *et al*. (2019) conducted a 2-year field experiment in an arid region to assess the co-use of biochar and nitrogen (N) fertilizer on soil microbial biomass and enzyme activity in the rhizosphere of the wheat crop. The study indicated that biochar amendments enhance the microbial biomass carbon and nitrogen increased by 18% and 63% with biochar amended at 1% C ha^{-1} with nitrogenous fertilizer and the same trend was observed in the following year. Urease and dehydrogenase activities also significantly increased with biochar applied at 1% C ha^{-1} with N fertilization illustrating 15% and 19%, respectively.

Das *et al*. (2020) conducted an experiment to study the ecotoxicological responses of four weed biochar on seed germination and seedling growth in acidic soil at three different level of application in maize and black gram. With increase in biochar application rate the seed germination increased for both maize and black gram. The seedling growth parameter was significantly enhanced by low biochar application rate (5 t ha^{-1}) than high rate (10 t ha^{-1}).

Das *et al*. (2021) carried out investigation to examine the infuence of diferent biochar type (dissimilar feedstock) on the MBC and soil enzyme activity. The increased biological indicator was more at 2.5 t ha^{-1} biochar application rates than 5.0 t ha^{-1} *i.e*. lower concentration of biochar enhanced more than higher concentration.

2.2 EFFECT OF PIG MANURE

2.2.1 Effect on crop performance

Jama *et al*. (1997) reported that application of inorganic and organic sources of manure increased maize yields and provided residual benefit to the following maize crop.

Singh and Agarwal (2001) reported that application of graded levels of nitrogen, FYM @ 20 tonnes ha^{-1} and recommended dose of fertilizer significantly enhanced plant height, dry matter accumulation, effective tillers, grain, straw and biological yields.

Prabhakaran (2003) conducted field experiment to determine the nutrient uptake and yield of tomato with different organic amendments (poultry manure, pig manure, fish meal, pressmud). The treatment comprised the recommended or half of the N applied through the organic amendments. The application of recommended N through poultry manure increased the nutrient uptake and yield in tomato.

Ibeawuchi *et al*. (2007) conducted an experiment, on the effect of graded replacement of inorganic fertilizer with organic manure on maize production. Results showed that NPK + PM (8.0 t ha^{-1}) and NPK + PM (6.0 t ha^{-1}) performed better in the production of *Zea mays* and had significantly higher maize grain yield, dry matter yield and improved soil fertility.

Hati *et al.* (2008) conducted a field experiment on long-term effects of inorganic fertilizer, manure and lime application on organic carbon content and physical properties of an acidic Alfisol under an annual soybean–wheat crop rotation. Application of balanced fertilizer along with manure (NPKM) or lime (NPKL) improved soil aggregation, soil water retention, microporosity and available water capacity and reduced bulk density, exchangeable aluminium of the soil in 0–30 cm depth over control.

Omotoso (2014) studied about the influence of NPK 15-15-15 fertilizer and pig manure on nutrient dynamics and production of cowpea (*Vigna unguiculata* L. Walp) consisting of six treatments laid out in a randomized complete block design with three replicates. The result showed that 8 t ha^{-1} PM + 60 kg NPK gave significantly higher number of nodules $plant^{-1}$, dry matter, number of pods $plant^{-1}$, number of seeds pod^{-1} and 100 seed weight respectively.

Akinmutimi *et al*. (2015) evaluated the comparative effects of poultry manure, piggery manure and NPK fertilizer on the growth, yield and nutrient content of okra (*Abelmoschus esculentus*). The results obtained from the study found out that plant height, stem girth and the number of leaves of okra was significantly increased with 10 t ha^{-1} Piggery manure over the other treatments.

Rambuatsaiha *et al*. (2017) conducted a field investigation with sole and combined applications of different organic nutrient sources viz., FYM, vermicompost, pig manure, *rhizobium* and PSB (Phosphate Solubilizing Bacteria) were evaluated in order to optimize organic nutrient management for green gram under rainfed conditions. Results showed that the combined application of

Rhizobium + PSB + vermicompost @ 0.7 t ha^{-1} was found to be the most responsive nutrient management practice recording significantly higher crop growth and yield attributes and ultimately recording the highest seed and stover yields of 369 and 989 kg ha^{-1} respectively.

Adeyemo *et al*. (2018) found that application of 6 Mg ha^{-1} of animal manure increased dry shoot biomass weight by 36% on a sandy clay loam and by 86% on a clay loam. This study also showed an increase in 1000-grain weight and cob weight with increasing manure application rate.

Jan *et al*. (2018) found that application of 1.5 Mg ha^{-1} of poultry manure increased spike length, 1000-grain weight, and grain yield of rice.

Rahimabadi *et al*. (2018) found significant increase in grain yield of more than 800 kg ha^{-1} with 30 Mg of manure ha^{-1}.

Mahto and Dutta (2018) conducted a field experiment designed after RCBD considering five organic treatments, *viz*. T_1: amritjal (1%); T_2: sanjivani (10%); T_3: shasyagavya (10%); T_4: FYM @ 6 t ha^{-1} + vermicompost @ 3t ha^{-1}; and T_5: absolute control. The result showed that T_4 emerged as the best treatment with the highest green pod yield of 21.15 t ha^{-1}, higher amount of dry matter (9.54%), TSS (4.600Brix), ascorbic acid (65.27 mg $100g^{-1}$) and protein content (10.63 %) in edible green pods, respectively.

2.2.2 Effect on nutrient composition and uptake

Bolan (1991) narrated that applying livestock manure improves microbial population and also phosphorus nutrient uptake from the soil by plants.

Motavalli *et al*. (2002) reported an increase in macro and micronutrients as a result of manure application, which in turn positively affects the growth and productivity of crops.

Mc Andrews *et al*. (2006) investigated the residual effect of fresh or composted hoop house swine manure on the growth and yield of soybean [*Glycine max* (L.) Merr.] The result showed that there was a 21 to 34% greater K concentration in soybean plants grown in the manure-amended sites than in the other plots.

Khan *et al*. (2007) reported that the addition of 10 Mg ha^{-1} and 20 Mg ha^{-1} of dairy manure in addition to inorganic fertilizer increased plant N concentration by 24% and 27%, respectively, compared to inorganic fertilizer alone.

Bandyopadhyay *et al*. (2010) investigated the effect of sole application of inorganic fertilizers (NPK) (NPK- 30:26:25 kg ha^{-1}) and combined application of farmyard manure (FYM) @ 4 Mg ha^{-1} and inorganic fertilizers (NPK + FYM) and manures (control) on changes in soil physical properties and plant growth characteristics of soybean. The result showed that integrated use of NPK and FYM significantly improved the N uptake by soybean grain, straw and grain + straw by 55.5, 63.2, and 58.6%, respectively over control.

Nikoli and Matsi (2011) reported that micronutrient availability increases with manure application.

Hou *et al*. (2012) showed that the application of chicken manure in combination with inorganic fertilizer significantly increased the N content in plant.

Soremi *et al*. (2017) reported the effects of poultry manure on concentrations of N, P and K in plant tissues. Highest concentrations of N, P and K in plant tissues were mostly obtained at 7.5 and 10 t ha^{-1} of poultry manure.

2.2.3 Effect on soil properties

Ndayegamiye and Cote (1989) showed that there was no increase or decrease in the soil pH as a function of farmyard manure or pig slurry. This was attributed to the fact that this soil had been limed before the experiment. The variability in results shows that the effect of manure on soil acidity depends on the properties of the manure type and the soil conditions.

Gilley *et al*. (2000) reported that addition of manure to soils in general does not only impact soil chemical properties but it also greatly impacts soil physical conditions such as soil water, structure, bulk density, and resistance against erosion

Hao *et al*. (2002) evaluated the effect of long-term manure application on CEC and found that applying cattle manure at 90 Mg ha^{-1} increased the CEC by 5.6 cmol kg^{-1} under non-irrigated conditions. Under irrigation the application of the same rate of manure increased the CEC from 19.6 cmol kg^{-1} to 33.5 cmol kg^{-1}.

Parham *et al*. (2003) demonstrated that manure application enhances the bacterial community in the soil, thus leading to an improvement in soil productivity. Further, manure application also increases fungal diversity in the soil and when applied with inorganic fertilizers, reverses the declining microbial biodiversity trend associated with inorganic nutrients applied alone.

Plaza *et al*. (2004) corroborated in a pig slurry study and concluded that adding manure is beneficial in improving soil microbial biomass carbon. Since

SOC serves as a binding agent for aggregate stability, applying manure improves this process through several ways including its ability to enhance microbial biomass.

Ubochi and Ano (2007) reported a consistent increase in soil pH with the application of 10, 20, 30, and 40 Mg ha^{-1} of rabbit, swine, goat, chicken, and cow manures. The increase in the pH as a function of manure application has been attributed to the calcium carbonate and bicarbonate found in manure, the addition of cations such as Ca and Mg, and the presence of organic anions in the manure which can neutralize H^+ ions.

Steiner *et al*. (2007) reported that the application of chicken manure @ 47 Mg ha^{-1} increased the CEC with significantly higher concentrations of base cations in comparison to the control plots.

Ewulo *et al*. (2008) found that with the application of 10, 25, 40, and 50 Mg chicken manure per hectare (ha), SOM levels respectively increased by 0.85, 1.50, 1.72, and 1.95 percentage points relative to the control treatment with no addition of manure.

Saha *et al*. (2008) observed the dehydrogenase activity to be positively affected by the favourable soil management practices, i.e. organic treatment along with NPK fertilizers.

Butler *et al*. (2008) showed a 10 fold increase in soil P with the addition of 70 Mg ha^{-1} of composted dairy manure relative to the treatment with no compost application.

Bakayoko *et al*. (2009) have shown that the addition of animal manures to soil increased SOM or retards the process of SOM depletion.

Liu *et al*. (2010) found that in comparison to the control and inorganic fertilizer treatments the addition of farmyard manure to soil alone and in combination with N and P resulted in higher SOC contents of 9.98 g kg^{-1} and 10.52 g kg^{-1}, respectively.

Bandyopadhyay *et al*. (2010) observed that integrated use of NPK and FYM significantly improved the soil organic carbon content by 29.8 and 45.2% compared to NPK and control treatment

Celik *et al*. (2010) showed that the addition of compost or manure at 25 Mg ha^{-1} $year^{-1}$ resulted in the lowest bulk densities in comparison to synthetic fertilizer.

Adeniyan *et al.* (2011) conducted a pot experiment to compare different organic manures with NPK fertilizer for improvement of chemical properties of acid soil. Results showed that application of different types of organic manures reduced the acidic levels of both the soils. Cow dung application resulted in the highest pH levels of 6.37 and 6.50 in acid soil and nutrient depleted soil respectively while NPK fertilizer gave lowest pH levels of 5.28 and 5.74 for both soils.

Adeli *et al*. (2011) showed that the application of 2.2 Mg of manure per ha increased the total soil N by 110 mg kg^{-1} doubling the application to about 4.5 Mg ha^{-1} increased soil N by an additional 30 mg kg^{-1} relative to the control.

Opala *et al*. (2012) found that farmyard manure (FYM) and Tithonia diversifolia (tithonia) were more effective in increasing the soil pH and reducing exchangeable acidity and exchangeable aluminium than the inorganic P sources.

Omotoso (2014) narrated that sole application of pig manure and it combination with NPK fertilizer significantly increased soil N, P, K, Ca and Mg.

Wang *et al*. (2015) showed that over a 23-year period, pig manure alone and in combination with N, P, and K increased SOC by 25% and 30% relative to the treatment without any additional fertilizer or manure.

Soremi *et al*. (2017) reported that application of poultry manure significantly improved soil nutrient status as shown in increases in organic C, available P, exchangeable cations, and ECEC.

Meng *et al*. (2019) results showed that long-term annual manure applications decreased the bulk density and increased the total porosity of the soil. This study showed that 20 years of manure application increased the total porosity of the soil by 11.9%, while the bulk density decreased by 13.1% relative to the control treatment.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled "Effect of Biochar and Pig Manure on Performance of Ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] and Soil Properties in Dystrudepts" was conducted in the experimental farm of the Department of Agricultural Chemistry and Soil Science, School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema during the *Kharif* seasons, 2019 and 2020. A brief detail of material used and analytical techniques engaged for analysis of soils and plant material are concisely mentioned in this chapter.

3.1. Experimental site

The experimental site lies at 25˚45'30" N latitude and 93˚53'04" E longitude at an elevation of 310 m above mean sea level.

3.2. Climatic condition

The experimental farm lies in the humid sub-tropical zone with an average rainfall ranging from 2000 to 2500 mm per annum spread over 6 months *i.e.,* April to September, while remaining period from October to March remains dry. The mean temperature ranges from 21˚ to 32˚ C during summer and rarely goes below 8˚C in the winter season due to high atmospheric humidity. Monthly meteorological data during the experimentation period is given in Table 3.1 and depicted in fig 3.1

3.3. Characteristic of the experimental soil

The soil was sandy clay loam in texture. The composite soil sample was collected from experimental field (0-15 cm depth) before initiating the experiment. Pre-experimentation soil sample was analyzed for some important physicochemical properties. The results of analysis are presented in Table 3.2.

Table 3.1: Meteorological observations during experimental period (June-December)

Month	Max temp (ºC)	Min temp (ºC)	Max RH (%)	Min RH (%)	Rainfall (mm)	Sunshine hours	Rainy days
2019							
June	33.5	24.0	91	69	195.0	4.5	15
July	33.0	24.8	93	72	271.3	3.1	14
August	34.1	24.9	93	73	274.5	4.9	16
September	32.7	23.9	94	72	173.4	4.1	11
October	30.3	21.7	95	73	244.8	5.9	11
November	28.8	16.3	97	64	52.9	7.0	4
December	23.7	10.4	97	62	0.9	6.1	0
2020							
June	32.5	23.8	92	72	266.2	3.9	17
July	32.4	24.5	94	74	199.9	2.6	17
August	33.7	25.0	93	70	80.3	4.4	9
September	32.8	24.3	95	73	157.6	4.8	9
October	31.3	23.0	95	74	175.7	5.2	8
November	27.9	15.6	97	59	35.2	6.7	2
December	24.5	9.8	97	52	0	7.0	0

(Source: ICAR, Research Complex, NEH Region, Nagaland Centre, Jharnapani, Medziphema)

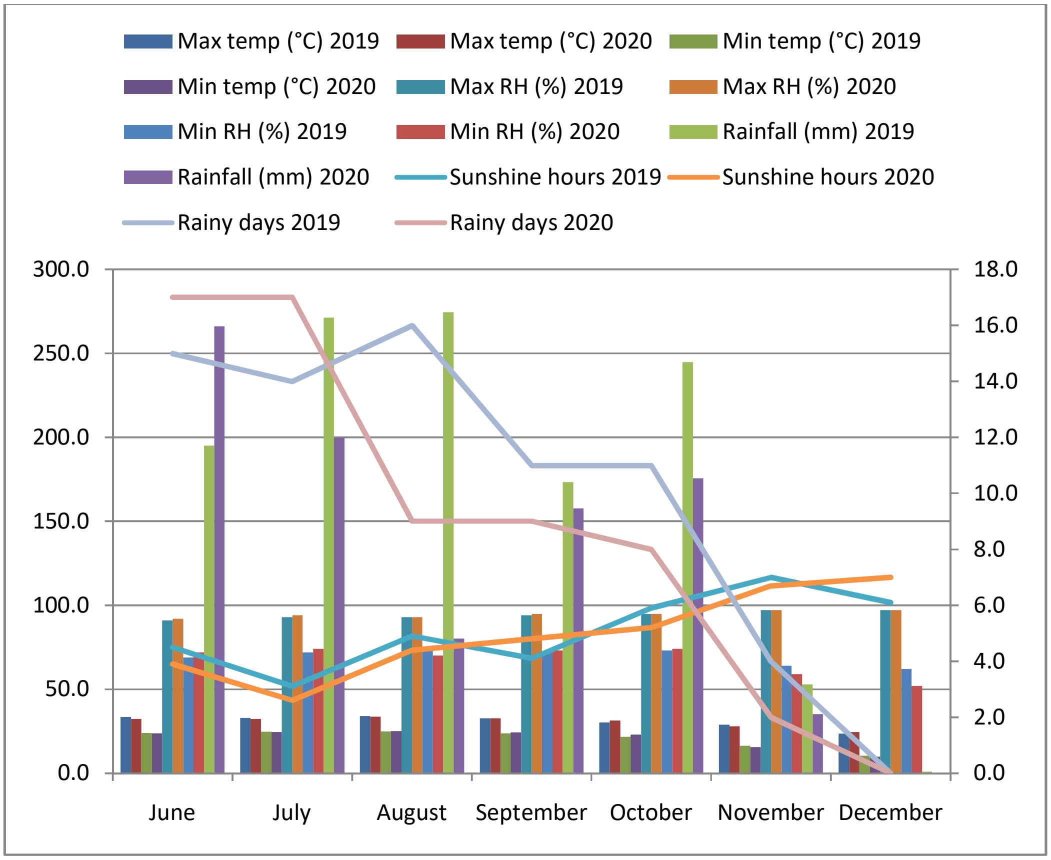


Figure 3.1: Meteorological observations during the period of investigation (June – December)

Table 3.2: Physicochemical properties of the experimental soil

Soil parameters	Values		Methods
	2019	2020	
Soil pH	5.20	5.22	Glass electrode method (Jackson 1973)
Organic carbon (g kg^{-1})	16.80	16.85	Rapid titration method by Walkley and Black (Jackson, 1973)
Available N (kg ha^{-1})	215.1	235.2	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	10.01	11.05	Bray and Kurtz method (1945)
Available K (kg ha^{-1})	137.4	138.4	Ammonium acetate method (Jackson, 1973)
Available S (kg ha^{-1})	11.19	12.09	Turbidimetric method (Chensin and Yien, 1950).
Exchangeable Ca [cmol(p^+)kg^{-1}]	2.12	2.27	Versenate method (Black, 1965)
Exchangeable Mg [cmol(p^+)kg^{-1}]	1.09	1.11	0.01 N EDTA using erichrome black T indicator (Black, 1965)
CEC [cmol(p^+)kg^{-1}]	9.70	9.91	NH_3 distillation method (Chapman, 1965)
Base saturation (%)	33.04	35.01	1 *N* NH_4OAc at pH 7.0 (Chapman, 1965)
Exchangeable Al^{3+} [cmol(p^+)kg^{-1}]	2.30	2.26	NaF solution (4%) in 1 *N* KCl extract titrated against 0.1*N* HCl (Baruah and Barthakur, 1997)
Exchangeable H^+ [cmol(p^+)kg^{-1}]	0.71	0.73	Exchangeable H^+= Exchangeable acidity- Exchangeable Al^{3+}
Exchangeable acidity [cmol(p^+)kg^{-1}]	3.01	2.99	1 *N* KCl solution titrated against 0.1 *N* NaOH solution (Baruah and Barthakur, 1997)
Total potential acidity [cmol(p^+)kg^{-1}]	17.58	17.43	$BaCl_2$- triethanolamine extract buffered at pH 8.0 to 8.2 (Baruah and Barthakur, 1997)
Dehydrogenase activity (µg TPF g^{-1} h^{-1})	19.21	19.35	2-3-5-triphenyltetrazolium chloride reduction technique (Casida, 1964)
Microbial biomass carbon (µg g^{-1} soil)	217.78	220.3 3	Fumigation extraction method (Vance *et al.*, 1987).
Acid phosphatase activity (µg p-nitrophenol g^{-1} h^{-1})	135.76	141.4 5	*p*- nitrophenyl phosphate tetrahydrate (pH 6.5) (Tabatabai and Bremner,1969)
Alkaline phosphatase activity (µg p-nitrophenol g^{-1} h^{-1})	79.12	80.45	*p*- nitrophenyl phosphate tetrahydrate (pH 11) (Tabatabai and Bremner,1969)
Mechanical analysis Sand (%) Silt (%) Clay (%)	50.4 19.1 30.5	49.8 23.4 26.8	International pipette method (Piper, 1966)
Textural class	Sandy clay loam	Sandy clay loam	

3.4. Experimental details:

In order to study the effects of the treatments, field experiments were carried out in the experimental farm of the Department of Agricultural Chemistry and Soil Science during *Kharif* season of 2019 and 2020. The detail of experiment is given below:

i- Treatment:

T_1- Control

T_2- RDF (20 kg N, 40 kg P_2O_5 and 30 kg K_2O ha^{-1})

T_3- RDF + 2.5 t ha^{-1} wood biochar

T_4- RDF + 5.0 t ha^{-1} wood biochar

T_5- RDF +2.5 t ha^{-1} bamboo biochar

T_6- RDF + 5.0 t ha^{-1} bamboo biochar

T_7- RDF + 2.0 t ha^{-1} pig manure

T_8- RDF + 2.0 t ha^{-1} pig manure + 2.5 t ha^{-1} wood biochar

T_9- RDF + 2.0 t ha^{-1} pig manure + 5.0 t ha^{-1} wood biochar

T_{10}- RDF + 2.0 t ha^{-1} pig manure + 2.5 t ha^{-1} bamboo biochar

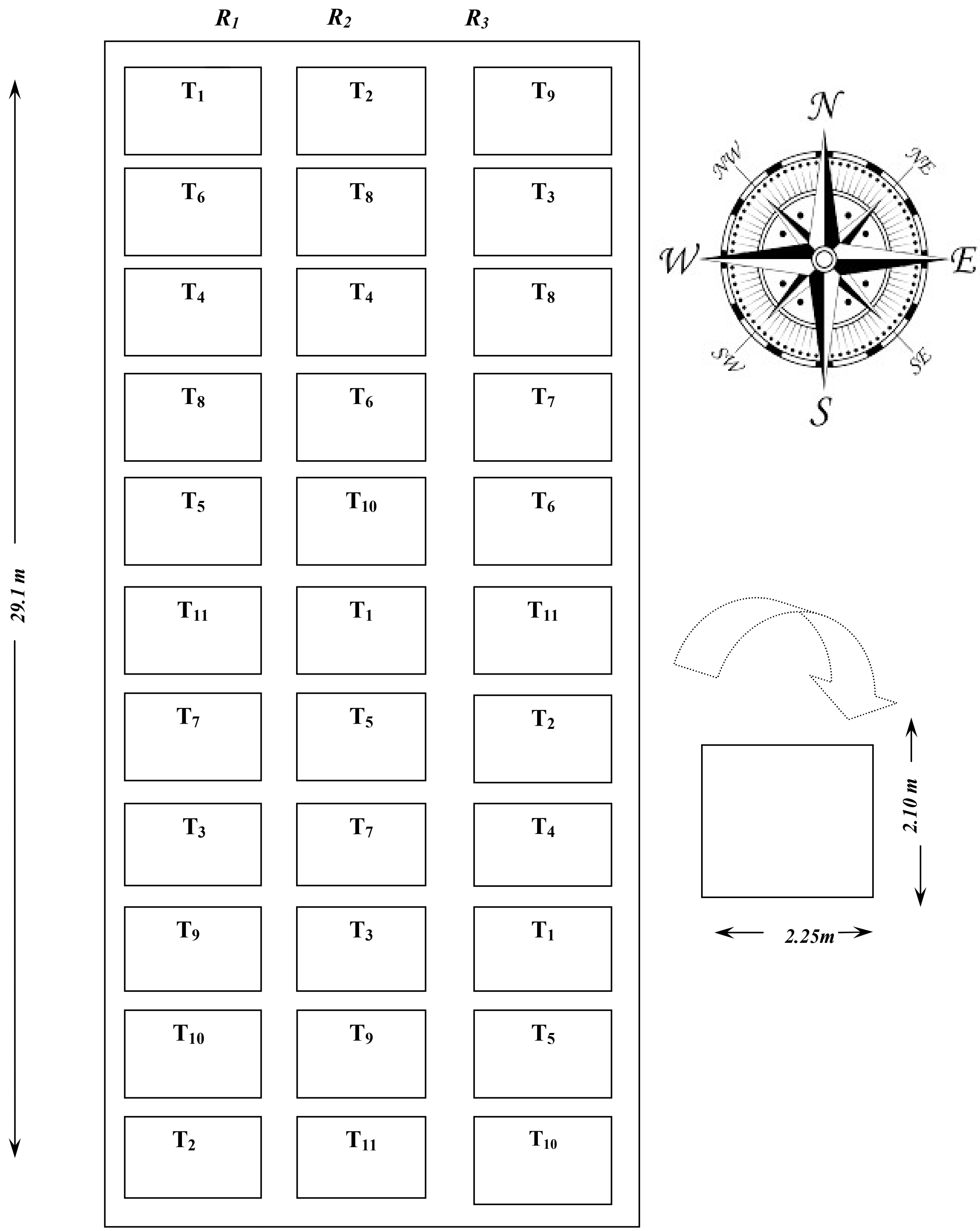
T_{11}- RDF + 2.0 t ha^{-1} pig manure + 5.0 t ha^{-1} bamboo biochar

ii- Crop	: Ricebean
iii- Spacing	: 45 × 30 cm
iv- Plot size	: 2.25 × 2.10 m^2
v- Variety	: Bidhan-1
vi- Design	: RBD
vii- Number of replications	: 3
viii- Total number of plots	: 11×3=33

Experimental procedure:

A rectangular plot having uniform fertility and even topography was selected for conducting field trial. The field was ploughed twice using tractor drawn plough. All stubbles were removed manually and large sized clods

Fig 3.2**:** Field layout of the experiment in Randomized Block Design



were again broken using a tractor drown rotavator to make a final seed bed. The field was then laid out accordingly as per the layout plan. Biochar was applied 14 days before sowing. Calculated amount of pig manure was applied one month before sowing. Biochar and pig manure were broadcasted uniformly in the plot and mixed properly. The recommended dose of nitrogen, phosphorus and potassium (20 kg N, 40 kg P_2O_5 and 30 kg K_2O ha^{-1}) were applied through urea, single superphosphate and muriate of potash. The soil was mixed well after incorporating measured quantities of fertilizers and biochar. The seeds were sown on 18th July, 2019 and 16th July, 2020 at a depth of 5 cm at optimum soil moisture to ensure proper germination. Thinning operation was carried out 2 weeks after germination with a view to maintain optimum plant population in all the plots. Intercultural operation such as hand weeding was done from time to time with the help of hand hoe or *khurpi* whenever required. Standard agronomic practices were adopted through the experimentation.

3.4.1 Harvesting and threshing

Harvesting of the crop was done in four to five batches. Plot wise hand picking of pods were done five times and after fifth picking, plants were cut with the help of sickles. Harvested crop of each plot were tied in bundles, sundried, threshed, cleaned manually and weight was recorded for seed and stover yield data.

3.5 Characteristics of biochar

Characteristics	Value	
	Wood biochar	Bamboo biochar
pH	7.91	7.70
Electrical conductivity (dSm^{-1})	3.58	1.68
Carbon (%)	86.90	83.40
Hydrogen (%)	1.17	3.85
Moisture (%)	3.81	3.60
Ash (%)	6.78	6.54
Volatile matter (%)	17.83	32.02
Fixed carbon (%)	71.58	57.84
Total nitrogen (%)	0.76	0.57
Total phosphorus (%)	0.89	0.72
Total potassium (%)	0.81	0.23
Total calcium (%)	2.35	0.37
Total magnesium (%)	0.45	0.36

Determination of biochar was done at CSIR-NEIST Jorhat, laboratory

3.6 Properties of pig manure

Characteristics	Value
pH	6.41
Electrical conductivity (dSm^{-1})	1.04
Nitrogen (%)	0.81
Phosphorus (%)	0.70
Potassium (%)	0.55

3.7. Biometrical observation

3.7.1 Plant height (cm)

Plant height was measured from the ground level to the tip of the main shoot of the plant at 40, 80 DAS and at harvest. The average height of the plant for each treatment was calculated.

3.7.2 Number of branches plant^{-1}

From the main stem the total number of branches was counted from the selected plants at 40, 80 DAS and at harvest and average was calculated for each treatment.

3.7.3 Number of pods plant^{-1}

From each treatment total number of pods from five tagged plants was counted manually. Average was worked out and expressed as number of pods plant^{-1}.

3.7.4 Pod length (cm)

The length of all the pods were measured from the tagged plant of each plot and the average was recorded in cm.

3.7.5 Seed pod^{-1}

The number of seeds from the five pods taken from the five selected plants was counted and the average values were taken to obtain the number of seeds per pod.

3.7.6 Test weight (g)

From the threshed seeds of individual plots, 1000 seed samples were taken randomly and weighed to get the test weight of seed.

3.7.7 Seed yield (kg ha^{-1})

Plot wise pods were picked, sundried, threshed and cleaned manually after final picking. After drying weight of seed was taken and seed yield was calculated and expressed in terms of kg ha^{-1}**.**

3.7.8 Stover yield (kg ha^{-1})

After final picking the harvested plants from each plot was sundried properly and plot wise stover yield (including pod husk) was recorded and expressed in kg ha^{-1}.

3.8 Chemical analysis of plant material

The ricebean seeds and stover samples were oven dried at a temperature of 60ºC to 70ºC to attain a constant weight. The dried seeds and stover samples were then powdered and stored in a polythene bags with proper labeling for chemical analysis. The powdered seed and stover samples were analyzed for N, P, K, S, Ca and Mg content.

3.8.1 Nitrogen

Half a gram powdered sample was digested with concentrated H_2SO_4 in presence of digestion mixture ($CuSO_4$ + K_2SO_4) till the digest gave clear bluish green colour. The digested sample was further diluted carefully with distill water to known volume. Then a known volume of aliquot was transferred to distillation unit (Micro kjeldahl- apparatus) and liberated ammonia was trapped in boric acid containing mixed indicator. Later it was titrated against standard H_2SO_4 and the amount of ammonia liberated was estimated in the form of nitrogen as per the procedure given by Bremner (1996).

3.8.2 Phosphorus

The samples were wet digested with nitric acid (HNO_3) and perchloric acid ($HClO_4$). Ammonium molybdate vanadate Chapman and Pratt (1962) method was followed for the determination of phosphorus in the plant extract by using spectrophotometer at 470 nm.

3.8.3 Potassium

The aliquot after wet digestion for phosphorus estimation was diluted to the desirable level and were analyzed for potassium by using flame photometer as decribed by Hanway and Heidal (1952).

3.8.4 Sulphur

Sulphur content was estimated by wet ashing of plants tissue sample (as described under phosphorous di-acid digestion) and the sulphur was estimated by turbidimetry method as described by Tandon (1993).

3.8.5 Calcium

The calcium content was determined in the di-acid digest of plant sample by versenate (EDTA) method (Prasad, 1998).

3.8.6 Magnesium

It was determined by di-acid (HNO_3-$HClO_4$) digestion of plant samples and titration of the aliquot against versenate (EDTA) method (Prasad, 1998).

3.9. Nutrient uptake

The uptake values of nitrogen, phosphorus, potassium, sulphur, calcium and magnesium by ricebean were calculated by using the nutrient content (%) in plant and corresponding yield. The uptake values of nutrients were calculated using the following relationship.

$$\text{Nutrient uptake (kg /ha)} = \frac{\text{Nutrient content (\%) x Yield (kg /ha)}}{100}$$

3.10. Soil analysis

The soil samples were collected from a depth of 0-15 cm from each experimental plot after the crop harvest. The soil samples were dried in shade, ground using mortar and pestle and sieved through 2 mm sieve and stored in polythene bags with proper labeling for the analysis of various parameters using standard protocol as mentioned below.

3.10.1 Mechanical analysis

The sand, silt and clay fractions of soil samples were determined by the International Pipette method using 1N sodium hydroxide (NaOH) as a dispersing agent Piper (1966).

3.10.2 Soil pH

Soil pH was determined in soil: water (1:2.5) ratio by glass electrode pH meter Jackson (1973).

3.10.3 Soil organic carbon

Organic carbon was determined by rapid titration method of estimation outlined by Walkley and Black as described by Jackson (1973) and the result was expressed in g kg^{-1}.

3.10.4 Cation exchange capacity (CEC)

The cation exchange capacity (CEC) of the soil was determined by NH_3 distillation method Chapman (1965).

3.10.5 Base saturation

Base saturation is the percentage of total CEC occupied by Ca^{2+}, Mg^{2+}, K^+ and Na^+. The base saturation was worked out by using the formula given below.

$$BS(\%) = \frac{\text{Sum of exchangeable bases}}{\text{CEC}} x100$$

3.10.6 Available nitrogen

The available nitrogen was determined by alkaline potassium permanganate method suggested by Subbiah and Asija (1956) and the result was calculated in terms of kg ha^{-1}.

3.10.7 Available phosphorus

Available phosphorus was extracted with 0.03 N NH_4F in 0.025 N HCl solutions. The procedure is primarily meant for soils which are moderate to strongly acidic with pH around 5.5 or less and determined by Brays and Kurtz method (1945).

3.10.8 Available potassium

Available potassium content in soil was extracted with neutral normal ammonium acetate (pH 7.0). The potassium content in the extract was determined by flame photometer (Jackson, 1973).

3.10.9 Exchangeable calcium

The exchangeable calcium was extracted with neutral normal ammonium acetate and determined by versenate method, where known volume of soil extract was titrated with standard 0.01*N* versenate (EDTA) solution using murexide (ammonium purpurate) indicator in the presence of NaOH solution (Black, 1965).

3.10.10 Exchangeable magnesium

The exchangeable magnesium was determined by using erichrome black T indicator with 0.01*N* EDTA method in the presence of ammonium chloride and ammonium hydroxide buffer (Black, 1965).

3.10.11 Available sulphur

The sulphate in the soil was extracted using monocalcium phosphate solution (500 ppm) and determined turbidimetrically using a spectrophotometer as described by Chensin and Yien, 1950.

3.10.12 Total potential acidity

The total potential acidity of soil includes all the acidity components like extractable acidity, non exchangeable acidity, weak acidic carboxylic and phenolic hydroxyl groups of soil organic matter and partially neutralized hydroxyl Al polymers that could be present even in soils. The total potential acidity was determined by using $BaCl_2$ -triethanolamine extract buffered at pH 8.0-8.2 as described by Baruah and Barthakur (1997).

3.10.13 Exchangeable acidity

Exchangeable acidity was determined by using 1*N* KCl solution and titrating against 0.1*N* NaOH until a pink colouration is obtained as mentioned by Baruah and Barthakur (1997).

3.10.14 Exchangeable Al^{3+}

Exchangeable Al^{3+} in soil was determined by adding 5 ml of NaF solution (4%) in 1*N* KCl. This solution was then titrated against 0.1*N* HCl until the pink colour disappeared as described by Baruah and Barthakur (1997).

3.10.15 Exchangeable H^+

The exchangeable H^+ was estimated by the difference between exchangeable acidity and exchangeable Al^{3+}.

Exchangeable H^+ = Exchangeable acidity – Exchangeable Al^{3+}

3.10.16 Dehydrogenase activity

Soil dehydrogenase activity was measured as per the methodology of (Casida *et al*., 1964) by reducing 2, 3, 5-triphenyltetrazolium chloride (TTC). For this 5 g soil sample mixed with 50 mg of $CaCO_3$ and 1 ml of 3% (w/v) TTC. Then it was incubated at 37±ºC for 24 h where dehydrogenase enzyme converted TTC to 2, 3, 5-triphenylformazan (TPF) and the produced TPF was extracted with acetone solvent. Then the extracts were filtered followed by spectrophotometric analysis at 485 nm.

3.10.17 Microbial biomass carbon

The microbial biomass carbon of soil was determined by using the fumigation-extraction method by (Vance *et al*., 1987). The fresh soil sample were placed in 50 ml beakers and kept in vacuum desiccators for fumigation with chloroform for 24 hours. The fumigated soil samples were treated with K_2 SO_4 and placed in the shaker for few minutes. The extracts were filtered and digested using H_2SO_4 and then titrated against ferrous ammonium sulphate. The microbial biomass carbon was calculated as the difference between the values obtained from fumigated and non fumigated soil samples.

3.10.18 Acid and alkaline phosphatase activity

For estimation of acid phosphatase *p*-nitrophenhyl phosphate tetrahydrate (pH 6.5) solution was used and for alkaline phosphatase the same solution of (pH 11.0) was used. For these assay soil samples were incubated at

37±1ºC for 1 hr. Then yellow colour filtrate obtained using Whatman No. 42 filter paper was estimated using UV-VIS double beam spectrophotometer at 440 nm as per the methodology of Tabatabai and Bremner (1969).

3.11. Analysis of data

The data related to each character were analyzed statistically by applying the techniques of analysis of variance and the significance of different source of variation was tested by ‘F’ test (Cochran and Cox, 1962).

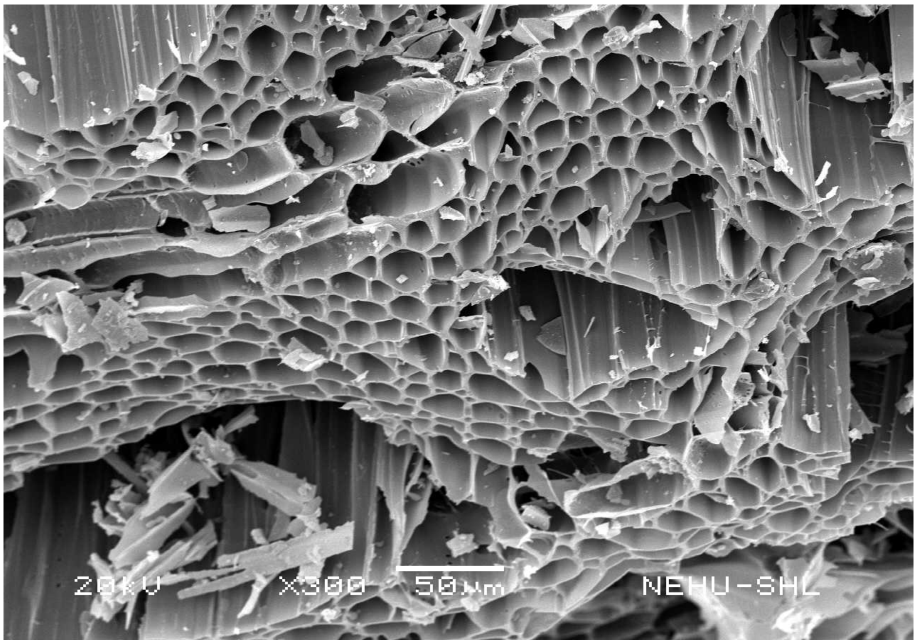


Plate No.1: SEM image of wood biochar

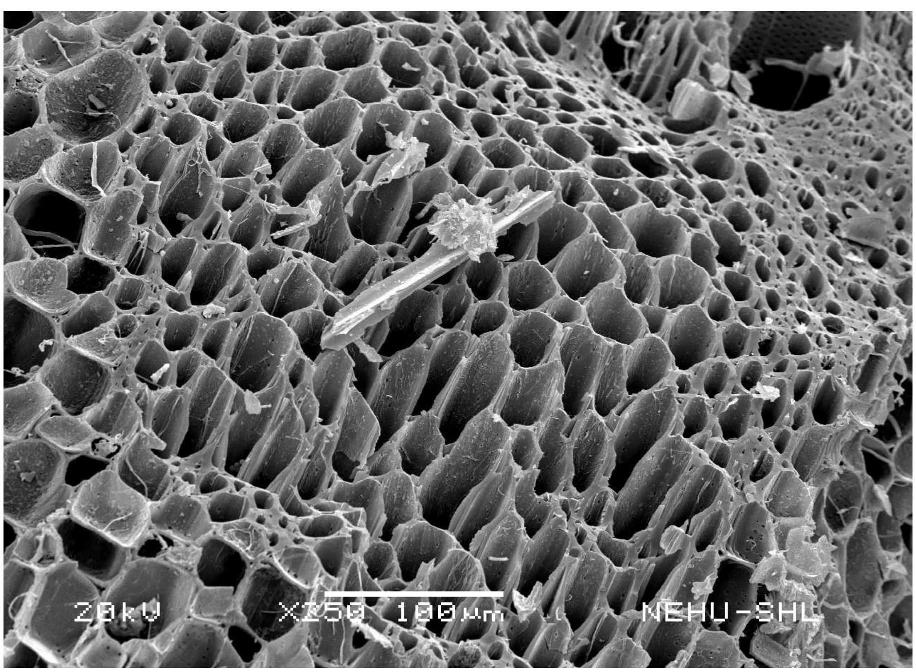


Plate No. 2: SEM image of bamboo biochar

Plate No. 3: Field preparation

Plate No. 4: General view of the prepared field

Plate No. 5: Field view at 7 days after sowing

Plate No. 6: Field view at 40 days after sowing

Plate No. 7: Field view at 80 days after sowing

Plate No. 8: Flowering stage

Plate No. 9: Pods development

Plate No. 10: Seeds

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Aresearch investigation pertaining to "Effect of biochar and pig manure on the performance of ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] and soil properties in Dystrudepts" carried out during the *Kharif* season of 2019 and 2020 are mentioned below in this chapter. Effect of treatments on crop and soil is depicted by the use of tables and graphs at appropriate places.

4.1 Effect of treatments on performance of ricebean

4.1.1 Effect on plant height

It is apparent from Table 4.1. and Fig. 4.1 that there was a visibledifference in plant height with application of different treatments. Irrespective of year, plant height of ricebean varied from 28.64 to 48.12 cm, 70.22 to 131.68 cm and 75.23 to 155.41 cm at 40, 80 DAS and at harvest respectively. Application of RDF (T_2) enhanced plant height significantly over control (T_1) at all stages of plant growth. It was observed that biochar and pig manure application alone did not increase plant height significantly at 40 DAS over RDF. But at 80 DAS and at harvest plant height was increased significantly with application of biochar and pig manure. However combine application of biochar and pig manure along with RDF significantly enhanced plant height over RDF (T_2) treatment. This increase in plant height may be associated with improvement of soil health and release of nutrient from biochar which helps in the cell division and cell enlargement ultimately leading to enhanced plant growth specifically plant height (Squire, 1990).

Table 4.1: Effect of biochar and pig manure on plant height of ricebean

Treatments	Plant height (cm)								
	At 40 DAS			At 80 DAS			At harvest		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	28.64	25.31	26.97	70.22	73.16	71.69	75.23	79.71	77.47
T_2- RDF(20:40:30)	36.83	39.74	38.28	99.52	107.19	103.35	114.51	117.84	116.17
T_3- RDF+2.5t ha^{-1} WB	41.61	40.43	41.02	120.87	123.97	122.42	131.87	136.23	134.05
T_4 -RDF+5.0 t ha^{-1} WB	42.59	42.88	42.74	121.86	125.02	123.44	132.84	138.16	135.50
T_5 -RDF+2.5t ha^{-1} BB	39.50	40.19	39.85	117.17	121.83	119.50	129.87	135.78	132.83
T_6- RDF+5.0 t ha^{-1} BB	40.53	40.33	40.43	119.57	124.27	121.92	130.15	135.89	133.02
T_7- RDF+2.0 t ha^{-1} PM	39.26	38.85	39.06	119.20	124.09	121.65	131.84	135.29	133.56
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	43.55	46.95	45.25	125.19	130.92	128.06	143.89	147.45	145.67
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	46.26	48.12	47.19	126.84	131.68	129.26	152.54	155.41	153.97
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	40.58	44.40	42.49	123.89	128.81	126.35	138.53	141.84	140.19
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	41.54	44.47	43.01	125.16	129.90	127.53	140.49	144.33	142.41
SEm±	2.59	1.86	1.60	6.38	4.36	3.86	5.13	6.55	4.16
CD (P=0.05)	7.65	5.50	4.56	18.82	12.86	11.04	15.12	19.32	11.89

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

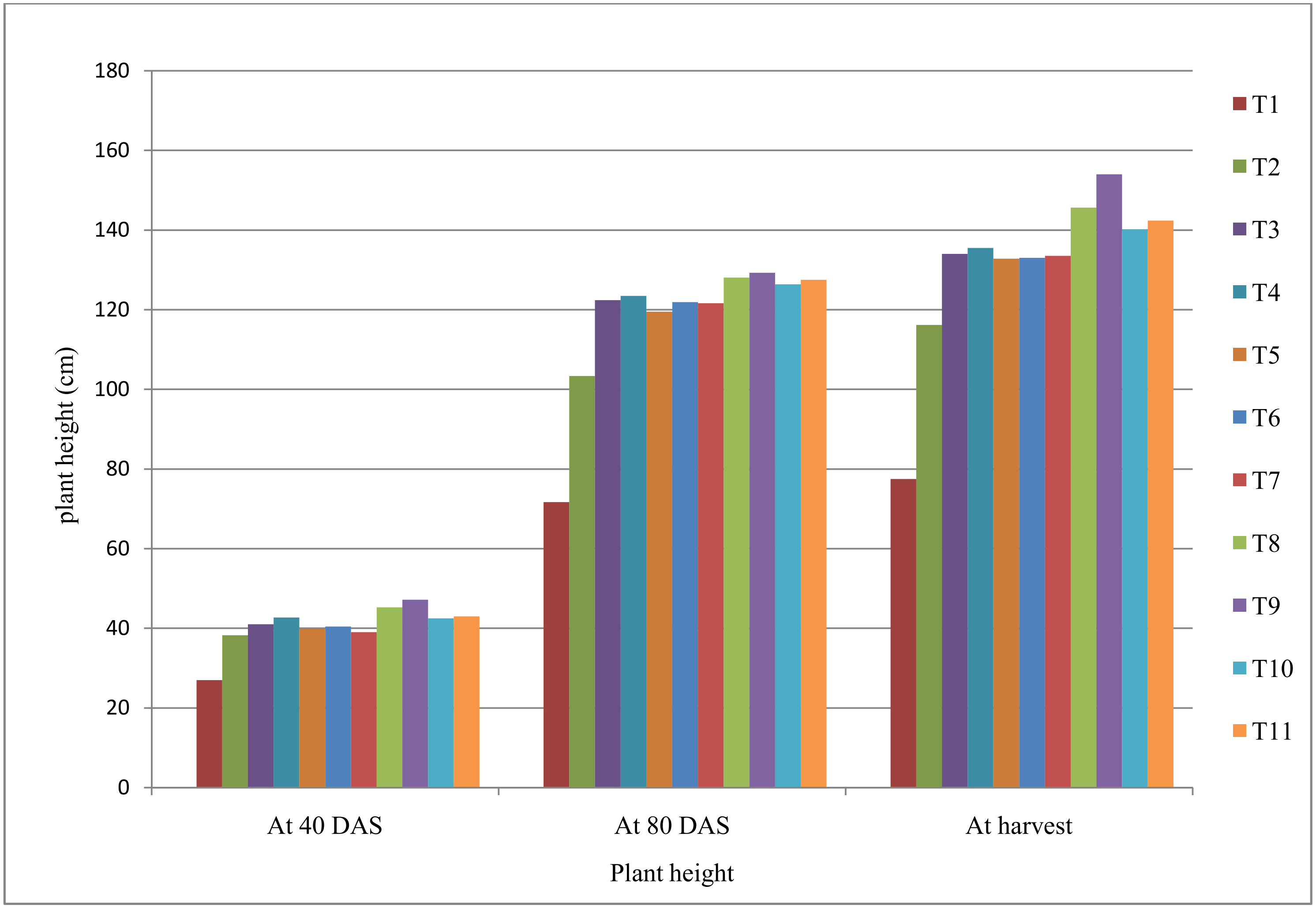


Fig 4.1: Effect of biochar and pig manure on plant height of ricebean

The tendency of the soil to store moisture and improved adsorption capacity to retain nutrients following biochar treatment may have attributed to supply more nutrients for plant growth Thies and Rillig (2009). It is well observed that in the year 2019 as well as 2020, the maximum plant height at 40, 80 DAS and at harvest was recorded in the treatment T_9 which, received (RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB) followed by treatment T_8(RDF + 2.0 t ha^{-1} PM + 2.5 t ha^{-1} WB). However, treatment T_9 was found to be at par with T_8, T_{10} and T_{11} in all the growth stages. The minimum plant height at 40, 80 DAS and at harvest was recorded in control *i.e.*, T_1. Based on the pooled data, at harvest application of treatment T_9 augmented the plant height by 98.7% over control and 32.5% over RDF (T_2). The significant increase in plant height at all stages of crop growth might be largely contributed to the residual effect of biochar which continuously provides nutrients for better plant growth while improvement in soil properties. The variation of plant height was considered due to variation in availability of major nutrientsArunkumar and Thippeshappa (2020). Similar effect of combined application of biochar and organic manure was reported by Agboola and Moses, 2015; Bandara *et al*., 2015. Similarly, maximum values in plant height were observed with combined application of pig manure and NPK fertilizer Omotoso (2014).

4.1.2 Effect on number of branches per plant

Results of different treatments on the number of branches per plant at 40, 80 DAS and at harvest have been presented in Table 4.2 and depicted in Fig4.2. As indicated in the data, application of RDF,biochar and pig manure significantly affected number of branches per plantat all growth stages. It is apparent from Table 4.2 that, highest number of branches per plantat 40, 80 DAS and at harvest was recorded in treatment T_9 with 7.91, 7.98, 9.84, 9.63, 10.60 and 10.65 respectively,during 2019 and 2020 while pooledwas 7.94, 9.74 and 10.63 followed by treatment T_8 T_{11} and T_{10}. The lowest number of branches $plant^{-1}$ was

Table 4.2: Effect of biochar and pig manure on number of branches per plant of ricebean

Treatments	Number of branches								
	At 40 DAS			At 80 DAS			At harvest		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	5.56	5.54	5.55	6.47	6.49	6.48	7.22	7.27	7.24
T_2- RDF(20:40:30)	6.80	7.21	7.00	7.86	7.97	7.92	9.22	9.32	9.27
T_3- RDF+2.5t ha^{-1} WB	7.26	7.55	7.40	9.20	9.25	9.23	10.23	10.25	10.24
T_4 -RDF+5.0 t ha^{-1} WB	7.29	7.57	7.43	9.56	9.60	9.58	10.25	10.30	10.28
T_5 -RDF+2.5t ha^{-1} BB	7.21	7.50	7.36	8.82	8.95	8.88	10.20	10.23	10.21
T_6- RDF+5.0 t ha^{-1} BB	7.24	7.52	7.38	8.85	8.97	8.91	10.24	10.26	10.25
T_7- RDF+2.0 t ha^{-1} PM	7.27	7.64	7.46	8.88	8.92	8.90	10.24	10.28	10.26
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	7.87	7.93	7.90	9.55	9.56	9.55	10.56	10.58	10.57
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	7.91	7.98	7.94	9.84	9.63	9.74	10.60	10.65	10.63
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	7.84	7.89	7.86	8.90	9.46	9.18	10.31	10.34	10.33
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	7.86	7.92	7.89	8.93	9.53	9.23	10.55	10.59	10.57
SEm±	0.40	0.26	0.24	0.40	0.32	0.25	0.44	0.45	0.32
CD (P=0.05)	1.19	0.76	0.68	1.17	0.93	0.73	1.30	1.33	0.90

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

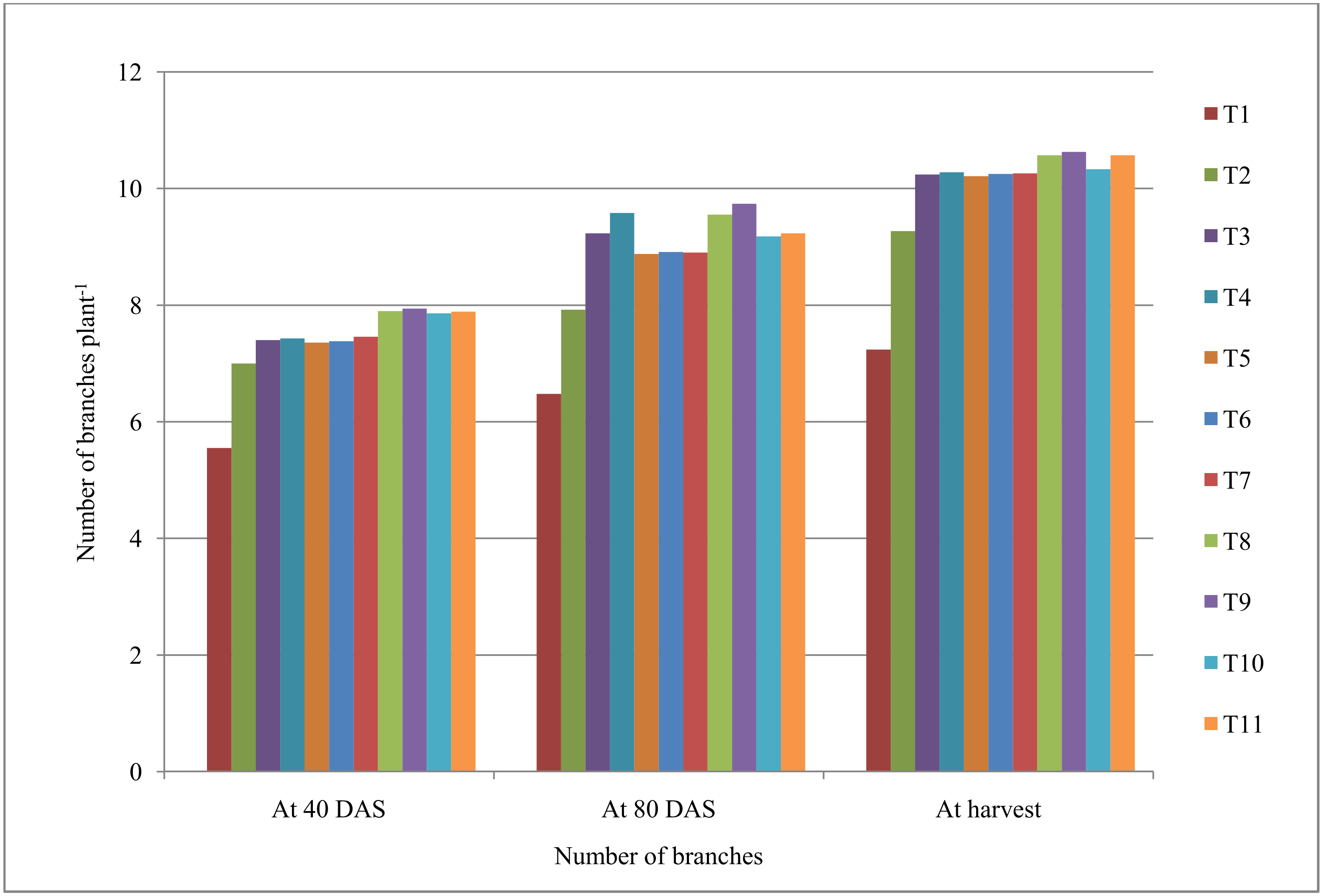


Fig 4.2: Effect of biochar and pig manure on number of branches plant^{-1} of ricebean

observed in control treatment T_1. Pooled data further elucidated that number of branchesat harvest increased by 46.8% and 14.7% over control and RDF (T_2) respectively with application of T_9 treatment. A critical examination of the data indicates that in case of pooled values of number of branches per plant at harvest, T_9 was statistically at par with T_8, T_{10} and T_{11}.

Thus, the combined application of treatments resulted in maximum number of branches per plantwhich may be attributed to slow release of nutrients such as nitrogen, which is an integral part of plant chlorophyll and plays a major role in process of photosynthesis and plant vegetative growth, therefore resulted in more number of branchesYooyen *et al*., 2015; Arunkumar and Thippeshappa, 2020.Similar findings were reported by Hussain *et al*. (2017).

4.1.3 Effect on number of pods per plant and pod length

The data presented in Table 4.3 and fig. 4.3 pertaining to the number of pod per plant of ricebean depicted that significant variations occurred due to the combined application of treatments. As portrayed, biochar treatment along with RDF and pig manure has resulted in significantly higher number of pod plant^{-1} when compared to control. However, effect of wood biochar treatment T_3 and T_4 at the rate of (2.5-5.0 t ha^{-1}) along with RDF was at par with bamboo biochar treatment T_5 and T_6. Maximum number of podper plantwas recorded in treatment T_9 with 31.21 and 32.55 followed by treatment T_8, T_{11} and T_{10} with 30.56 and 31.87, 30.19 and 32.23, 28.77 and 30.91 during 2019 and 2020 respectively, with pooled value of 31.88, 31.22, 31.21 and 29.84. Minimum number of pods per plant was recorded in control treatment T_1.Addition of biochar at higher dose also showed significant increase in number of pod per plant in compare to lower dose of biochar. Further from the pooled data it was observed that number of podper plantincreased by 63.1% and 24.8% over control and RDF (T_2) with application of T_9 treatment. Balanced supply of nutrients may have enabled ricebean crop to produce high pod bearing auxiliary branches leading to higher number of pods per plant. Combined application of biochar and organic manures had synergistic effect on the pods per plant of mungbean due to the increase inadequate nutrients leading to higher vegetative growth, longer linear growth rate and the accumulation of more dry matter resulting in increment in pod number per plant Agboola and Moses (2015). The RDF applied along with biochar is responsible to increase the availability of various nutrients to the soil thereby enhancing the plant growth. These findings are in line with Zhu *et al*., (2015) who reported that biochar amendment may improve crop growth through its nutrients and indirect fertility.

Data related to pod length of ricebean are presented in Table 4.3 and fig 4.4. It is apparent that there was a significant difference among pod length with respect to the given treatments. The maximum pod length was recorded in treatment T_9 with 8.14 and 8.22 cm during first and second year of experimentation respectively, while the pooled value was 8.18 cm. The minimum pod length was observed in control treatment T_1 with 5.54 and 5.88 cm with pooled value of 5.71cm. A critical examination of the data inferred that application of biochar at lower rate (2.5 t ha^{-1}) along with fertilizer and pig manure showed statistically similar pod length as recorded with higher dose of biochar (5.0 t ha^{-1}). However, pod length of ricebean obtained from wood biochar treatments along with pig manure and RDF (treatment T_9) was statistically at par with treatment T_8, T_{10} andT_{11}.

When the plant attain more vigour and strength as a result of sufficient photosynthetic activities, better sunlight and nutrientsin balanced quantities,

Table 4.3: Effect of biochar and pig manure on number of pod plant^{-1} and pod length of ricebean

Treatments	Pod plant^{-1}			Pod length (cm)		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	18.22	20.87	19.54	5.54	5.88	5.71
T_2- RDF(20:40:30)	24.23	24.90	24.56	7.08	7.11	7.09
T_3- RDF+2.5t ha^{-1} WB	29.50	30.25	29.87	7.42	7.47	7.44
T_4 -RDF+5.0 t ha^{-1} WB	30.54	30.57	30.56	7.45	7.51	7.48
T_5 -RDF+2.5t ha^{-1} BB	26.86	29.54	28.20	7.38	7.41	7.40
T_6- RDF+5.0 t ha^{-1} BB	28.53	30.31	29.42	7.41	7.48	7.45
T_7- RDF+2.0 t ha^{-1} PM	29.55	30.22	29.89	7.42	7.46	7.44
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	30.56	31.87	31.22	8.10	8.17	8.14
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	31.21	32.55	31.88	8.14	8.22	8.18
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	28.77	30.91	29.84	7.58	7.68	7.63
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	30.19	32.23	31.21	7.76	7.78	7.77
SEm±	1.11	1.32	0.86	0.44	0.34	0.28
CD (P=0.05)	3.27	3.89	2.46	1.29	1.00	0.79

WB-Wood biochar, BB- Bamboo biochar, PM- Pig manure

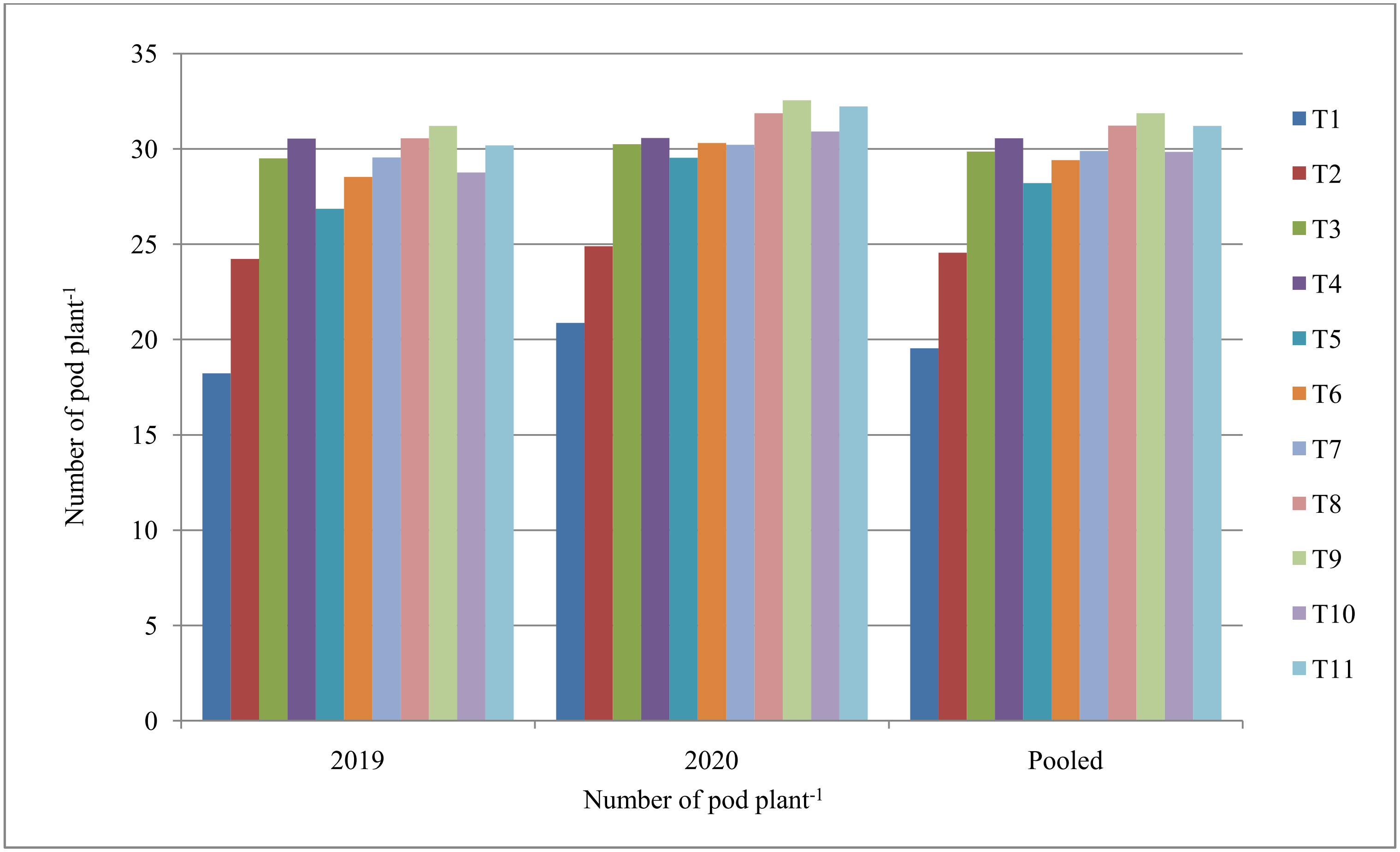


Fig 4.3: Effect of biochar and pig manure on number of pod per plant of ricebean

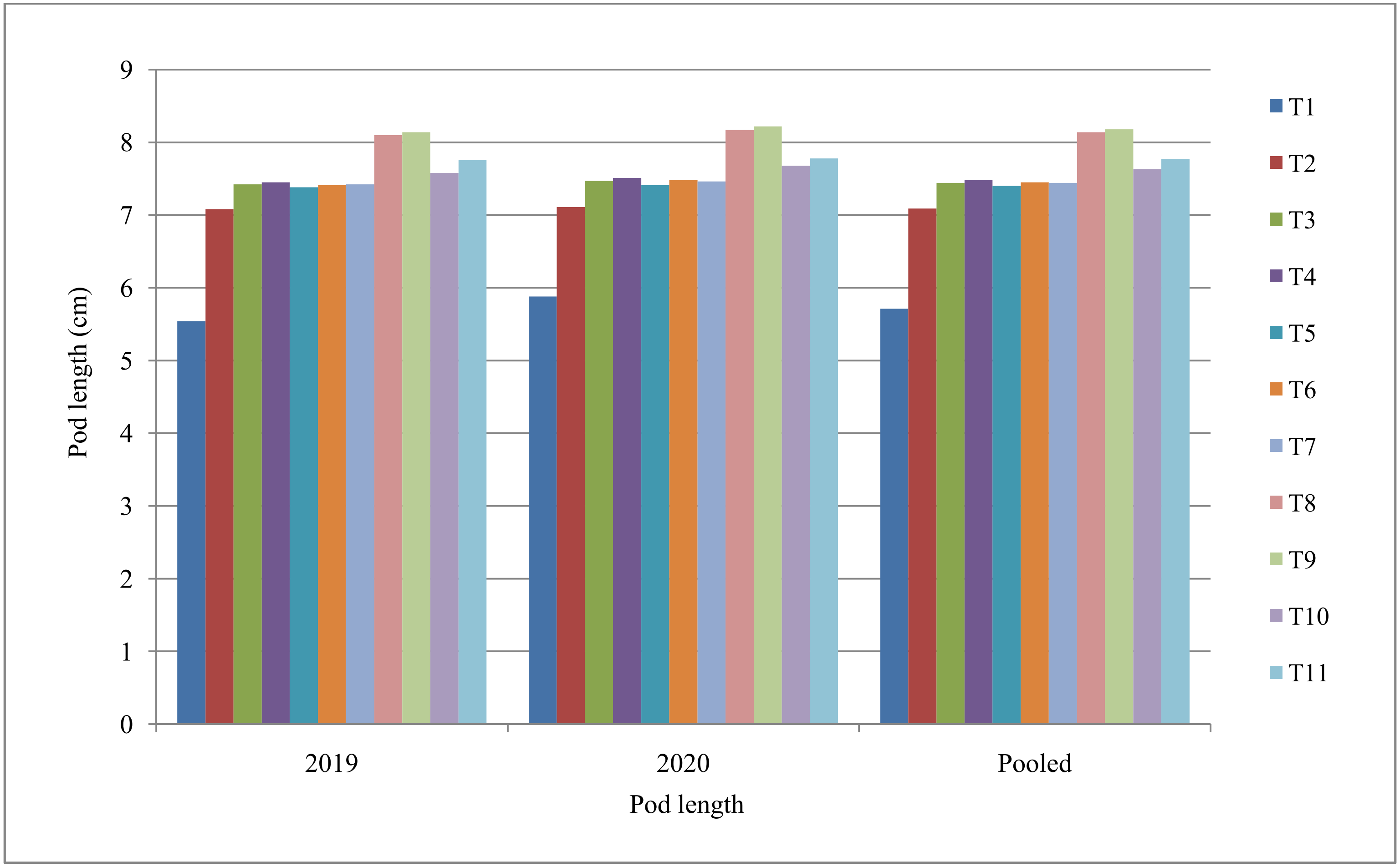


Fig 4.4: Effect of biochar and pig manure on pod length of ricebean

it resulted into increase pod length (Abdul *et al*., 2016).Similarly Lehmann *et al*., (2003a)reported that plant response increases with increasing rate of biochar addition, until it reaches the maximum point where the growth response turns out negative for legumes. This increase could be attributed to residual effect of biochar and pig manure which provided continuous and steady supply of nutrients for better growth and development while ameliorating soil properties. These results are in agreement with Rambuatsaiha *et al*., 2017; Mahto and Dutta, 2018 which recorded an increment in crop yield parameters with prior applied low cost organic manures as compared to fertilizer alone applied treatments.

4.1.4 Effect on number ofseed per pod and test weight

The data recorded on the number of seed per pod are presented in Table 4.4 and fig. 4.5. The data showed significant disparity occurred among the treatments due to the application of RDF, biochar and pig manure during both the years of experimentation. The maximum number of seed per pod 7.18 and 7.20 was recorded with application of treatment T_9 (RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB) during 2019 and 2020 respectively, with pooled value of 7.19. This was followed by treatment T_8, T_{11} and T_{10} with pooled value of 7.18, 6.93 and 6.91. A critical examination of data indicated that treatment T_9 was at par with treatment T_8, T_{10} and T_{11} with regard to pooled number of seeds per pod. The positive effect of different treatments on the number of seed per pod can be ascribed to the sufficient supply of phosphorus with the biochar addition which is responsible to seed formation, thereby enhancing seed production per pod (Arif *et al*., 2017). Similar results were reported by (Yooyen *et al*., 2015) who found out that addition of biochar increased the number of seeds per pod in soybean. It may also be attributed to increase in the level of nutrients released from biochar and pig

Table 4.4: Effect of biochar and pig manure on number of seed pod^{-1} and test weight of ricebean

Treatments	Seed pod^{-1}			Test weight (g)		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	6.03	6.09	6.06	69.74	70.10	69.92
T_2- RDF(20:40:30)	6.26	6.31	6.28	70.14	70.18	70.16
T_3- RDF+2.5t ha^{-1} WB	6.45	6.49	6.47	70.16	70.24	70.20
T_4 -RDF+5.0 t ha^{-1} WB	6.47	6.50	6.49	70.19	70.25	70.22
T_5 -RDF+2.5t ha^{-1} BB	6.42	6.47	6.45	70.15	70.24	70.19
T_6- RDF+5.0 t ha^{-1} BB	6.44	6.48	6.46	70.18	70.24	70.21
T_7- RDF+2.0 t ha^{-1} PM	6.43	6.46	6.45	70.14	70.19	70.17
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	7.16	7.19	7.18	71.11	71.13	71.12
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	7.18	7.20	7.19	71.13	71.16	71.15
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	6.77	7.04	6.91	70.21	70.24	70.23
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	6.78	7.07	6.93	70.23	70.25	70.24
SEm±	0.18	0.21	0.14	0.59	0.72	0.47
CD (P=0.05)	0.54	0.63	0.40	NS	NS	NS

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

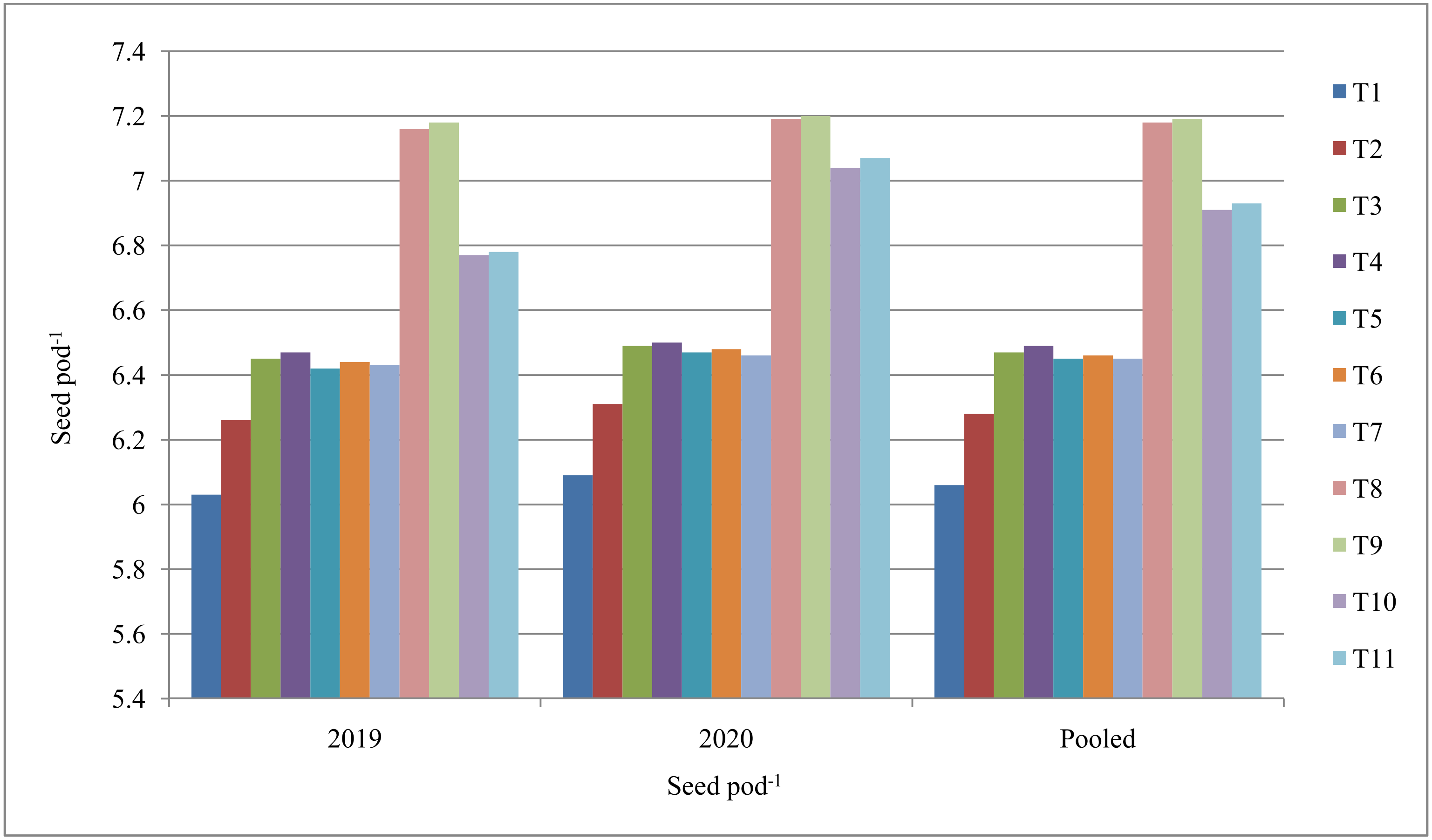


Fig 4.5: Effect of biochar and pig manure on seed pod^{-1} of ricebean

manure which in turn increased the number of pod per plant and seed per pod (Major *et al*., 2010).

A further examination of the data revealed that treatment T_8, T_9, T_{10} and T_{11} in case of pooled values enhanced the number of seed per pod to the extent of 18.4, 18.6, 14.0 and 14.3%, respectively over control while these treatmentsenhanced seed per pod by 14.3, 14.5, 10.0 and 10.3% respectively over RDF alone (T_2). Co-application of inorganic fertilizers along with biochar in leguminous crops may lead to better utilization of nutrients, improving N economy indication higher crop productivity. These findings are in line with Raboin *et al*. (2016) and Garamu *et al*. (2019)

It is apparent from Table 4.4 that test weight exhibited non-significant increasing trend with combined application of RDF, biochar and pig manure. The highest test weight was recorded in treatment T_9 with 71.13 and 71.16 g respectively, with pooled value of 71.15 g. However the addition of the treatment exerted non significant response for test weight during both years of experimentation.

4.1.5 Effect on seed and stover yields

The observation recorded on seed yield of ricebean after harvest as influence by RDF, biochar and pig manure for both the years and pooled has been presented in Table 4.5 and depicted in Fig. 4.6

It is evident from Table 4.5 that the effect of biochar, RDF and pig manure had significant effect on seed yield during both the years of experimentation. The highest seed yield was recorded in treatment T_9 with the value of 1264.42 and 1277.12 kg ha^{-1} during 2019 and 2020 respectively, with pooled value of 1270.77 kg ha^{-1}. The lowest seed yield was found in control treatment T_1 with 678.43 and 725.22 kg ha^{-1}, with pooled value of 701.82 kg ha^{-1}. It was also observed that RDF (T_2) application improved seed yield significantly over control and the treatment with biochar and pig manure enhanced seed significantly over T_2 treatment (RDF). The treatments with 5 t ha^{-1} biochar were at par with those treatments contained 2.5 t ha^{-1} biochar and difference between wood biochar and bamboo biochar containing treatments was also statistically non-significant in case of seed yield. Efficacy of wood and bamboo biochar was at par but higher seed yield was obtained in wood biochar treated plots. Further, evaluation of the data reflected that application of treatment T_9 (RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB) enhanced seed yield by 86.3% and 76.1% during the first and second year of experimentation, respectively while pooled seed yield enhanced to the extent of 81.0% over control. The T_9 treatment enhanced pooled seed yield by 38.7% over RDF (T_2 treatment). Application of RDF (T_2) increased pooled seed yield to the extent of 30.5% over control (T_1). The increment in yield attributes such as pod per plant, pod length and number of seed per pod induced by nutrient release from biochar and organic manure, which could have been taken up by plants for an enhanced partitioning of phothosynthatesleading to increased seed yield Steiner *et al*. (2007a) and Major *et al*. (2010).

Furthermore, the liming effect of biochar eliminate the toxic effect of soil acidity thereby resulted in better crop growth and yield. The yield of crops particularly at acid soil could be increased when biochar is applied in combination with organic and inorganic fertilizers (Singh *et al*., 2016). Similar findings were observed by (Rondon *et al*., 2007) where combined application of biochar and fertilizer, in making nutrients available to plants which in turn increased the yields, improved biological nitrogen fixation, also significantly improved biomass production and yield of common beans. Another possible explanation for increase in seed yield in biochar applied plots may be due to the influence of biochar on soil physio-

Table 4.5: Effect of biochar and pig manure on seed and stover yields of ricebean

Treatments	Seed yield (kg ha^{-1})			Stover yield (kg ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	678.43	725.22	701.82	1649.77	1651.61	1650.69
T_2- RDF(20:40:30)	903.43	928.59	916.01	1922.06	1929.21	1925.64
T_3- RDF+2.5t ha^{-1} WB	1062.05	1137.25	1099.65	2362.83	2368.68	2365.76
T_4 -RDF+5.0 t ha^{-1} WB	1149.08	1147.10	1148.09	2430.04	2436.76	2433.40
T_5 -RDF+2.5t ha^{-1} BB	1023.50	1051.40	1037.45	2159.91	2163.45	2161.68
T_6- RDF+5.0 t ha^{-1} BB	1108.72	1141.60	1125.16	2314.85	2319.80	2317.32
T_7- RDF+2.0 t ha^{-1} PM	1125.15	1139.82	1132.49	2332.28	2340.88	2336.58
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	1238.78	1258.09	1248.44	2473.16	2478.50	2475.83
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	1264.42	1277.12	1270.77	2567.31	2590.82	2579.06
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	1118.64	1217.74	1168.19	2480.03	2450.22	2465.12
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	1182.41	1228.33	1205.37	2544.88	2555.50	2550.19
SEm±	39.99	34.97	26.56	41.36	43.59	30.04
CD (P=0.05)	117.96	103.16	75.92	122.01	128.59	85.88

WB- Wood biochar, BB- Bamboo biochar,PM- Pig manure

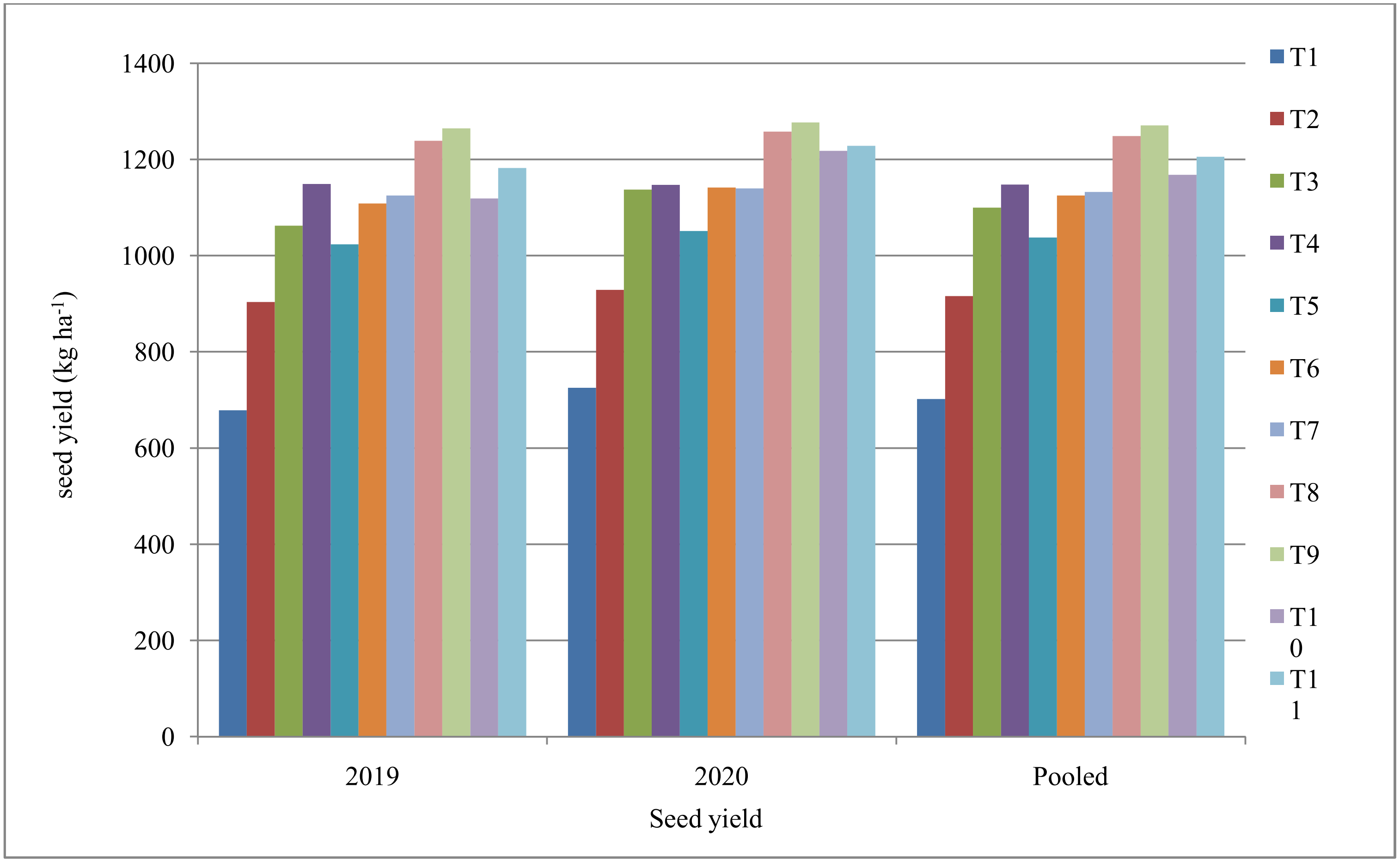


Fig 4.6: Effect of biochar and pig manure on seed yield of ricebean

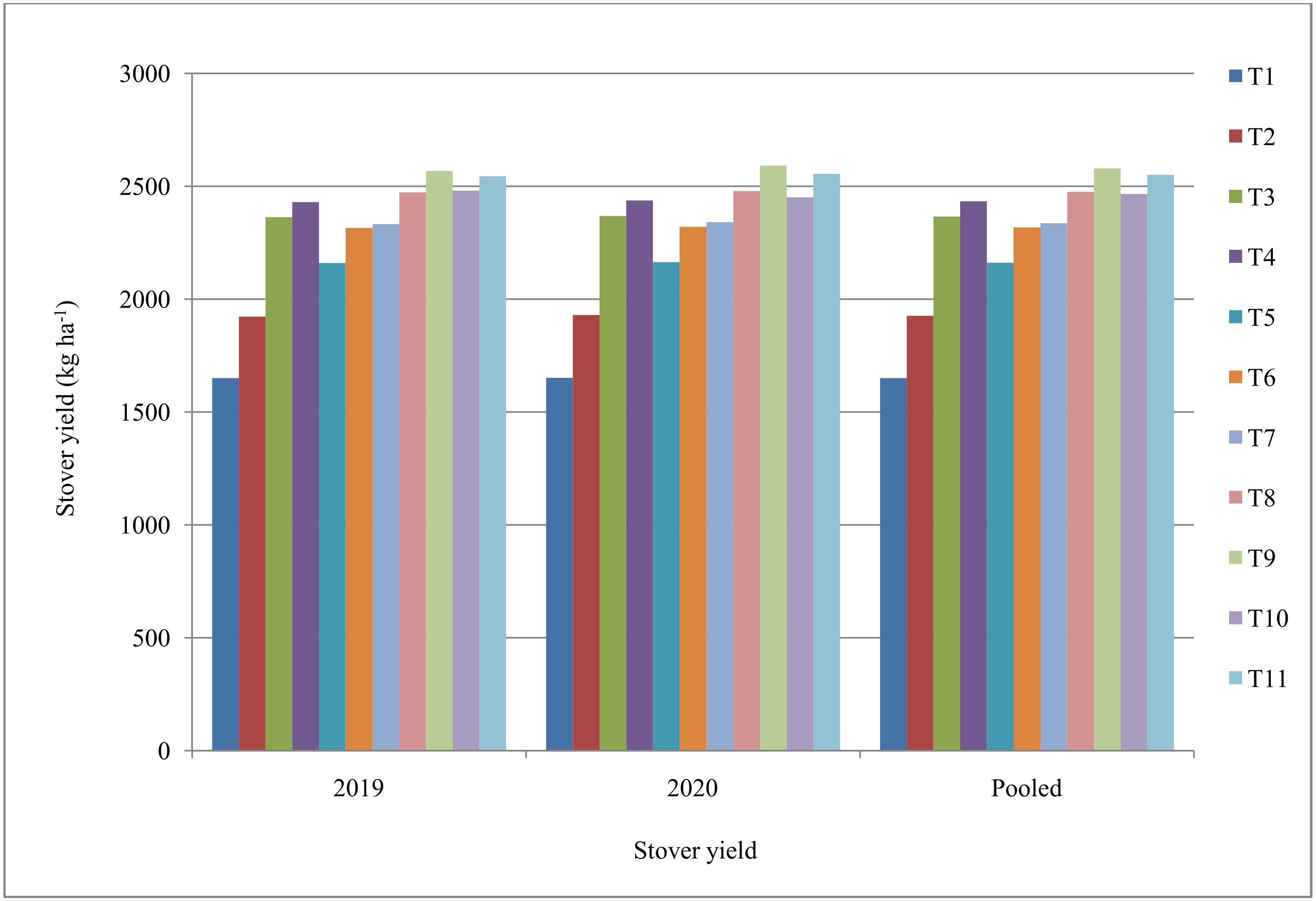


Fig 4.7: Effect of biochar and pig manure on stover yield of ricebean

chemical properties such as increased cation exchange capacity (CEC) thereby providing a medium for adsorption of plant nutrients and improvedconditions for soil micro-organisms (Sohi *et al*., 2009).

The data regarding the stover yield are presented in Table 4.5 and depicted in figure 4.7. A perusal of the data indicates that stover yield of the ricebean increased significantly with the combined application of RDF, biochar and pig manure. Maximum increase in stover yield was observed at treatment T_9 (RDF + 2.0 t ha^{-1} + 5.0 t ha^{-1} WB) during both the year of experimentation. The minimum stover yield was observed in control treatment. Irrespective of treatment and years, the stover yield of ricebean varied from 1649.77 to 2590.82 kg ha^{-1}. A critical examination of the data indicated that application of biocar and pig manure (treatment T_3 to T_{11}) did not increase stover yield significantly over RDF (T_2) during both years of experimentation. Treatment T_9 increased the stover yield to the extent of 55.6%, 56.8% during the first and second year of experimentation over control with pooled value of 56.2%. Similar results were reported by Dharmakeerthi *et al*.(2012) who observedsignificant increase in dry matter yield thatoccurred with increase in levels of biochar and organic manure. This increase could be attributed to improved nitrogen availability in soil, increase rate of photosynthesis which enhanced the fertilizer use efficiency thereby leading to increase plant biomass Steiner *et al*.(2007b).

4.1.6. Effect on nutrient content

4.1.6.1 Nitrogen content

Thedata related to nitrogen content in seed and stover of ricebean is presented in Table 4.6. A perusal of data presented in Table 4.6 indicated that combined effect of biochar, RDF and pig manure on nitrogen content in both seed

Table 4.6: Effect of biochar and pig manure on nitrogen and phosphorus content in seed and stover of ricebean

Treatments	Nitrogen content (%)						Phosphorus content (%)					
	Seed			Stover			Seed			Stover		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	3.13	3.15	3.14	1.14	1.15	1.15	0.24	0.25	0.24	0.11	0.12	0.12
T_2- RDF(20:40:30)	3.21	3.28	3.25	1.24	1.25	1.25	0.30	0.33	0.32	0.13	0.15	0.14
T_3- RDF+2.5t ha^{-1} WB	3.30	3.33	3.32	1.28	1.29	1.29	0.34	0.38	0.36	0.17	0.18	0.17
T_4 -RDF+5.0 t ha^{-1} WB	3.32	3.35	3.34	1.30	1.32	1.31	0.36	0.39	0.38	0.18	0.19	0.18
T_5 -RDF+2.5t ha^{-1} BB	3.31	3.32	3.32	1.26	1.27	1.27	0.33	0.36	0.35	0.16	0.17	0.17
T_6- RDF+5.0 t ha^{-1} BB	3.32	3.34	3.33	1.27	1.30	1.29	0.34	0.37	0.36	0.17	0.18	0.18
T_7- RDF+2.0 t ha^{-1} PM	3.41	3.42	3.42	1.31	1.35	1.33	0.37	0.40	0.38	0.18	0.19	0.18
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	3.42	3.44	3.43	1.35	1.36	1.36	0.39	0.41	0.40	0.19	0.20	0.20
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	3.44	3.46	3.45	1.36	1.38	1.37	0.40	0.42	0.41	0.20	0.21	0.21
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	3.42	3.43	3.43	1.33	1.33	1.33	0.36	0.39	0.38	0.17	0.18	0.18
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	3.43	3.44	3.43	1.34	1.36	1.35	0.38	0.40	0.39	0.18	0.19	0.18
SEm±	0.03	0.02	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	0.074	0.071	0.050	0.071	0.101	0.060	0.029	0.031	0.021	0.017	0.029	0.017

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

and stover had significant result during the two years of experimentation. In seed, the highest nitrogen content was observed in the treatment T_9 with 3.44 and 3.46% during 2019 and 2020 respectively, with pooled value of 3.45% and the lowest nitrogen content was recorded in T_1 with value of 3.13 and 3.15% respectively, with pooled value of 3.14%. Application of RDF (T_2) significantly enhanced nitrogen content in seed as compared to control. It was also observed that application of biochar and pig manure alone or combined,enhances nitrogen content significantly over RDF (T_2). Similarly in stover, the nitrogen content was observed maximum in treatment T_9 with 1.36 and 1.38% during 2019 and 2020 respectively, with pooled value of 1.37%, and minimum nitrogen content was recorded in T_1 with the value of 1.14 and 1.15% respectively, with pooled value of 1.15%. A significant improvement in stover nitrogen content was observed with fertilizer application (T_2) over control. Combined application of biochar and pig manure (T_8 to T_{11}) significantly increased the nitrogen content in stover in comparison to RDF (T_2) during both the years of experimentation. The substantial improvement in N concentration in plants may be related to improved nodulation and N_2 fixation after biochar application leading to increase nutrient content in both seed and stover Mia *et al*. (2014).

Another reason for the enhanced nitrogen content in seed and stover of ricebean application of fertilizer along with biochar might have increased with supply of nutrients those are helpful in nodule formation, improve plant growth and N uptake by reducing the nitrogen mineralization and nitrification while increasing N concentrations to plants Zheng *et al*. (2013). Furthermore, biochar and pig manure application enhanced nitrogen concentration in soil solution which resulted plant to absorb more nitrogen. These results are in accordance with those of Inal*et al*., 2015; Muhammad *et al*., 2017 who reported an increased N concentration in plant of faba beans and maize as a result of addition of biochar in acid soil.

4.1.6.2 Phosphorus content

The data pertaining to phosphorus content in seed and stover of ricebean are presented in Table 4.6. The data shows that with increase in rate of treatment application there was a significant increase in phosphorus content as compare to control treatment in case of both of seed and stover. Irrespective of treatment and years, phosphorus content in seed ranged from 0.24 to 0.42%. Significant increment in phosphorus content of seed was observed with RDF and biochar application. Type of biochar could not produce significant impact on phosphorus content of seed. The highest phosphorus content in seed was recorded in T_9 with0.40 and 0.42% with pooled value of 0.41%, whereas the lowest phosphorus content in seed was observed in T_1 with 0.24 and 0.25% during 2019 and 2020 respectively, with pooled value of 0.24%. From the pooled data it was observed that P content in seed was found to increase by 70.8% over control with application of T_9.

Similarly in stover, the phosphorus content was highest in T_9 with 0.20 and 0.21% during 2019 and 2020 respectively, with pooled value of 0.21%. The lowest phosphorus content was observed in T_1 with 0.11 and 0.12% with pooled value of 0.12%. Further evaluation of pooled data indicated that P content in stover increased to the extent of 75.0% over control. Biochar is a soil amendment that has the potential to increase plant-available P concentration by directly supplying P in the biochar.The significant increase of P content in plant tissue might be as a result of biochar induced increase in soil pH (liming) especially in acidic soils. Liming effect of biochar reduces the adsorption of toxic elements, increases water holding capacity and improved phosphorus concentration Alexandre *et al*. (2019). Lehmann *et al*. (2003b) and Adekiya *et al*. (2019) also observed an increase in P concentration and uptake in plants as a result in increasing biochar application rates. Similar findings were recorded by Gao and De Luca, 2016; Syuhada *et al.*, 2016 who reported that N, P, K concentration of miaze, okra and cassava were greatly improved due to enhanced soil nutrient content supply to crops arbitrated in the presence of biochar.

4.1.6.3 Potassium content

The data regarding the potassium content in seed and stover of ricebean are presented in Table 4.7. A critical examination of the data shows that potassium content in seed and stover of ricebean increased significantly with combined application of biochar, fertilizer and pig manure. It was also observed that combined application of biochar and pig manure (T_8 to T_{11}) significantly enhanced potassium content in seed in comparison to sole RDF treatment (T_2) and control (T_1) during both the years of experimentation. In seeds, maximum potassium content 0.96 and 0.97% was recorded in treatment T_9 during 2019 and 2020 with pooled value of 0.97%, while minimum potassium content was recorded in T_1 with 0.81 and 0.82% with pooled value of 0.82%. Further, from the pooled data it was observed that potassium content in seed increased by 18.2% over control with application of T_9 treatment. Further evaluation of the data also disclosed that effect of T_9 was at par with T_{11} while T_8 was at par with T_{10}.

From the Table 4.7 it is apparent that maximum potassium content in stover was recorded in treatment T_9 with 1.55 and 1.56% with pooled value of 1.55%, respectively during both the years of experimentation, while minimum potassium content was recorded in T_1. Treatment T_9 improved the potassium content in stover of ricebean by 11.5%, over control. A critical examination of the data further revealed that lone application of wood and bamboo biochar along with RDF or combined application of the treatment enhanced potassium content significantly over RDF (T_2). The reason for the increase may be due to the reduction in leaching losses after biochar addition thereby leading to increased in the plant K concentration (Laird *et al*., 2010). Further, porous structure of biochar, large surface area and negative charge may have improved the soil's cation exchange capacity, thus helping in the retention of nutrients such as K. These findings are in line with Inal *et al*. (2015) and Adekiya*et al*. (2019)who observed that addition of biochar and organic manure increased K content in plants. The positive responses due to biochar application were attributed to either nutrient savings or improved fertilizer-use efficiency and can therefore be regarded as an indirect effect of biochars (Wardle *et al*, 1998).

4.1.6.4 Sulphur content

The dataregarding the sulphur content in seed and stover of ricebean has been presented in Table 4.7. It is apparent from the data that maximum sulphur content in seed and stover was recorded in treatment T_9 while minimum was recorded in control treatment (T_1) during 2019 and 2020. It is evident from the Table 4.7 that sulphur content in seed during both the years of experimentation was found to be non-significant, pooled value influenced significantly. A critical examination of the pooled data reflected that combined of application of bamboo biochar along with pig manure and RDF treatment (T_{10} and T_{11}) did not increase sulphur content in seed significantly over RDF (T_2). Further, evaluation indicated an increase in sulphur content in seed by 19.2% on combined application of RDF + 2.0 t ha^{-1} Pig manure + 5.0 t ha^{-1} Wood biochar (T_9). The minimum sulphur content in seed was recorded in control treatment (T_1) during both the years of experimentation. From the pooled data in seed it was also observed that effect of T_9 was statistically was at par with T_8, T_{10} and T_{11}. Increase in sulphur content of pooled data in seed may be due to the presence of numerous micropores on the surface of the biochar which act as a favorable habitat for the growth of microbes

Table 4.7: Effect of biochar and pig manure on potassium and sulphur content in seed and stover of ricebean

Treatments	Potassium content (%)						Sulphur content (%)					
	Seed			Stover			Seed			Stover		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	0.81	0.82	0.82	1.38	1.40	1.39	0.25	0.26	0.26	0.11	0.12	0.12
T_2- RDF(20:40:30)	0.85	0.87	0.86	1.42	1.44	1.43	0.27	0.28	0.27	0.12	0.13	0.13
T_3- RDF+2.5t ha^{-1} WB	0.88	0.89	0.88	1.47	1.49	1.48	0.28	0.29	0.29	0.13	0.14	0.13
T_4 -RDF+5.0 t ha^{-1} WB	0.89	0.90	0.90	1.48	1.50	1.49	0.29	0.30	0.30	0.14	0.15	0.15
T_5 -RDF+2.5t ha^{-1} BB	0.86	0.88	0.87	1.45	1.47	1.46	0.26	0.28	0.27	0.13	0.14	0.14
T_6- RDF+5.0 t ha^{-1} BB	0.87	0.89	0.88	1.46	1.48	1.47	0.27	0.29	0.28	0.14	0.14	0.14
T_7- RDF+2.0 t ha^{-1} PM	0.91	0.92	0.92	1.49	1.51	1.50	0.28	0.29	0.29	0.13	0.15	0.14
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	0.94	0.96	0.95	1.51	1.54	1.52	0.29	0.30	0.30	0.14	0.16	0.15
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	0.96	0.97	0.97	1.55	1.56	1.55	0.30	0.31	0.31	0.15	0.16	0.15
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	0.93	0.94	0.94	1.50	1.53	1.52	0.28	0.29	0.29	0.13	0.14	0.14
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	0.95	0.95	0.95	1.53	1.55	1.54	0.29	0.30	0.29	0.14	0.14	0.14
SEm±	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	0.056	0.040	0.033	0.037	0.042	0.027	NS	NS	0.023	NS	NS	NS

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

when added to the soil, therefore an increase of microbes such as bacteria can easily access plant unavailable sources of sulphur (S) and phosphorus (P) from the soil or the biochar directly which can have a beneficial impact on plant nutrient availability and plant growth ultimately making sulphur content available for plants Warnock *et al*. (2007) and Fox *et al*. (2014). However the result on the effect of sulphur content in stover was found non-significant.

4.1.6.5 Calcium content

The result on calcium content in seed and stover of ricebean are presented in Table 4.8. It is apparent from the data that maximum calcium content in both seed and stover was recorded in T_9 with combined application of RDF, biochar and pig manure (RDF + 2.0 t ha^{-1} Pig manure + 5.0 t ha^{-1} Wood biochar), whereas the minimum calcium content in seed and stover was recorded in control treatment T_1 during both the years of experimentation. Among the biochars, wood biochar showed higher calcium content than bamboo biochar with similar application rate. Effect of RDF, biochar and pig manure was statistically insignificant during second year and pooled value.

A critical examination of the data revealed that pooled calcium content in seed increased from 0.11% to 0.15%. Application of the treatment T_9 enhanced pooled calcium content in seed to the extent of 36.4% over control and 25.0% over RDF (T_2). It was also observed that application of biochar and pig manure alone or combined did not significantly enhanced the calcium content in seed over RDF (T_2) during 2019. Further, the data revealed that treatment T_4 was statistically at par with T_3 while T_6 was at par with T_5, signifying that application of two different biochar at same rate had almost similar effect on calcium content in seed. However, the calcium content in stover during both the years of experimentation was found to be non-significant. Whereas, the pooled data of calcium content in

Table 4.8: Effect of biochar and pig manure on calcium and magnesium content in seed and stover of ricebean

Treatments	Calcium content (%)						Magnesium content (%)					
	Seed			Stover			Seed			Stover		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	0.10	0.12	0.11	0.21	0.22	0.21	0.05	0.06	0.06	0.14	0.15	0.15
T_2- RDF(20:40:30)	0.11	0.13	0.12	0.22	0.23	0.23	0.06	0.07	0.07	0.15	0.16	0.16
T_3- RDF+2.5t ha^{-1} WB	0.12	0.14	0.13	0.23	0.24	0.23	0.07	0.08	0.08	0.16	0.17	0.17
T_4 -RDF+5.0 t ha^{-1} WB	0.13	0.14	0.14	0.24	0.25	0.25	0.08	0.08	0.08	0.17	0.18	0.17
T_5 -RDF+2.5t ha^{-1} BB	0.11	0.12	0.11	0.22	0.22	0.22	0.07	0.07	0.07	0.16	0.17	0.17
T_6- RDF+5.0 t ha^{-1} BB	0.12	0.13	0.12	0.23	0.23	0.23	0.08	0.07	0.07	0.17	0.17	0.17
T_7- RDF+2.0 t ha^{-1} PM	0.11	0.13	0.12	0.23	0.24	0.23	0.07	0.08	0.08	0.17	0.18	0.18
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	0.13	0.14	0.14	0.24	0.25	0.24	0.08	0.08	0.08	0.18	0.19	0.18
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	0.14	0.15	0.15	0.25	0.26	0.25	0.08	0.09	0.08	0.19	0.20	0.19
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	0.12	0.13	0.12	0.22	0.23	0.22	0.07	0.07	0.07	0.17	0.18	0.18
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	0.13	0.14	0.14	0.23	0.25	0.24	0.07	0.08	0.07	0.18	0.18	0.18
SEm±	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	0.022	NS	NS	NS	NS	0.021	NS	NS	NS	NS	NS	0.021

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

stover inferred percent increase from 0.21% to 0.25% which was statistically significant. Application of treatment T_9 enhanced the calcium content in stover to the extent of 19.0% over control and 8.6% over RDF (T_2). Further, the pooled data also revealed that the effect of T_9 was statistically at par with T_8 and T_{11}. Miranda *et al*. (2017) and Alexandre *et al*. (2019) reported that dislocation of calcium and magnesium from the sites of exchange to the soil solution where the nutrient may have leached leading to decline in the calcium content. Hence this might be the reason for the non- significant effects of the treatment in seed and stover during both the years of experimentation.

4.1.2.6 Magnesium content

Data pertaining to magnesium content in seed and stover is presented in Table 4.8. As evident from the data, magnesium content in seed during both the years of experimentation and pooled value with respect to the application of treatment was found to be non-significant. A possible explanation of the observed phenomenon may be due to the antagonistic effect of potassium-magnesium interaction, where high concentration of potassium in the soil may have interfere with Mg content thereby inhibiting Mg uptake in plantsSenbayram *et al*.(2015).Also as an ion competing for cation exchange reactions, excess calcium may also inhibit Mg concentration in plantsRietra *et al*. (2017) and Alexandre *et al*. (2019). From the Table 4.8 it is evident that magnesium content was more in stover than in seed.However, magnesium content in stover during both years of experimentation was found non-significant. However, effect of treatments was significant in case of pooled magnesium content.A critical examination of the pooled data indicated that maximum magnesium content was recorded in T_9 with 0.19% and minimum was recorded in T_1. It was also observed that application of T_9 treatment was statistically at par with T_8, T_{10} and T_{11}. In case of pooled magnesium content biochar addition might haveenhanced soil pH and therefore nutrients especially basic cations like Ca and Mg, which are not available in acidic soil condition, are made available for the plant uptake and their concentration increased Lehmann *et al*. (2002) and Uzoma *et al*. (2011).

4.1.7 Effect on nutrient uptake

4.1.7.1 Nitrogen uptake

As can be seen from Table 4.9 and fig. 4.8 and 4.9,nitrogen uptake in both seed and stover showed significant effect among the treatments. It was observed that application of wood and bamboo biochar along with RDF alone (T_3 to T_7) significantly enhanced nitrogen uptake in seed of ricebean during both the years of experimentation. From the Table 4.9it is apparent that maximum nitrogen uptake in seed(43.53 and 44.13 kg ha^{-1}) was recorded with treatment T_9 during 2019 and 2020 respectively, with pooled value of 43.83 kg ha^{-1}. A critical examination of the data revealed that combined application of RDF, pig manure and biochar (T_9) augmented pooled nitrogen uptake in seeds by 98.5% over control while 47.4% over RDF (T_2).

Irrespective of years, nitrogen uptake in stover varied from (18.81 to 35.65 kg ha^{-1}) with pooled value of 35.25 kg ha^{-1}. Maximum nitrogen uptake in stover was observed intreatment T_9 (RDF + 2.0 t ha^{-1}PM + 5.0 t ha^{-1} WB)while minimum nitrogen uptake was recorded in control treatment T_1. A critical examination of the data indicated that application of biochar, pig manure and RDF combined or alone application significantly enhanced the nitrogen uptake in stover of ricebean over RDF (T_2) during both the years of experimentation. Further, from pooled data it can be observed that application of treatment T_9augmented nitrogen uptake in stover by 86.2%, over control and 46.8% over RDF (T_2). A deeper analysis of the data further conveyed that treatment T_9 was statistically at par with T_8 while T_{11} was at par with T_{10}. Biochar application serves as a source of

Table 4.9: Effect of biochar and pig manure on nitrogen and phosphorus uptake in seed and stover of ricebean

Treatments	Nitrogen uptake (kg ha^{-1})						Phosphorus uptake (kg ha^{-1})					
	Seed			Stover			Seed			Stover		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	21.26	22.87	22.07	18.81	19.05	18.93	1.60	1.79	1.70	1.81	2.04	1.93
T_2- RDF(20:40:30)	29.01	30.45	29.73	23.84	24.18	24.01	2.74	3.06	2.90	2.50	2.83	2.67
T_3- RDF+2.5t ha^{-1} WB	35.02	37.91	36.46	30.30	30.57	30.44	3.57	4.33	3.95	4.01	4.19	4.10
T_4 -RDF+5.0 t ha^{-1} WB	38.15	38.46	38.30	31.58	32.16	31.87	4.17	4.44	4.31	4.38	4.54	4.46
T_5 -RDF+2.5t ha^{-1} BB	33.84	34.96	34.40	27.22	27.49	27.36	3.42	3.82	3.62	3.45	3.67	3.56
T_6- RDF+5.0 t ha^{-1} BB	36.80	38.15	37.48	29.47	30.25	29.86	3.80	4.26	4.03	3.94	4.26	4.10
T_7- RDF+2.0 t ha^{-1} PM	38.43	39.03	38.73	30.54	31.68	31.11	4.13	4.56	4.35	4.20	4.36	4.28
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	42.38	43.24	42.81	33.43	33.74	33.58	4.83	5.16	4.99	4.69	4.95	4.82
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	43.53	44.13	43.83	34.84	35.65	35.25	5.01	5.36	5.19	5.14	5.44	5.29
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	38.26	41.72	39.99	32.98	32.73	32.86	4.03	4.75	4.39	4.22	4.40	4.31
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	40.56	42.23	41.39	34.03	34.80	34.42	4.52	4.92	4.72	4.58	4.76	4.67
SEm±	1.44	1.19	0.93	0.71	1.10	0.65	0.17	0.16	0.12	0.14	0.22	0.13
CD (P=0.05)	4.24	3.50	2.67	2.08	3.24	1.87	0.51	0.48	0.34	0.42	0.64	0.37

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

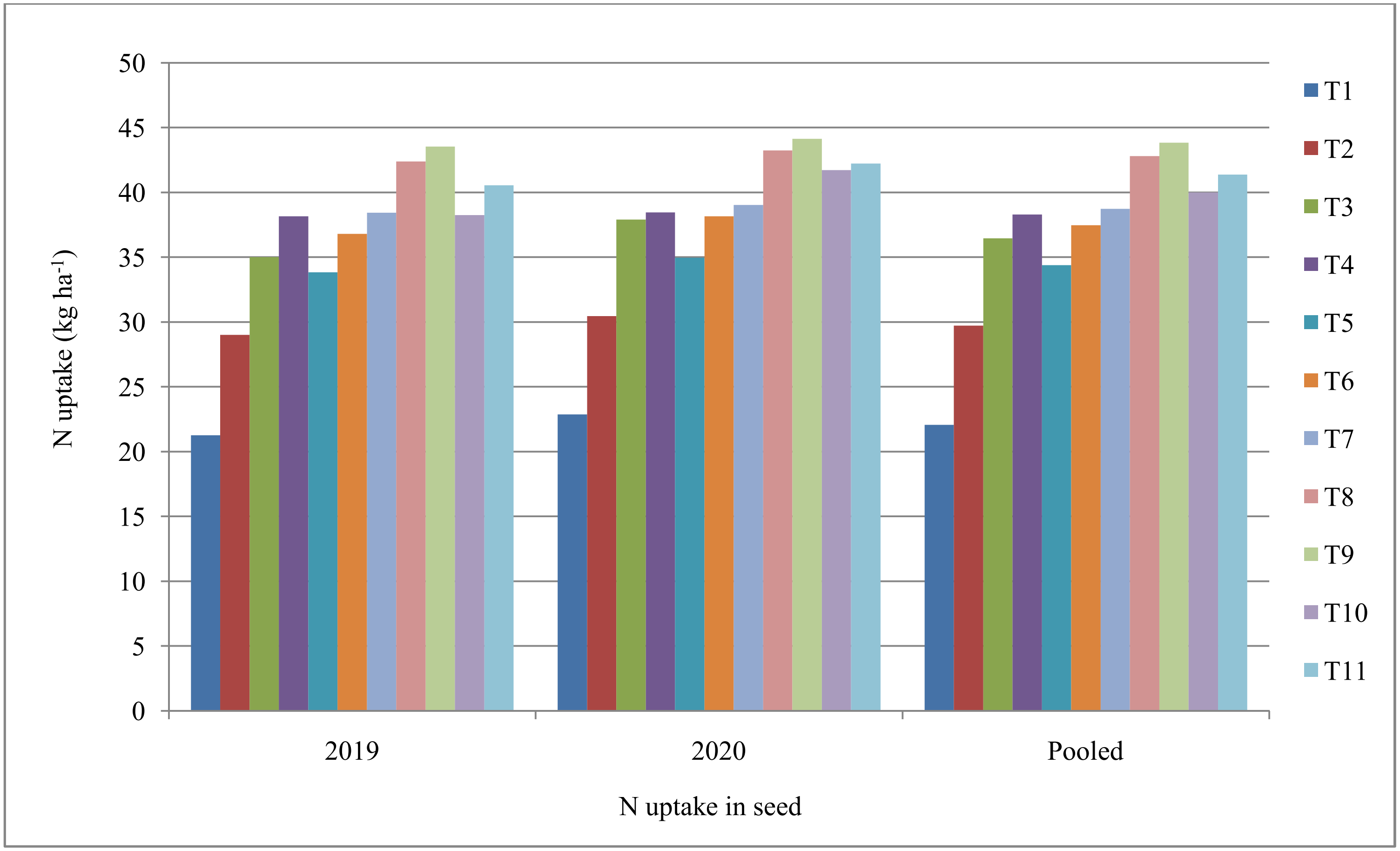


Fig 4.8: Effect of biochar and pig manure on nitrogen uptake in seed of ricebean

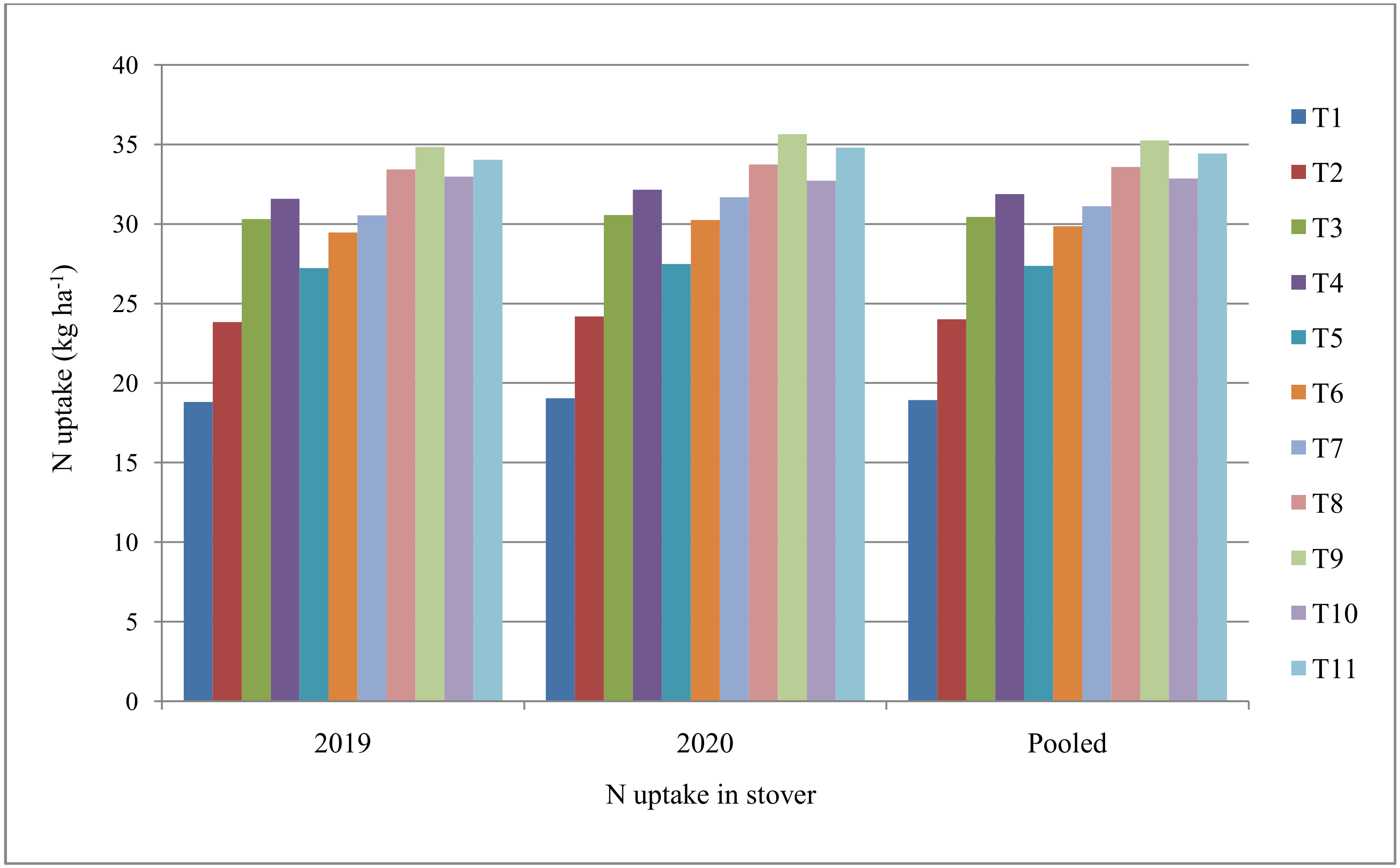


Fig 4.9: Effect of biochar and pig manure on nitrogen uptake in stover of ricebean

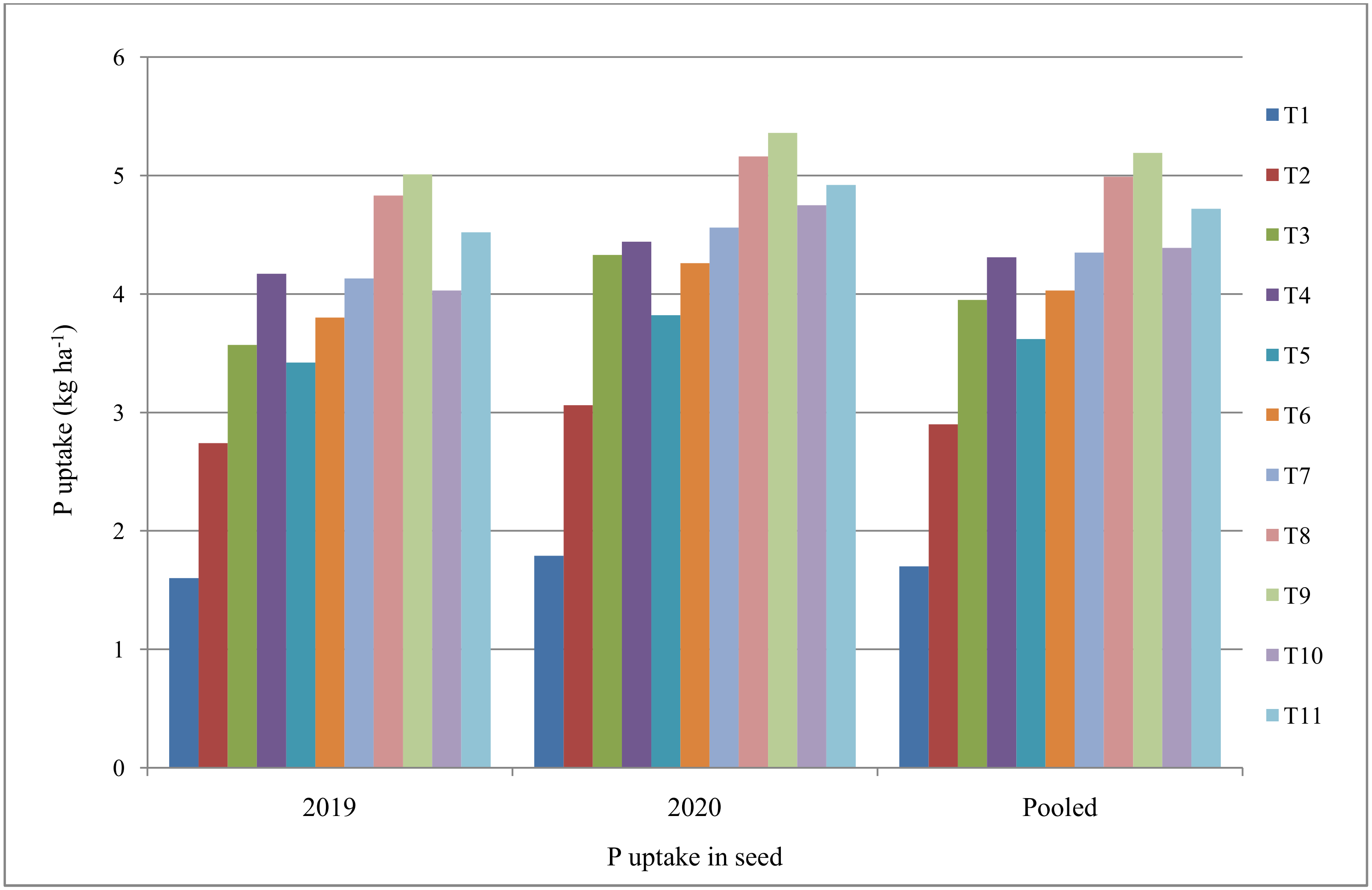


Fig 4.10: Effect of biochar and pig manure on phosphorus uptake in seed of ricebean

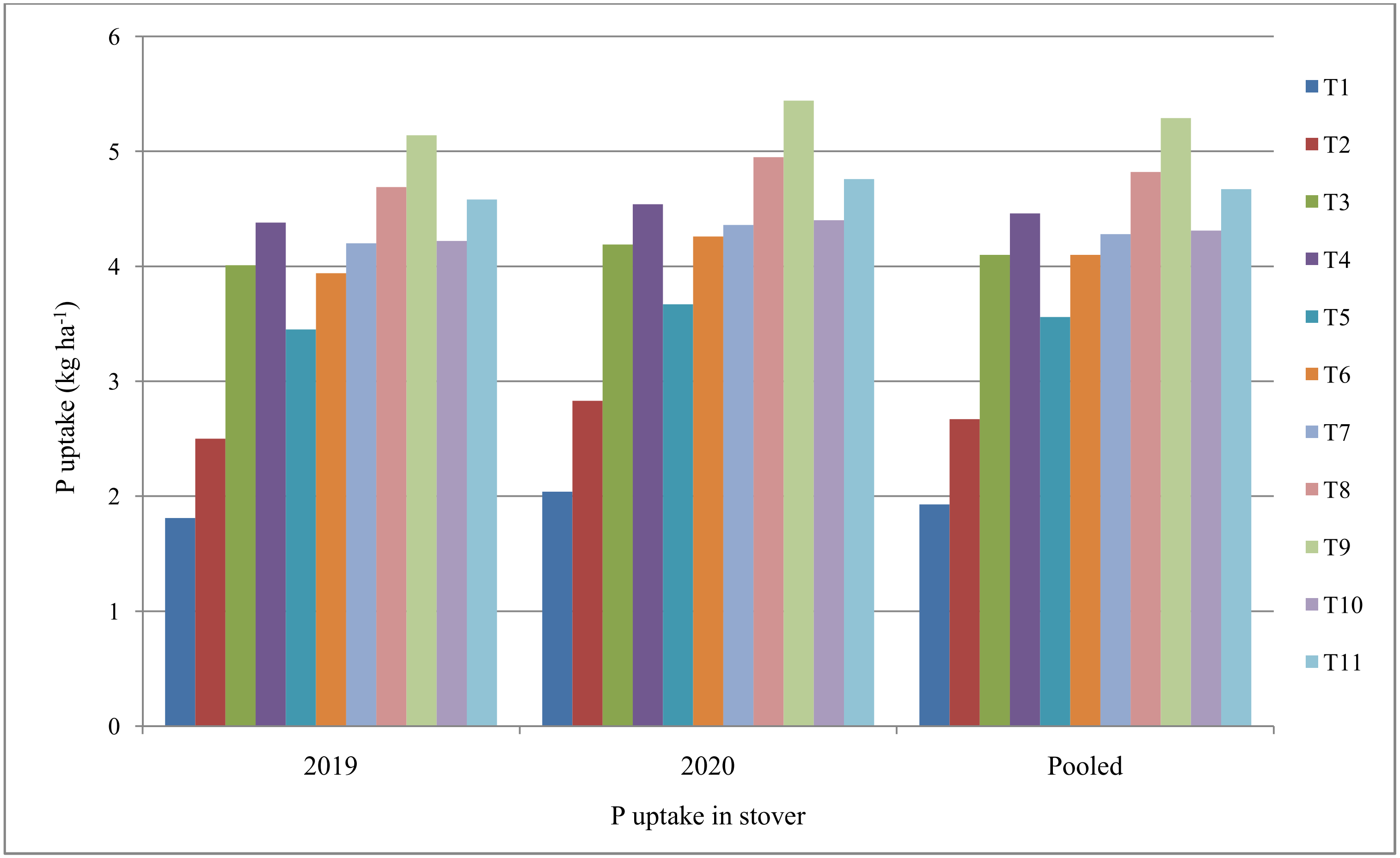


Fig 4.11: Effect of biochar and pig manure on phosphorus uptake in stover of ricebean

nutrients, and its structure and surface has the capacity to hold nutrient ions which ultimately enhances the nutrient availability and its uptake (Kleber *et al*., 2015). Increase in nitrogen uptake followed by biochar application has been reported by Chan *et al*. (2007)which may be due to positive effects of biochar on crop growth and also might be due to increase in pH of acidic soil which may have decreased Al activity, thereby enhanced the availability of N in soil for crop uptake. Similar findings were reported by Steiner *et al*., 2008b; DeLuca *et al*., 2009;Eazhilkrishna *et al*., 2017who found that application of biochar along with organic N source yielded an increase in net nitrification and improves the nitrogen uptake to the plants.

4.1.7.2 Phosphorus uptake

The uptake of phosphorus in ricebean as affected by the application of biochar, RDF and pig manure is shown in Table 4.9 and depicted in fig. 4.10 and 4.11. The result revealed that, maximum P uptake of (5.01 and 5.36 kg ha^{-1})in seed during 2019 and 2020 was recorded for the T_9 treatment, with pooled value of 5.19 kg ha^{-1}, while minimum P uptake was recorded in control treatment (T_1). A critical examination of the data indicated that application of biochar and pig manure (treatment T_3 to T_{11}) showed significant effect on phosphorus uptake of seed over RDF (T_2). Further, it was also observed thattreatment T_9 was statistically at par with T_8 while T_{11} was at par with T_{10}.Similarly in stover the phosphorus uptake was observed maximum in T_9 with 5.14and 5.44 kg ha^{-1} during 2019 and 2020, respectively with pooled value of 5.29 kg ha^{-1}.At lower rate of biochar, uptake of P in ricebean affected significantly withbiochar types treatment. A critical examination of the pooled data further revealed that phosphorus uptake was enhanced by 174.0% in stover with application of T_9 over control and 98.1% over RDF (T_2).

Biochar may have an indirect effect on P availability and uptake by providing a favorable environment for microorganisms that, in turn may haveimprove plants direct access to P through improved mycorrhizal activity Pietikäinen *et al.*, 2000; Warnock *et al.*, 2007; Grossman *et al.*, 2010. Another probable reason for the increase in P uptake may be due to the liming effect of biochar which may have increased the pH of acidic soil while decreasing the Al and H^+activity, ultimately leading to better root growth and nutrient uptake. Increase in rate of biochar application along with organic manure might have increased the biomass production leading to improved P uptake.This is in line with the findings of Milla *et al*. (2013) who opined increase in pH of acidic soil may have decreased the Al activity, hence leading to better root growth and nutrient uptake. Similar findings have also been reported by Nigussie*et al*. (2012) who observed that application of biochar along with fertilizer increased the uptake of phosphorus in plants.

4.1.7.3Potassium uptake

The results on the potassium uptake in seed and stover of ricebean have been presented in Table 4.10 and depicted in fig. 4.12 and 4.13 It is evident from the data that potassium uptake was significantly influenced by the combined application of RDF, pig manure and biochar. From the data it is evident that during 2019 and 2020 maximum potassium uptake in seed(12.11 and 12.43 kg ha^{-1}) recorded with T_9 treatmentwith pooled value of 12.27 kg ha^{-1}while minimum potassium uptake was recorded in control treatment (T_1). A critical examination of the data conveyed that combined application of biochar, pig manure and RDF (T_8 to T_{11}) significantly enhanced the potassium uptake in seed oversole application of RDF treatment (T_2) during both the years of experimentation. Pooled data reflects that application of treatment T_9 enhanced potassium uptake in seed by 114.1% over control and 55.5% over RDF (T_2). Further, it was also perceived that

Table 4.10: Effect of biochar and pig manure on potassium and sulphur uptake in seed and stover of ricebean

Treatments	Potassium uptake (kg ha^{-1})						Sulphur uptake (kg ha^{-1})					
	Seed			Stover			Seed			Stover		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	5.49	5.97	5.73	22.71	23.07	22.89	1.67	1.91	1.79	1.87	2.03	1.95
T_2- RDF(20:40:30)	7.68	8.10	7.89	27.23	27.72	27.47	2.41	2.60	2.51	2.30	2.50	2.40
T_3- RDF+2.5t ha^{-1} WB	9.30	10.12	9.71	34.67	35.22	34.95	3.01	3.26	3.14	3.00	3.31	3.16
T_4 -RDF+5.0 t ha^{-1} WB	10.23	10.37	10.30	36.05	36.48	36.26	3.37	3.40	3.38	3.32	3.74	3.53
T_5 -RDF+2.5t ha^{-1} BB	8.82	9.25	9.04	31.25	31.82	31.53	2.65	2.97	2.81	2.80	3.03	2.92
T_6- RDF+5.0 t ha^{-1} BB	9.62	10.16	9.89	33.80	34.32	34.06	2.95	3.34	3.15	3.16	3.24	3.20
T_7- RDF+2.0 t ha^{-1} PM	10.26	10.44	10.35	34.75	35.36	35.06	3.20	3.30	3.25	3.11	3.59	3.35
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	11.65	12.07	11.86	37.25	38.17	37.71	3.63	3.77	3.70	3.38	3.96	3.67
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	12.11	12.43	12.27	39.71	40.42	40.07	3.84	3.95	3.90	3.76	4.06	3.91
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	10.38	11.47	10.93	37.21	37.59	37.40	3.17	3.53	3.35	3.30	3.52	3.41
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	11.22	11.71	11.47	38.84	39.69	39.27	3.39	3.69	3.54	3.57	3.65	3.61
SEm±	0.46	0.32	0.28	0.68	0.83	0.53	0.18	0.17	0.13	0.26	0.32	0.21
CD (P=0.05)	1.37	0.94	0.80	2.00	2.44	1.53	0.54	0.50	0.36	0.77	0.93	0.59

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

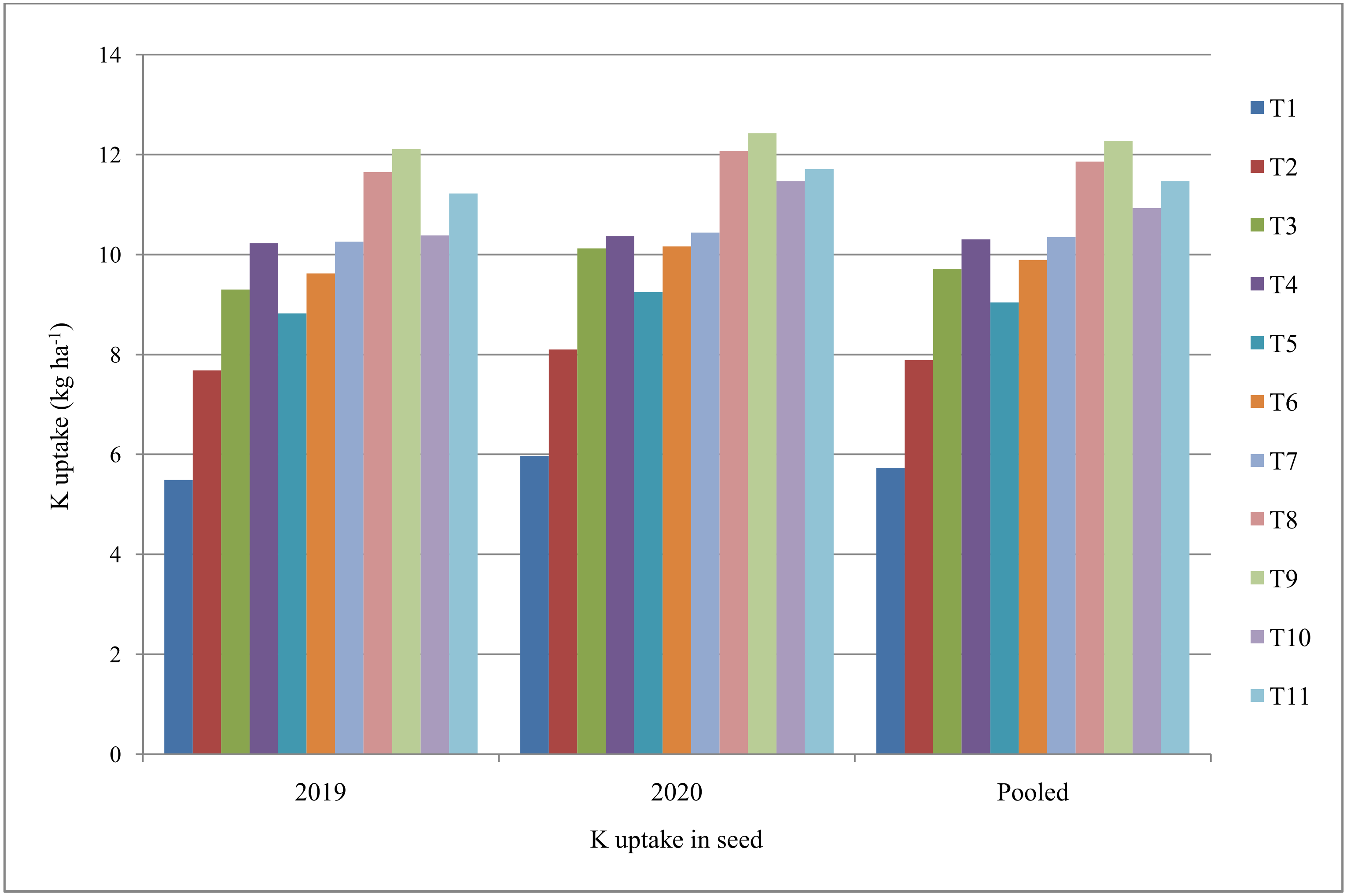


Fig 4.12: Effect of biochar and pig manure on potassium uptake in seed of ricebean

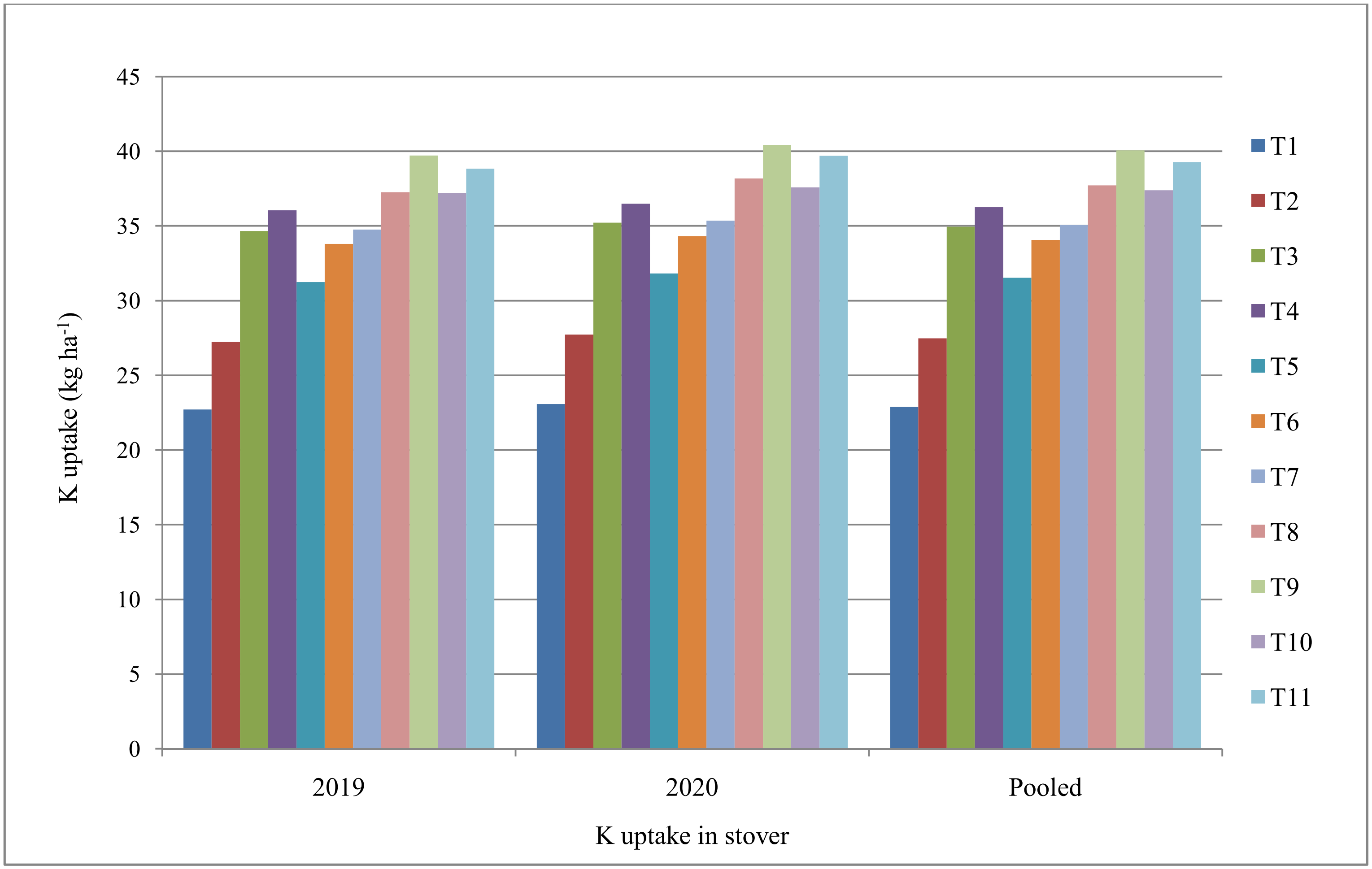


Fig 4.13: Effect of biochar and pig manure on potassium uptake in stover of ricebean

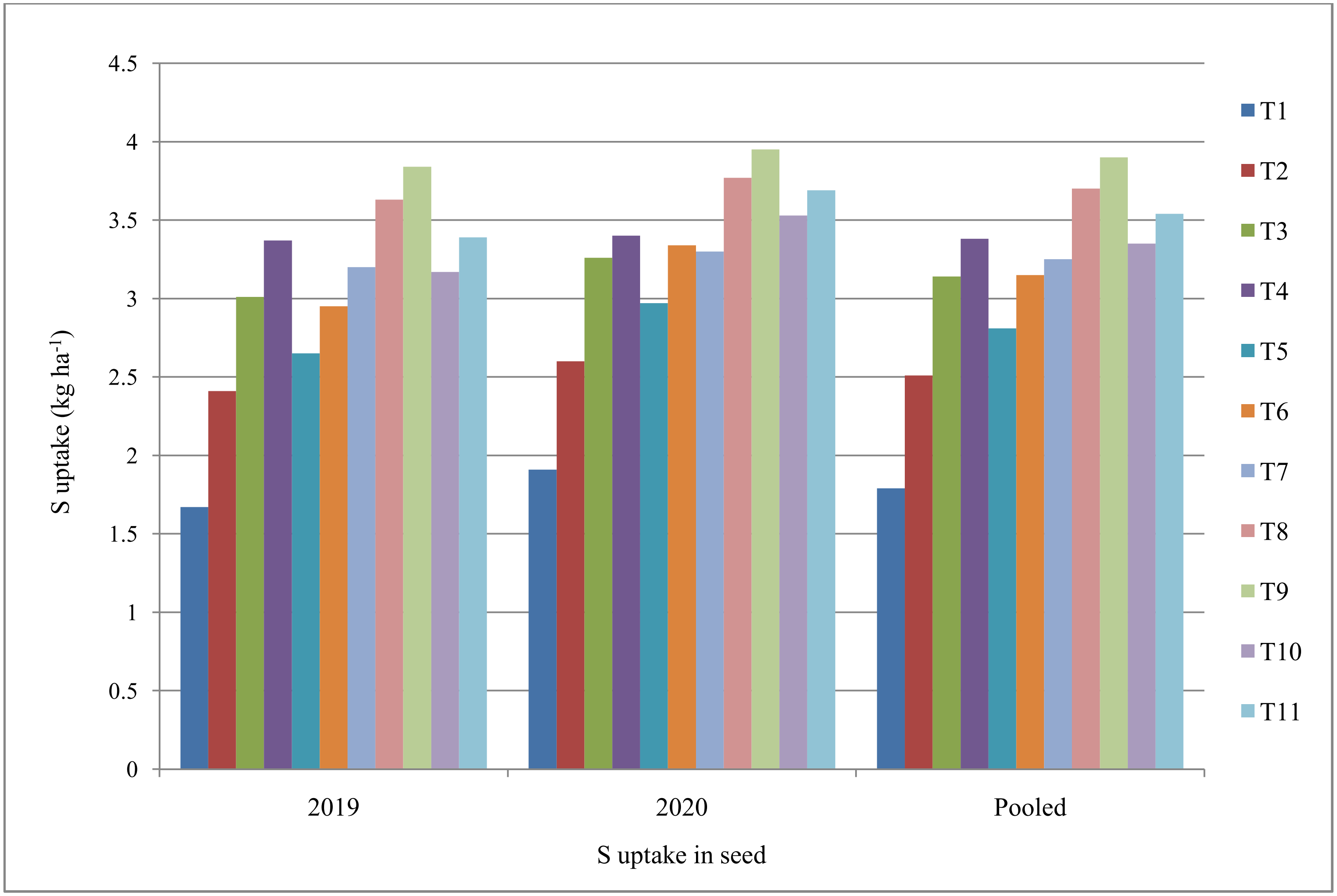


Fig 4.14: Effect of biochar and pig manure on sulphur uptake in seed of ricebean

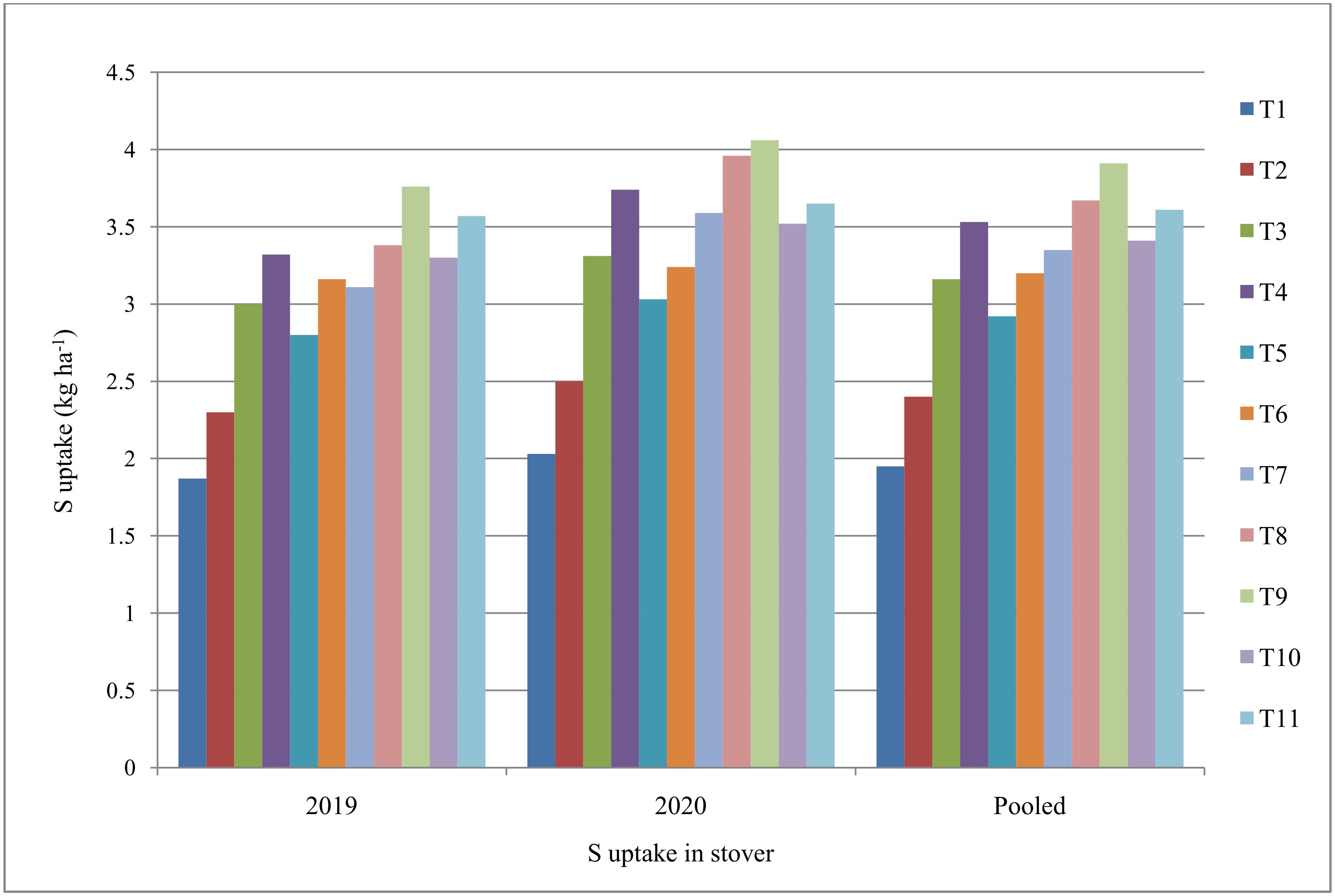


Fig 4.15: Effect of biochar and pig manure on sulphur uptake in stover of ricebean

treatment T_9 was found to be statistically at par with T_8 and T_{11}. Meanwhile in stover irrespective of yearspotassium uptake ranged from 22.71 to 40.42 kg ha^{-1}. Minimum potassium uptake was recorded in control treatment T_1. It was also observed that application of wood and bamboo biochar at similar rate along with RDF (T_3 to T_6) significantly enhanced the potassium uptake in stover over RDF (T_2) and control (T_1).A critical examination of the pooled data indicates that treatment T_9 enhanced potassium uptake in stover by 75.0% over control and 45.8% over RDF (T_2).Application of biochar along with chemical fertilizers and organic manure might have resulted in better proliferation of root system, resulting better biomass production and absorption of potassium, thus leading in increased K uptake in ricebean.Another possible reason may be attributed to biochar acting as clay particle which is able to retain nutrients and immobile water within its micropores. When biochar is applied as a soil amendment this nutrient gets released into the soil and make it available for the plant to uptake Schulz *et al.* (2013). The higher uptake of primary nutrients under combined application of RDF, biochar and pig manure might be due to positive impact of enriched biochar on crop growth as well as increase in N, P and K nutrient content in seed and stover of ricebean along. Nutrient uptake is a function of nutrient content and biomass production. This is in agreement with (Schulz and Glasner 2012; Oram *et al*. 2014), who reported that potassium uptake was enhanced with combined application of treatments in compare to sole application of biochar, fertilizer and pig manure.

4.1.7.4 Sulphur uptake

The data regarding the sulphur uptake in seed and stover are presented in Table 4.10 and depicted in fig. 4.14 and 4.14. From the data it is evident that the maximum sulphur uptake in seed was recorded in T_9 with 3.84 and 3.95 kg ha^{-1}during 2019 and 2020 respectively, with pooled value of 3.90 kg ha^{-1}. Among the biochar types, it was observed that application of wood biochar at the rate of (2.5 to 5.0 t ha^{-1}) along with RDF (T_3 and T_4) significantly enhanced the sulphur uptake in seed over sole application of RDF (T_2) during both the years of experimentation.A critical examination of the pooled data revealed that sulphur content in seed was enhanced by 117.8% with application of treatment T_9 over control (T_1) and 55.3% over RDF (T_2). From the pooled data in seed further elucidated that effect of treatment T_9 was statistically at par with $T_8$and T_{11}.Similarly in stover the sulphur uptake ranged from 1.87 to 3.76 kg ha^{-1} and 2.03 to 4.06 kg ha^{-1} respectively. It was also noted that combined application of RDF, biochar and pig manure (T_8 to T_{11}) significantly enhanced sulphur uptake in stover over sole RDF (T_2) application during 2019 and 2020. A critical analysis of the pooled data perceived that treatment T_9 enhanced sulphur uptake in stover by 100.5% over control treatment (T_1)and 62.9% over RDF (T_2), furthermore treatment T_9 was statistically at par with T_8, T_{10} and T_{11}.

Biochar application enhances the plant nutrient uptake as it affects the permeability of roots making it available to the plants. Furthermore, fertilizer, biochar and pig manure application enhanced the yield as well as sulphur content resulting in more sulphur uptake. Chowdhury *et al*. (2000) reported that compost amendment enhanced available S, thereby improves S uptake. Dhage *et al*.(2014) observedenhanced nutrient concentration, S uptake and availability in soybean.Fox *et al*. (2014) and Zhang *et al*. (2017)also reported that biochar amendment provides biota for microbial populations and thereby enhances S mobilization allowing plants to uptake more Sulphur.

4.1.7.5 Calcium uptake

The data pertaining to calcium uptake in seed and stover is summarized in Table 4.11 and illustrated in fig 4.16 and 4.17.It is apparent from the data that duringboth the years of experimentation, maximum calcium uptake in seed was recorded with treatment T_9 while, minimum calcium uptake was associated with control (T_1). Irrespective of years, calcium uptake in seed varied from 0.69 to 1.96 kg ha^{-1}. During 2020 the treatment effect was found insignificant. A critical examination of the pooled data elucidated that combined application of RDF, biochar and pig manure in (T_8 to T_{11}) significantly enhanced the calcium uptake in seed over sole application of RDF treatment (T_2). Furthermore from the pooled data it was noted that RDF, biochar and pig manure application (T_9) increased the calcium uptake in seed by 141.5% over control (T_1) and 70.6% over RDF (T_2).

Similarly in stover the calcium uptake varied from 3.41 to 6.34 kg ha^{-1} and 3.58 to 6.65 kg ha^{-1} during first and second yearsof experimentation respectively.A significant increase in calcium uptake in stover of ricebean following the combined application of RDF, biochar along with pig manure (T_3 to T_{11}) over sole application of RDF (T_2) and control was observed.Further analysis of the data conveyed that treatment T_9 was statistically at par with treatment $T_{8,}$ T_{10} and T_{11}.

Addition of combined application oftreatments had significant effect on calcium uptake in ricebean.Somebroek (1993) reported that calcium becomes readily available in the soil after biochar application.The potential of calcium uptake by plants is largely dependent on the root cation exchange capacity. The calcium content in biochar replaces monomeric Al species on soil mineral or soil organic matter exchangeable sites which may have helped in enhancing calcium availability for plant uptake (Novak *et al*., 2009). A significant increase in exchangeable Ca level and enhanced Ca uptake after addition of cow manure was reported by (Uzoma *et al*., 2011).Similar findings were reported by (Oguntunde *et al*., 2004;Inal *et al*., 2015;Syuhada *et al*., 2016;Adekiya *et al*., 2019)who observed an increase in P, Ca, Mg and K uptake following biochar application.

Table 4.11: Effect of biochar and pig manure on calcium and magnesium uptake in seed and stover of ricebean

Treatments	Calcium uptake (kg ha^{-1})						Magnesium uptake (kg ha^{-1})					
	Seed			Stover			Seed			Stover		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	0.69	0.84	0.77	3.41	3.58	3.49	0.31	0.46	0.39	2.36	2.42	2.39
T_2- RDF(20:40:30)	1.01	1.17	1.09	4.22	4.43	4.33	0.51	0.68	0.60	2.82	3.15	2.98
T_3- RDF+2.5t ha^{-1} WB	1.22	1.56	1.39	5.43	5.60	5.52	0.77	0.91	0.84	3.87	3.93	3.90
T_4 -RDF+5.0 t ha^{-1} WB	1.40	1.60	1.50	5.92	6.08	6.00	0.88	0.96	0.92	4.04	4.30	4.17
T_5 -RDF+2.5t ha^{-1} BB	1.15	1.22	1.19	4.82	4.83	4.83	0.67	0.74	0.71	3.53	3.60	3.56
T_6- RDF+5.0 t ha^{-1} BB	1.35	1.44	1.40	5.32	5.34	5.33	0.85	0.81	0.83	3.86	3.86	3.86
T_7- RDF+2.0 t ha^{-1} PM	1.20	1.43	1.32	5.28	5.62	5.45	0.74	0.96	0.85	4.04	4.14	4.09
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	1.54	1.68	1.61	5.94	6.11	6.02	0.96	1.05	1.01	4.36	4.63	4.50
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	1.75	1.96	1.86	6.34	6.65	6.50	1.01	1.11	1.06	4.79	5.09	4.94
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	1.29	1.58	1.44	5.46	5.55	5.50	0.73	0.89	0.81	4.30	4.50	4.40
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	1.56	1.78	1.67	5.94	6.31	6.13	0.82	0.95	0.89	4.59	4.60	4.60
SEm±	0.07	0.24	0.12	0.29	0.24	0.19	0.11	0.14	0.09	0.25	0.23	0.17
CD (P=0.05)	0.22	NS	0.35	0.86	0.71	0.54	0.33	NS	0.26	0.73	0.67	0.48

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

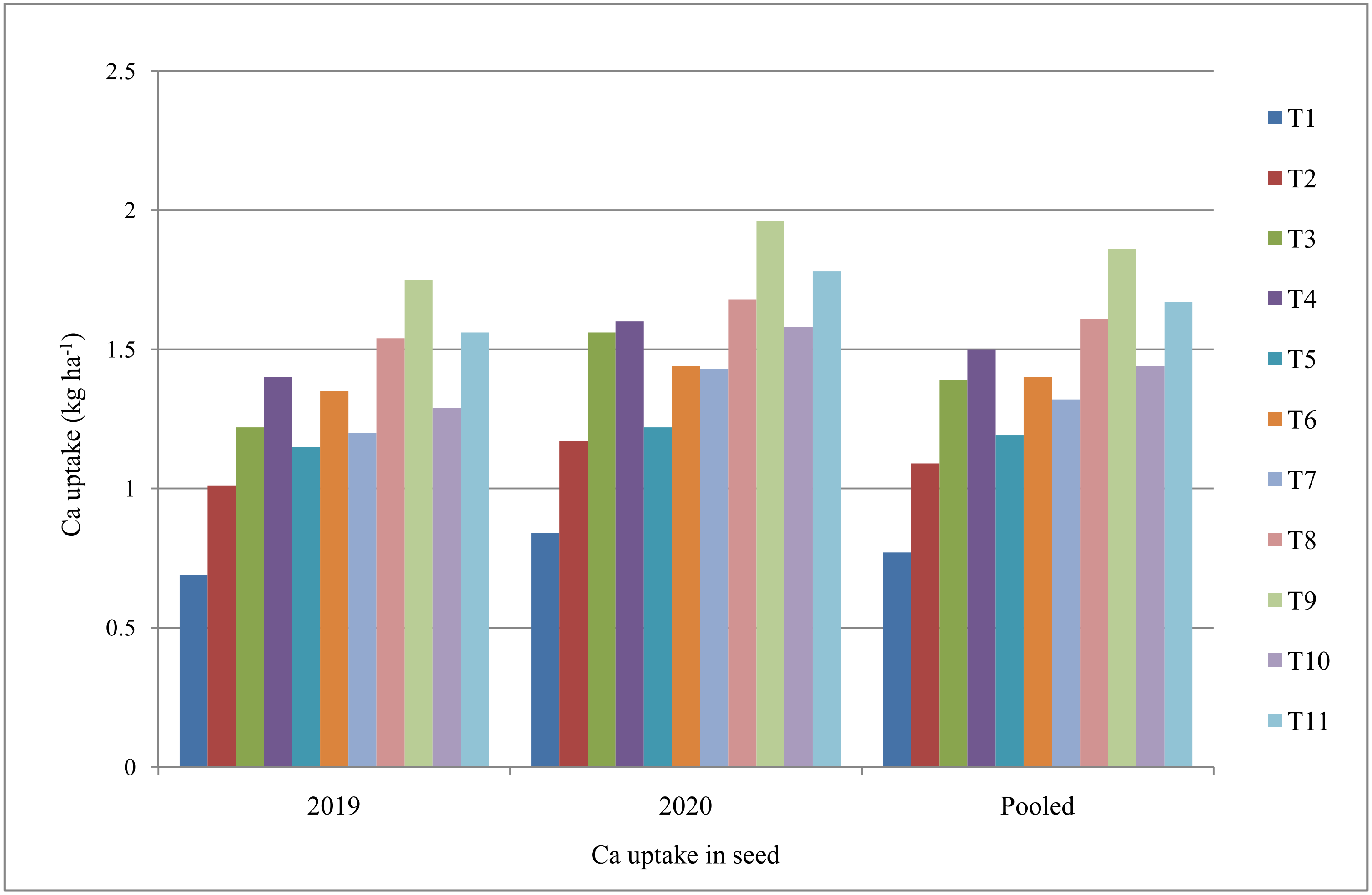


Fig 4.16: Effect of biochar and pig manure on calcium uptake in seed of ricebean

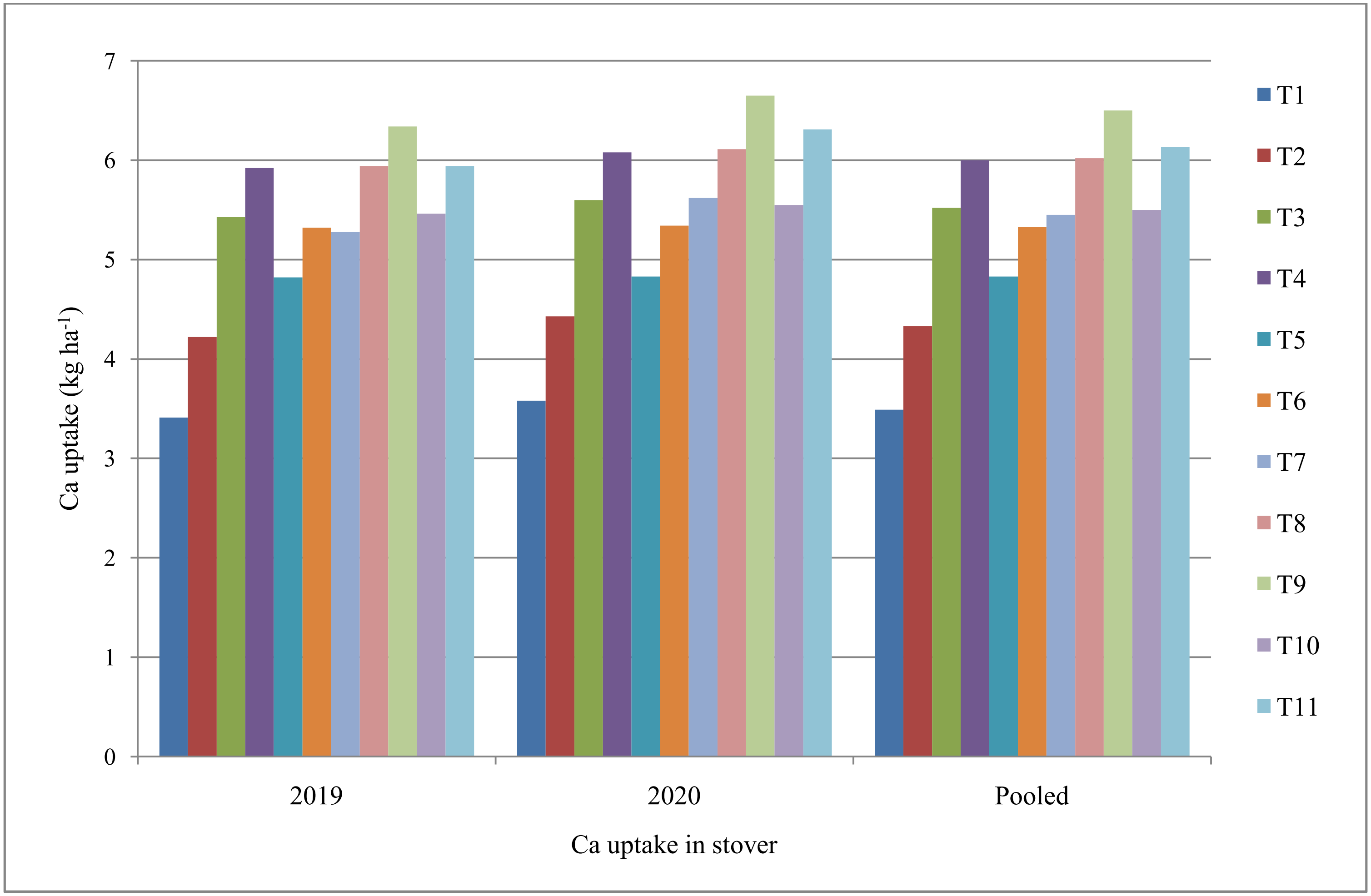


Fig 4.17: Effect of biochar and pig manure on calcium uptake in stover of ricebean

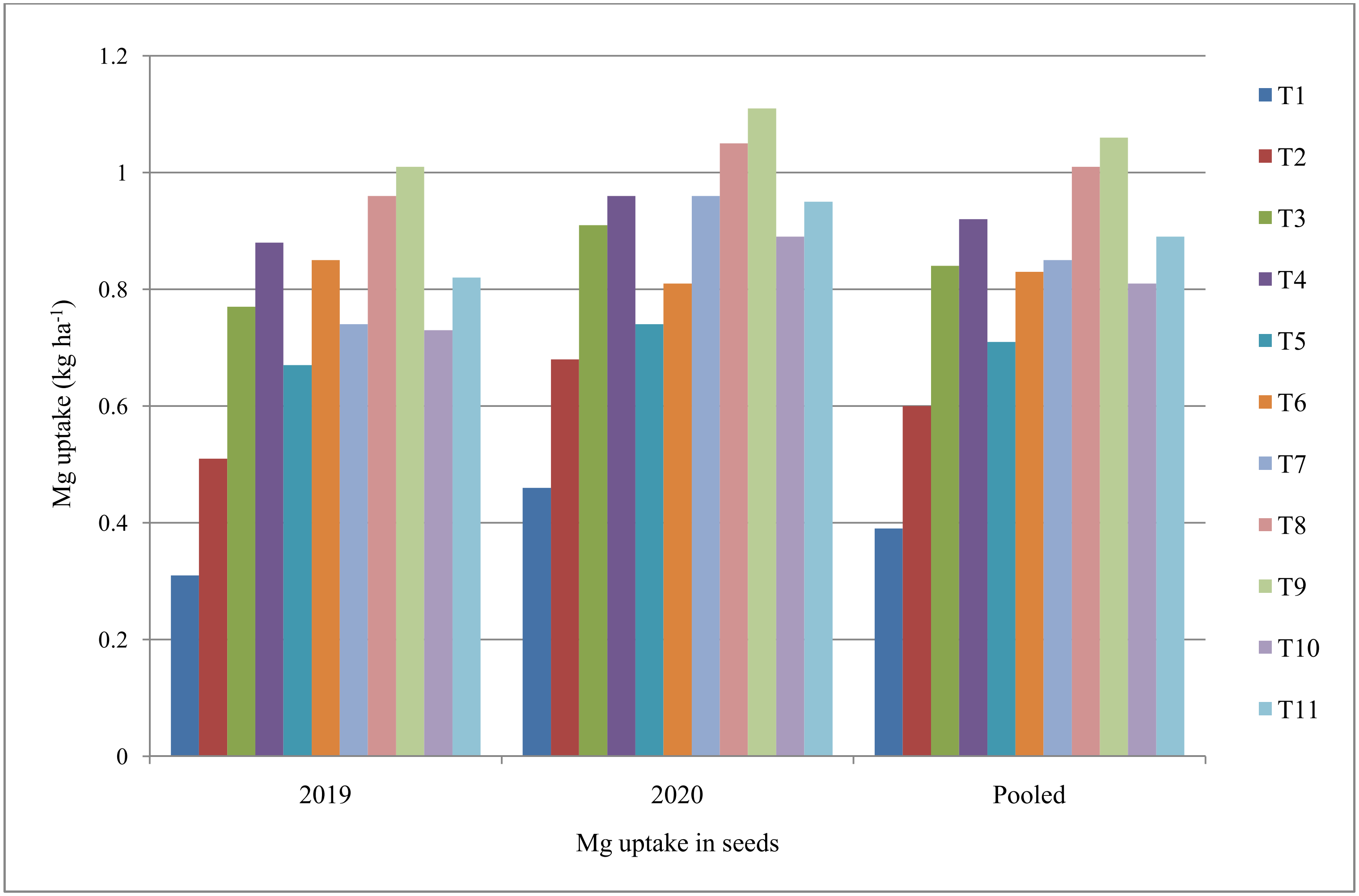


Fig 4.18: Effect of biochar and pig manure on magnesium uptake in seed of ricebean

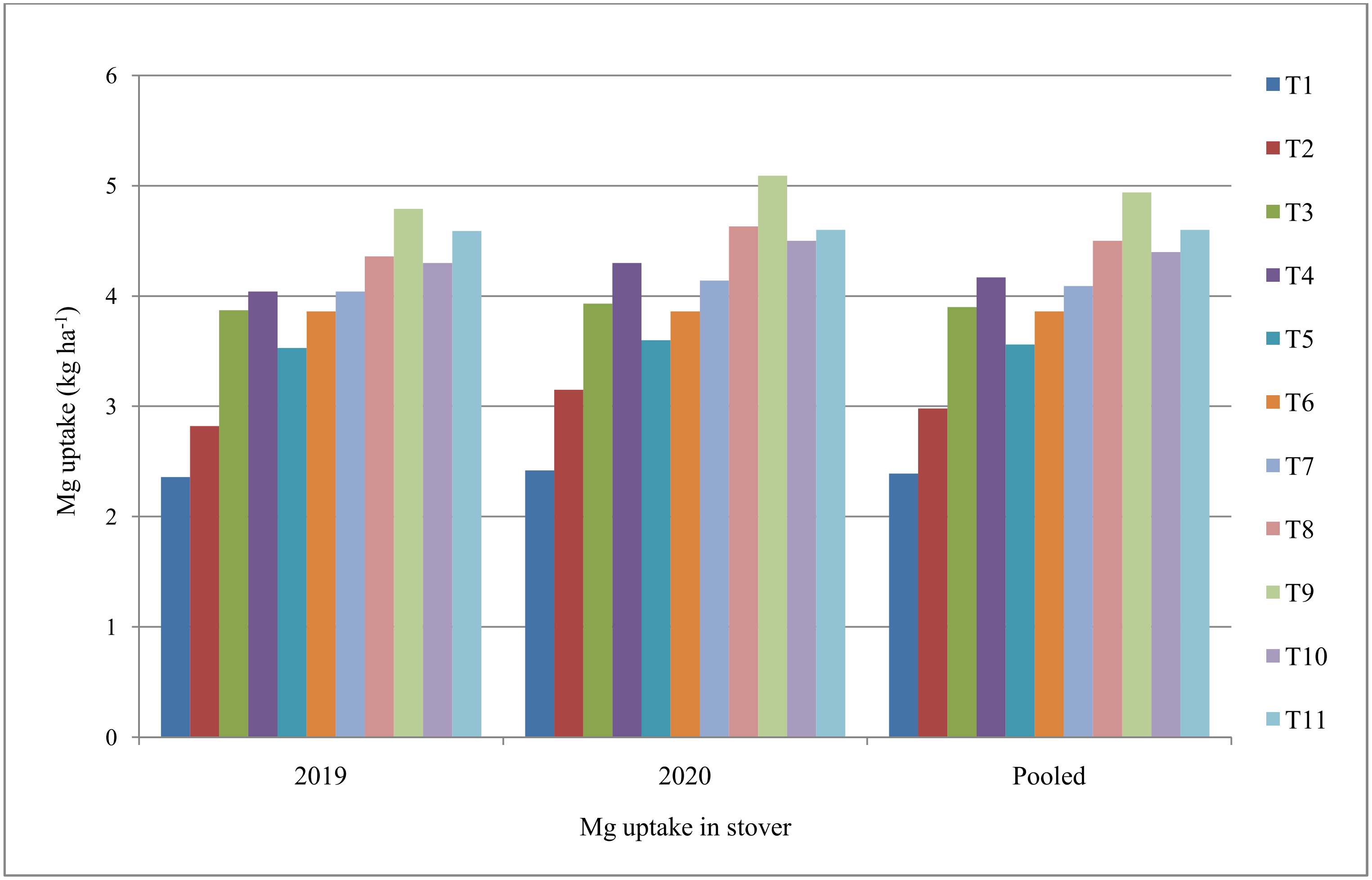


Fig 4.19: Effect of biochar and pig manure on magnesium uptake in stover of ricebean

4.1.7.6 Magnesium uptake

The dataregarding the effect of biochar and pig manure on magnesium uptake by ricebean in seed and stoveris presented in Table 4.11 and fig. 4.18 and 4.19. The higher uptake of magnesium in seed was influenced by combined application of RDF, biochar and pig manure(T_9) with 1.01 kg ha^{-1}during 2019, whereas the treatment effect was found non-significantduring 2020. From the pooled data it was inferred that application of treatment T_9 enhanced magnesium uptake in seed by 171.7% over control (T_1) and 76.6% over sole application of RDF (T_2). A critical examination of the data revealed that effect of $T_9$was statistically at par with T_8while T_{11}at par with T_{10} in magnesium uptake in seed during 2019 and pooled.

In stover, during both the years of experimentation maximum magnesium uptake was recorded in T_9 treatment which varied from 2.36 to 4.79 kg $ha^{-1}$and 2.42to 5.09 kg ha^{-1}. It was also observed that application of types of biochar along with RDF or combined with pig manure (T_3 to T_{11}) significantly enhanced magnesium uptake in stover over sole application of RDF (T_2) and control treatment (T_1). Further, analysis of the data depicted that treatment T_9 was statistically at par with T_8, T_{10} and T_{11} during both the years of experimentation. From the pooled data it was conveyed that magnesium uptake in stover was enhanced to the extent of 106.6% over control and 65.7% over RDF (T_2).

Increment in magnesium uptake might be due to increase in seed and stover yield as well as magnesium concentration in plants with application of treatments. Similar results were reported by Uzoma *et al*. (2011) who observed significantly high level of magnesium uptake in maize grain when biochar was applied insoil in compare to control.

4.2 Effect on soil properties

4.2.1 Soil pH and organic carbon

The result obtained on the soil pH and organic carbon in the soil after harvest in various treatments has been presented in Table 4.12 and fig. 4.20 and 4.21.It is apparent from the Table 4.12 that application of wood and bamboo biochar along with RDF, pig manure significantly increased pH of the soil during both the years of experimentation. From the data, it can be observed that during 2019 and 2020 maximum pH of the soil was recorded under T_9 treatment with 6.0 and 6.02respectively, with pooled value of 6.01 while minimum pH was observed in control(T_1) with a pooled value of 5.23. It was also found that application of biochar and pig manure (T_3 to T_{11}) solely or combinedly enhanced soil pH significantly over RDF (T_2) and control (T_1). Pooled pH of post harvest soil was increased by 14.9% with application of T_9 treatment over control.At lower rate, wood biochar (T_3) significantly increased soil pH as compared to bamboo biochar (T_5). It might be due to higher calcium content in wood biochar. The increase in soil pH following the combined application of biochar and pig manure can be attributed to the release of basic cation into the soil readily participating in exchange reaction which might have suppressed the Al^{3+} and H^+ ion on soil exchange complex. These finding are similar to those of (Rodrigquez *et al*., 2009; Chintala *et al*., 2014; Abewa *et al*.,2014) who observed increased soil pH with combine application of manure and biochar.

Further, the Table 4.12 and fig. 4.21also shows the effect of biochar, and pig manure on organic carbon in the soil after harvest was significant. It was also observed that during 2019 and 2020, maximum organic carbon was recorded under T_9 (18.80 and 18.82 g ka^{-1})with a pooled value of 18.81 g kg^{-1}, while minimum was recorded in T_1 with pooled value of 16.87 g kg^{-1}. Application of treatment T_9 enhanced the pooled organic carbon by 11.4% over

Table 4.12: Effect of biochar and pig manure on soil pH and organic carbon of post harvest soil

Treatments	Soil pH			Organic carbon (g kg^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	5.22	5.24	5.23	16.86	16.88	16.87
T_2- RDF(20:40:30)	5.24	5.28	5.26	16.88	16.92	16.90
T_3- RDF+2.5t ha^{-1} WB	5.71	5.74	5.72	18.70	18.75	18.72
T_4 -RDF+5.0 t ha^{-1} WB	5.74	5.76	5.75	18.78	18.80	18.79
T_5 -RDF+2.5t ha^{-1} BB	5.60	5.62	5.61	18.62	18.65	18.64
T_6- RDF+5.0 t ha^{-1} BB	5.70	5.69	5.70	18.65	18.68	18.67
T_7- RDF+2.0 t ha^{-1} PM	5.30	5.32	5.31	18.60	18.62	18.61
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	5.76	5.79	5.78	18.76	18.79	18.77
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	6.00	6.02	6.01	18.80	18.82	18.81
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	5.64	5.67	5.66	18.64	18.68	18.66
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	5.75	5.78	5.76	18.68	18.70	18.69
SEm±	0.03	0.03	0.02	0.13	0.14	0.09
CD (P=0.05)	0.079	0.086	0.057	0.38	0.40	0.27
Initial values	5.20	5.22		16.80	16.85	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

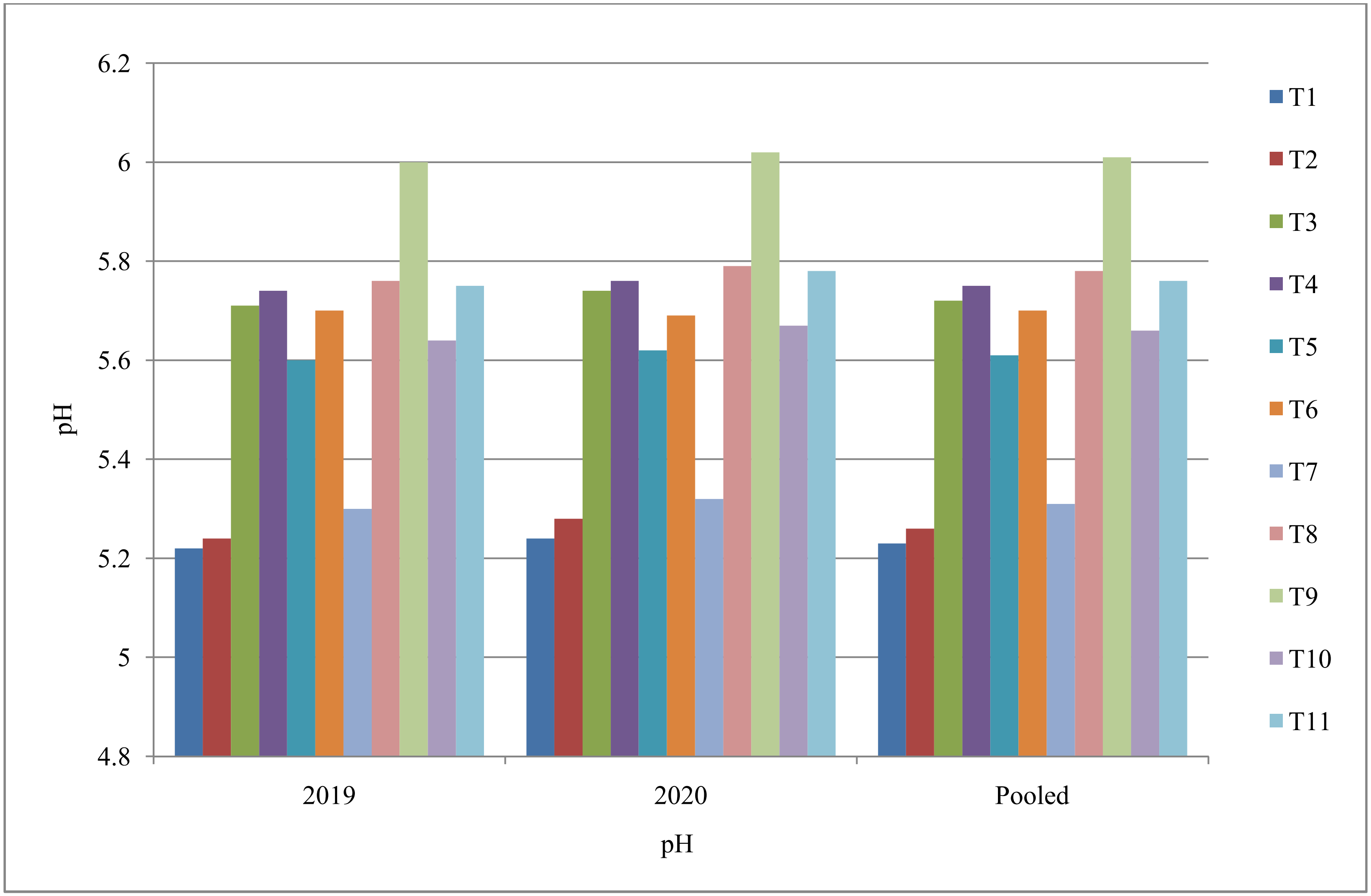


Fig 4.20: Effect of biochar and pig manure on pH of post harvest soil

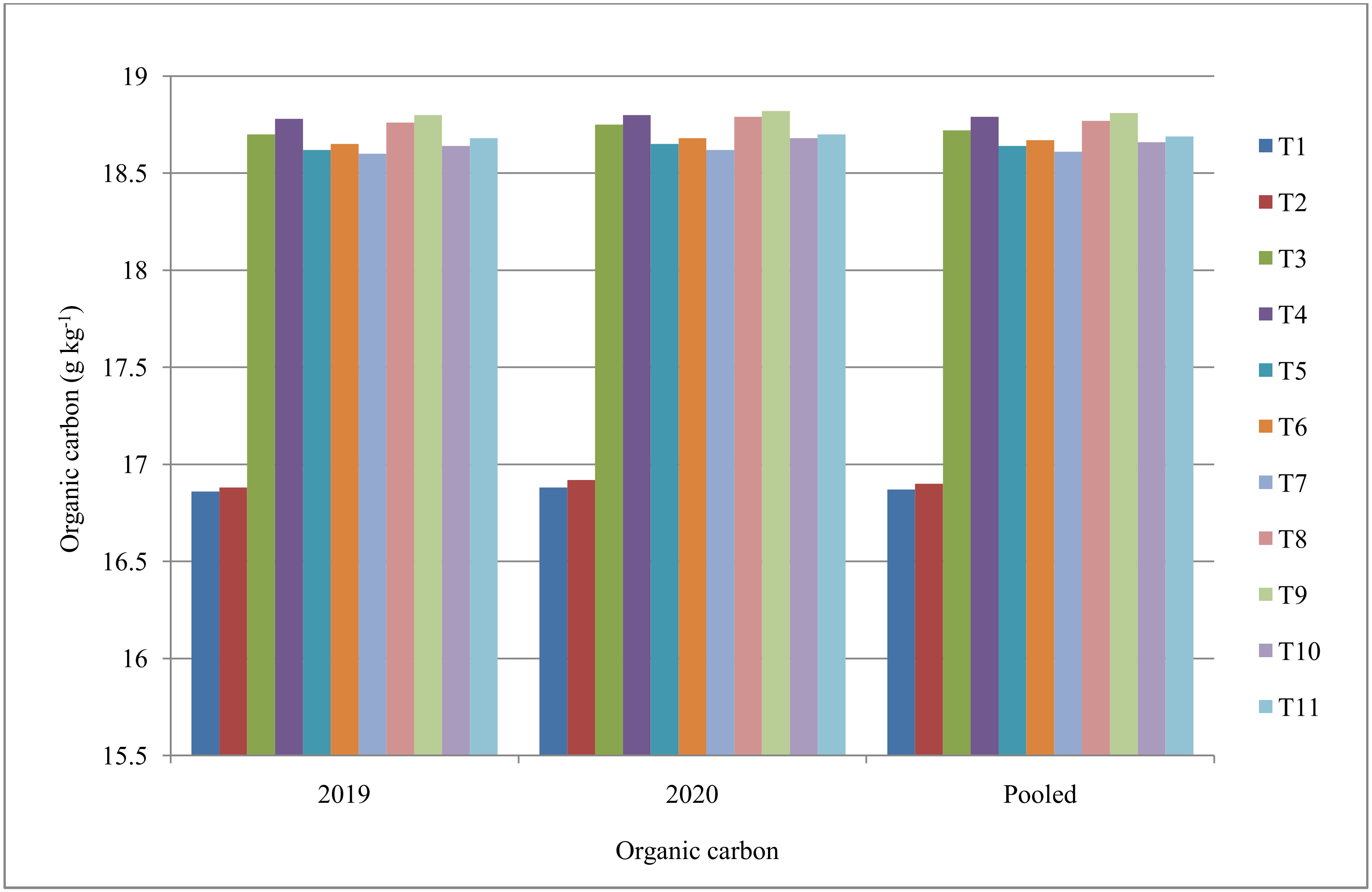


Fig 4.21: Effect of biochar and pig manure on organic carbon of post harvest soil

control treatment (T_1) and 11.3% over RDF (T_2). Further analysis of the data displayed that treatment T_9 was statistically at par with T_8, T_{10} and T_{11}. Sole application of pig manure (T_7) also significantly enhanced organic carbon over control (T_1) and RDF (T_2). However type and higher rate of biochar could not produce significant impact on organic carbon content of post harvest soil. The increase in organic carbon in biochar amended soil might be due to stabilized organic carbon through sorption on biochar surfaces and pores and another reason may also possibly be due to enhanced soil aggregation and organo-biochar-clay mineral interactions through cation bridging and ligand exchange reactions in the biochar amended soils (Han Weng *et al*., 2017). The highest carbon content in biochar-amended plots might be responsible for organic carbon build-up owing to slow degradation and recalcitrant nature of biochar in soil which is in conformity with the findings of Bayu *et al*. (2016) and Trupiano *et al*.(2017).

4.2.2 Effect on CEC and base saturation

The data related to cation exchange capacity and base saturation is presented in Table 4.13. The perusal of the data presented in Table 4.13 and fig. 4.22 indicates that incorporation of biochar and pig manure significantly increased the cation exchange capacity of the soil after crop harvest during both the years of experimentation. A critical examination of the data shows that treatment $T_9$was statistically at par with T_{11}while $T_8$was at par with T_{10}. Irrespective of years, cation exchange capacity of post harvest soil varied from 9.72 to 12.62 [cmol (p^+) kg^{-1}]. It was also perceived that application of biochar and pig manure along with RDF (T_9) enhanced pooled CEC to the extent of 28.0% over control (T_1) and 23.4% over RDF (T_2). Type of biochar as well as higher dose of biochar could not produce significant impact on CEC of post harvest soil.CEC is an important basisaffecting the strength of soil buffering capacity, assessing soil fertility and its retention capacity. The increased in CEC may be attributed to the large and

Table 4.13: Effect of biochar and pig manure on CEC and base saturation of post harvest soil

Treatments	CEC [cmol(p^+)kg^{-1})]			Base saturation (%)		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	9.72	9.95	9.84	34.92	36.14	35.53
T_2- RDF(20:40:30)	10.18	10.24	10.21	39.23	39.26	39.25
T_3- RDF+2.5t ha^{-1} WB	11.52	11.56	11.54	40.83	41.29	41.06
T_4 -RDF+5.0 t ha^{-1} WB	11.54	11.58	11.56	41.24	41.66	41.45
T_5 -RDF+2.5t ha^{-1} BB	11.51	11.55	11.53	39.99	40.89	40.44
T_6- RDF+5.0 t ha^{-1} BB	11.53	11.56	11.54	40.09	41.30	40.70
T_7- RDF+2.0 t ha^{-1} PM	12.53	12.54	12.53	42.13	41.87	42.00
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	12.58	12.61	12.60	44.76	45.15	44.95
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	12.59	12.62	12.60	44.98	45.65	45.32
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	12.26	12.30	12.28	43.39	43.13	43.26
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	12.29	12.32	12.31	43.86	44.22	44.04
SEm±	0.20	0.21	0.15	0.76	0.46	0.45
CD (P=0.05)	0.59	0.62	0.42	2.25	1.37	1.28
Initial values	9.70	9.91		33.04	35.01	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

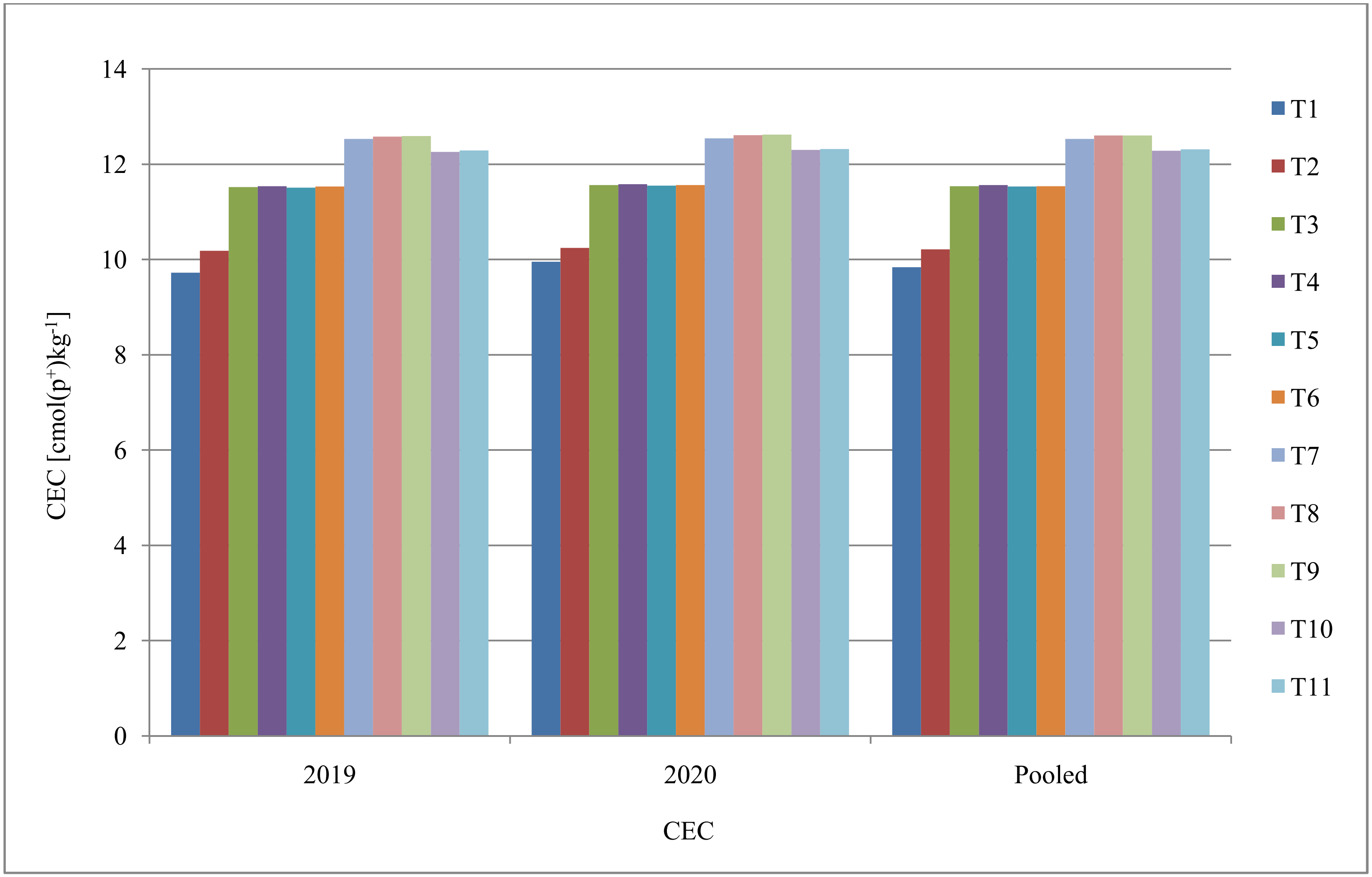


Fig 4.22: Effect of biochar and pig manure on CEC post harvest soil

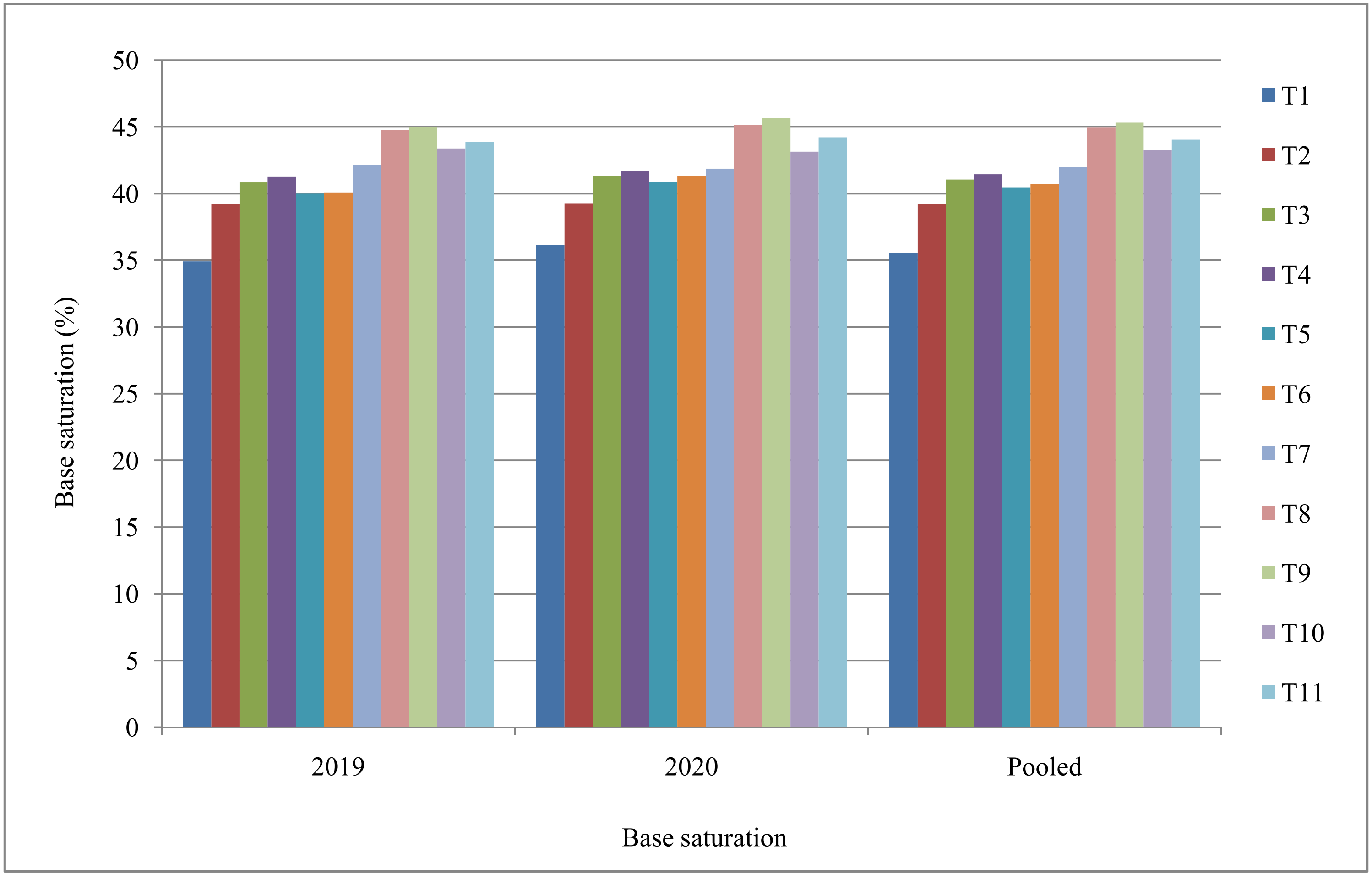


Fig 4.23: Effect of biochar and pig manure on base saturation post harvest soil

negative surface charge, charge density along with loose and porous structure of biochar which is able to absorb more base ions, thereby increasing the soil base saturation and CEC value(Liang *et al*., 2006; Li *et al*., 2018).As the freshly added biochar gets exposed to water and oxygen in soil, biochar may have undergone surface oxidation reactions leading to a rise in the net negative charge resulting in higher CEC(Cheng and Lehmann, 2009). Another possible reason may bethe presence of oxygenated (acid) functional groups on biochar surfaces that can also increase soil CEC (Sohi *et al*., 2010). Similar effects have been reported by (Chang *et al*., 2016) where there is increased in the value of CEC in the biochar amended soil.

Further, it can be observed from the Table 4.13 and fig. 4.23 that there was significant effect of biochar and pig manure application on base saturation of soil after harvest. The highest base saturation was recorded in T_9 treatment with 44.98% and 45.65% during 2019 and 2020 respectively, with pooled value of 45.32% and the lowest was recorded in T_1 with 34.92% and 36.14% with pooled value of 35.53%. It was also observed that type and high dose of biochar did not affect base saturation significantly. Combined application of biochar and pig manure (T_8 to T_{11}) indicated significant impact on base saturation in comparison to sole biochar application (T_3 to T_6).Furthermore, pooled base saturation with T_9 application was enhanced by 27.5% over control (T_1) and 15.4% over RDF (T_2). The increase in percent base saturation might be to due increase in soil exchangeable K^+, Ca^{2+} and Mg^{2+} leading to exchange of Ca^{2+} with hydrogen ion which is helpful in forming soil aggregate and enhancing soil fertilityHaojie *et al*. 2020.

4.2.3 Effect on available nitrogen and phosphorus

The data regarding available nutrient content in the soil after crop harvest are presented in Table 4.14. It is apparent from Table 4.14 and fig. 4.24

thathighest available nitrogen content in the soil after crop harvest was recorded in RDF + 2.0 t ha^{-1}PM + 5.0 t ha^{-1} WB (T_9) during 2019 and 2020, which was significantly superior over the rest of treatments. Application of sole biochar significantly enhanced available nitrogen content during second year only over RDF (T_2). The maximum available nitrogen was recorded in T_9 with 260.50 and 282.30 kg ha^{-1} during first and second year of experimentation respectively, with a pooled value of 271.40 kg ha^{-1} and the minimum was recorded in control treatment (T_1).It was also observed that T_9 was statistically was par with T_8 while T_{11} was at par with T_{10}. A critical analysis of the pooled data revealed that application of wood biochar along with fertilizer and pig manure (T_9) amplified available nitrogen by 14.1% over control and 9.0% over RDF (T_2).The increase might be attributed to direct addition of nitrogen through mineralization of organic nitrogen in biochar as well as release of organic matter from the manure and application of nitrogen through fertilizer. This is in agreement with Ibeawuchi *et al*. (2007) who reported that all the plots treated with poultry manure + inorganic fertilizer had high residual N, P, K, Ca and Mg. Mandal *et al*.(2016) reported that biochar application enhanced available N in soil due to mineralization of N from native soil organic matter and also microbial mineralization of organic N in the biochar.

The data on available phosphorus content of post harvest soil is given in Table 4.14 and depicted in fig. 4.25. Available phosphorus of the soil significantly increased withcombined application of wood and bamboo biochar along with RDF over control treatment (T_1) and sole application of RDF (T_2). Irrespective of years, the available phosphorus in soil varied from 10.07 to 14.38 kg $ha^{-1}$with pooled value of 13.87 kg ha^{-1}. Highest available phosphorus was observed in treatment (T_9), while minimum was recorded in control treatment (T_1). A critical examination of the pooled data showed that T_9 enhanced available phosphorus by 30.97% over control and 9.9% over RDF (T_2). According to Petter*et al*. (2012)

Table 4.14: Effect of biochar and pig manure on available nitrogen and potassium status of post harvest soil

Treatments	Available nutrients (kg ha^{-1})					
	Nitrogen			Phosphorus		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	225.16	250.52	237.84	10.07	11.10	10.59
T_2- RDF(20:40:30)	237.91	259.91	248.91	12.09	13.15	12.62
T_3- RDF+2.5t ha^{-1} WB	240.77	266.35	253.56	12.21	13.22	12.72
T_4 -RDF+5.0 t ha^{-1} WB	245.12	268.15	256.64	12.25	13.28	12.77
T_5 -RDF+2.5t ha^{-1} BB	239.09	264.03	251.56	12.20	13.21	12.71
T_6- RDF+5.0 t ha^{-1} BB	243.17	267.33	255.25	12.25	13.27	12.76
T_7- RDF+2.0 t ha^{-1} PM	249.52	270.66	260.09	13.28	14.30	13.79
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	254.73	276.33	265.53	13.31	14.32	13.81
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	260.50	282.30	271.40	13.36	14.38	13.87
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	245.32	279.13	262.22	13.29	14.31	13.80
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	248.60	280.02	264.31	13.32	14.35	13.84
SEm±	2.83	2.03	1.74	0.04	0.03	0.03
CD (P=0.05)	8.36	5.98	4.98	0.13	0.08	0.07
Initial values	215.11	235.25		10.01	11.05	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

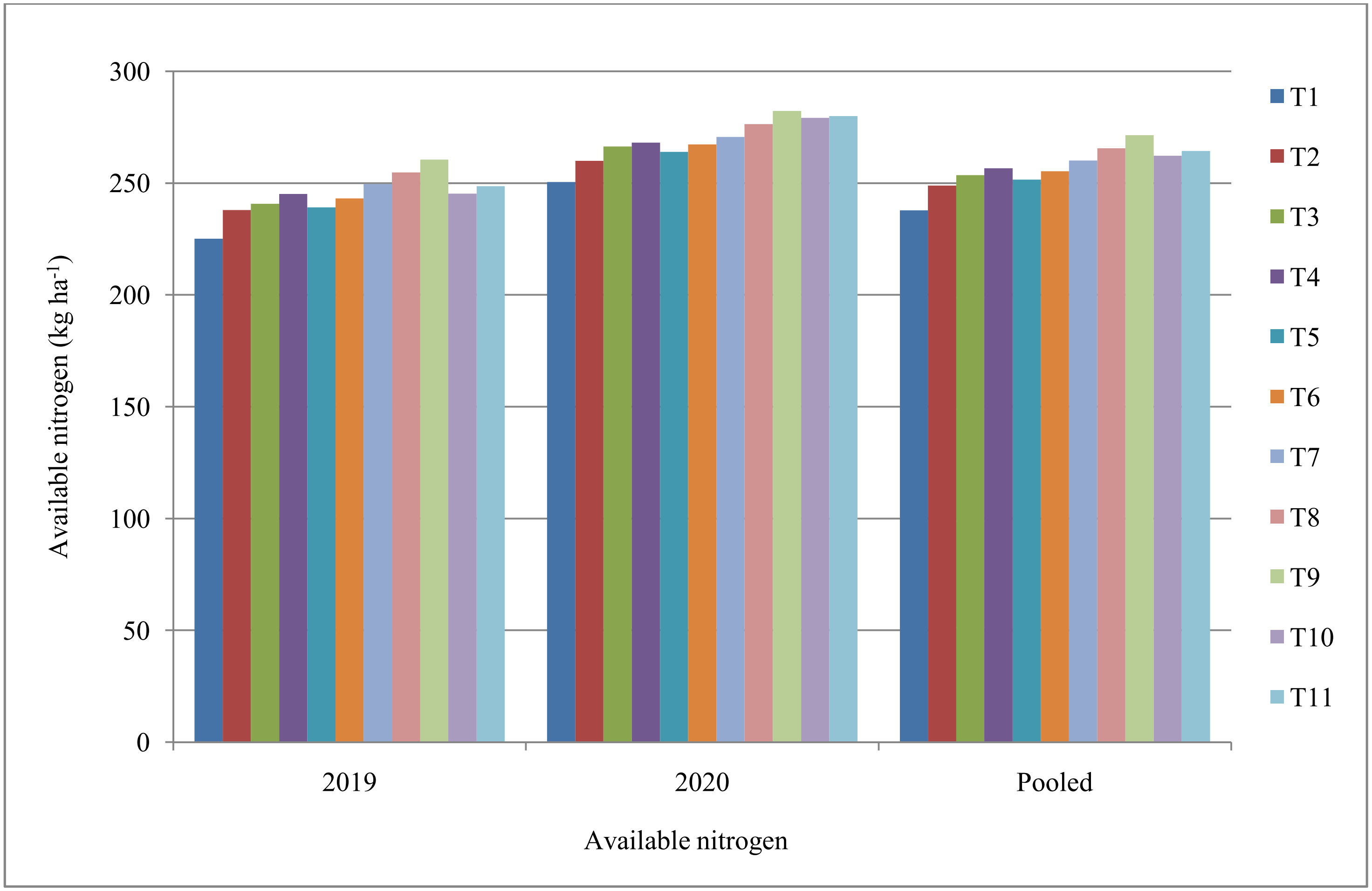


Fig 4.24: Effect of biochar and pig manure on available nitrogen of post harvest soil

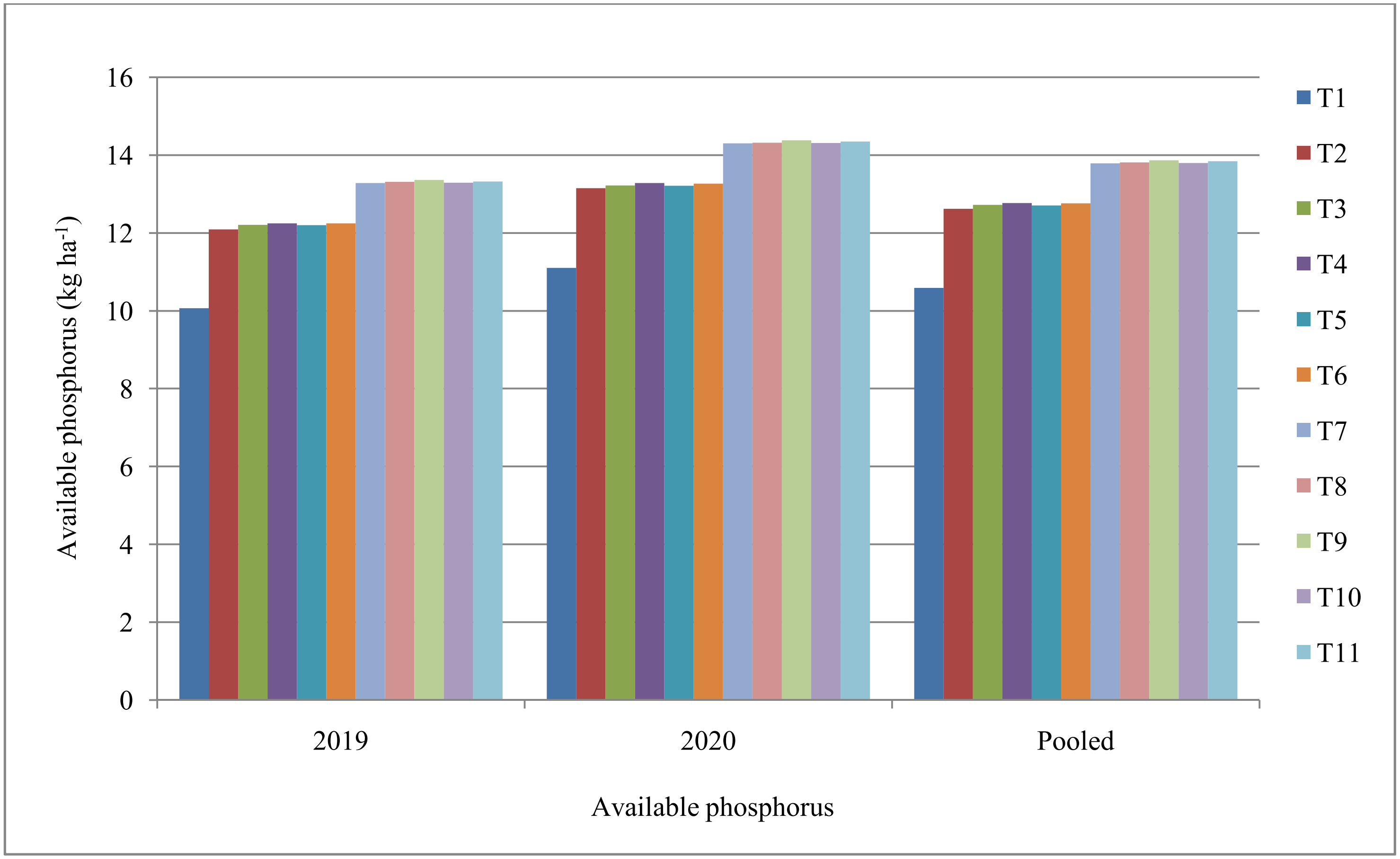


Fig 4.25: Effect of biochar and pig manure on available phosphorus of post harvest soil

increase in soil phosphorus may be attributed to the release of phosphorus by biochar, from its surface sites and presence of soluble and exchangeable phosphate in biochar when it forms linkages with different forms of organic matter.Besides an indirect effect of biochar on soil P availability may be due to the P content in ash fraction of biochar Sohi *et al*. (2010).Such increases in available P with biochar addition are in agreement withthose of Agegnehu *et al*., 2015; Naeem *et al*., 2018.Further, additions of organic residues such as biochar to acid soils can reduce Al toxicity (thus lowering the lime requirement) and improve P availability (Haynes and Mokoloblate, 2001).

4.2.4 Effect on available potassium and sulphur

The data pertaining to available potassium status of post harvest soil is presented in Table 4.15 and illustrated in Fig. 4.26 and 4.27. Application of RDF, biochar and pig manure significantly influenced potassium status of post harvest soil. The maximum available potassium in soil after harvest was recorded in T_9 treatmentwith 165.05 and 166.02 kg ha^{-1} during 2019 and 2020 respectively, with pooled value of 165.54 kg ha^{-1}. The lowest was recorded in control treatment (T_1) with 138.74 and 140.93 kg ha^{-1}. It was also observed that combined application of RDF, biochar and pig manure significantly enhanced available potassium in soil over control and sole RDF treatment (T_2) during both the years of experimentation. Furthermore, a critical analysis of the data displayed treatment T_9 enhanced the pooled availability of potassium by 18.3% over control (T_1) and 12.2% over RDF (T_2). Higher availability of potassium in soil might be due to increase in surface charge of the soil by addition of biochar which is responsible for holding positively charged ion and reducing leaching losses thereby enhancing available potassium in soil.

Table 4.15: Effect of biochar and pig manure on available potassium and sulphur status of post harvest soil

Treatments	Available nutrients (kg ha^{-1})					
	Potassium			Sulphur		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	138.74	140.93	139.84	12.03	12.50	12.26
T_2- RDF(20:40:30)	146.22	148.80	147.51	14.06	14.17	14.11
T_3- RDF+2.5t ha^{-1} WB	153.51	154.79	154.15	15.43	15.46	15.45
T_4 -RDF+5.0 t ha^{-1} WB	156.84	157.55	157.19	15.55	15.57	15.56
T_5 -RDF+2.5t ha^{-1} BB	152.55	153.75	153.15	15.41	15.44	15.42
T_6- RDF+5.0 t ha^{-1} BB	154.53	157.59	156.06	15.52	15.56	15.54
T_7- RDF+2.0 t ha^{-1} PM	158.22	160.01	159.12	15.55	15.58	15.57
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	162.36	164.18	163.27	15.63	15.66	15.64
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	165.05	166.02	165.54	15.67	15.69	15.68
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	161.59	162.89	162.24	15.61	15.85	15.73
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	163.71	164.50	164.10	15.64	15.65	15.65
SEm±	3.91	4.60	3.02	0.41	0.38	0.28
CD (P=0.05)	11.54	13.56	8.63	1.21	1.12	0.80
Initial values	137.41	138.42		11.19	12.09	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

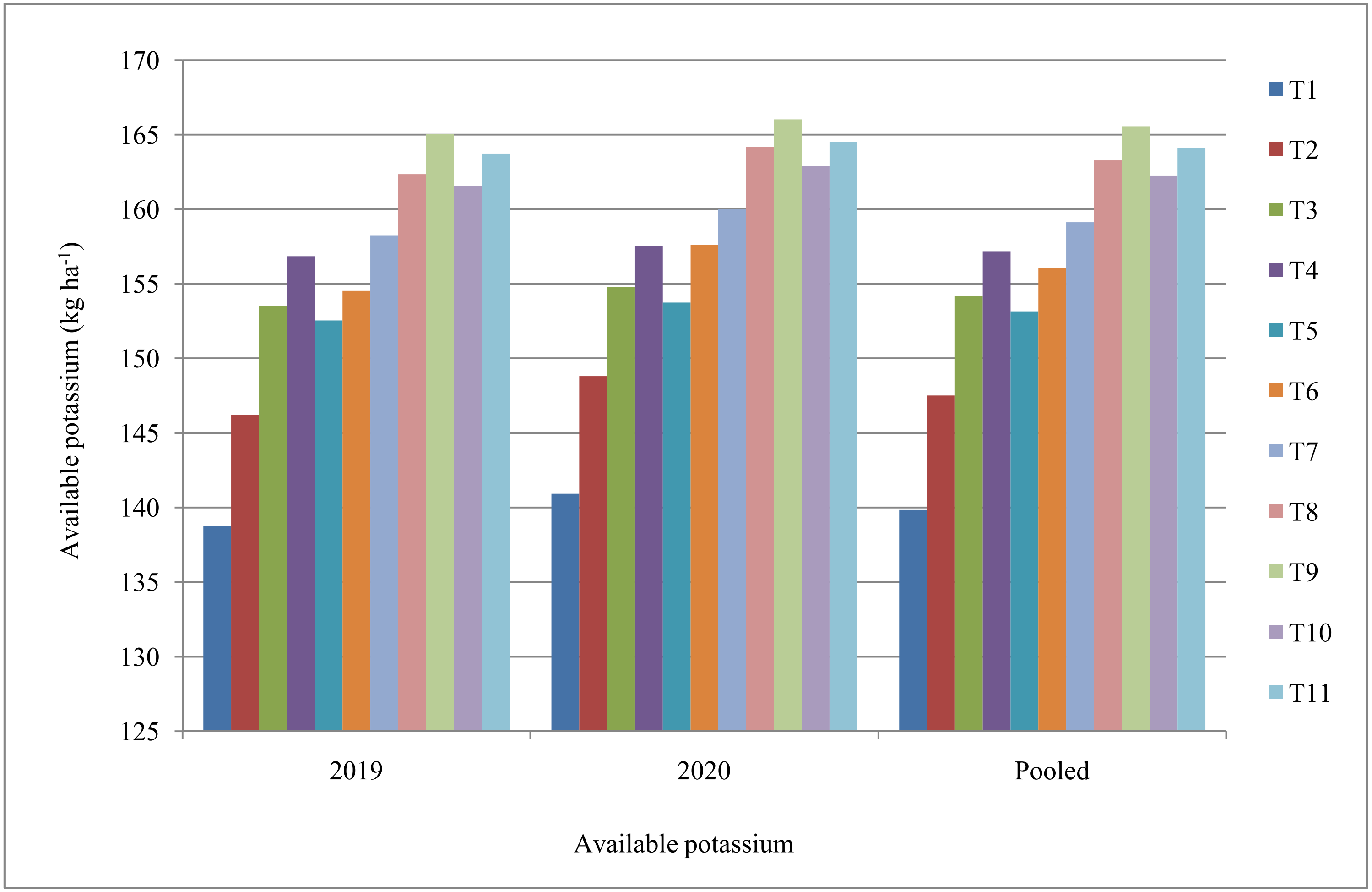


Fig 4.26: Effect of biochar and pig manure on available potassium of post harvest soil

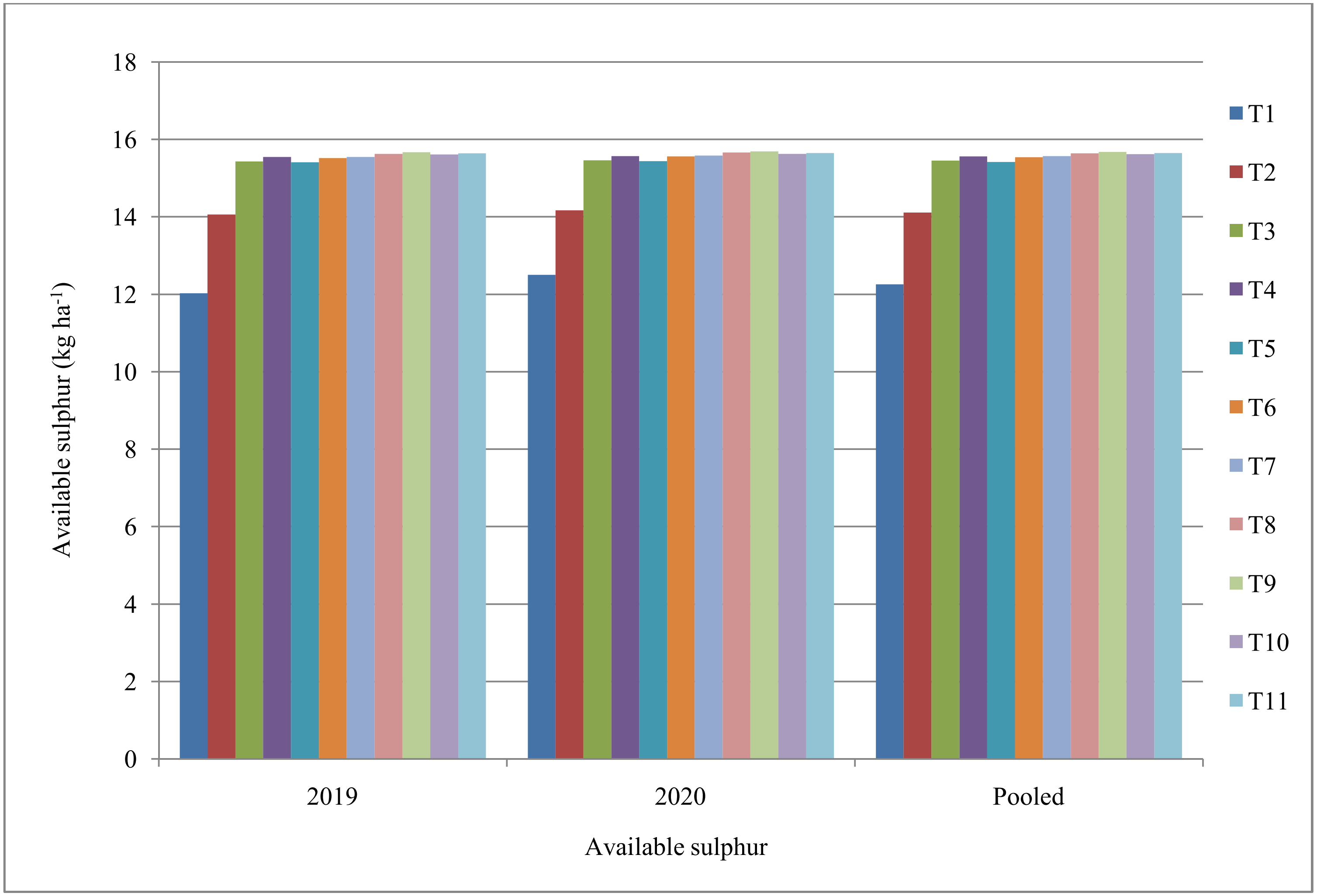


Fig 4.27: Effect of biochar and pig manure on available sulphur of post harvest soil

Similar results were also reported by Pandian *et al*., 2016; Naeem *et al*., 2018; Mavi *et al*., 2018. Masulili Agusalim (2010) draws similar conclusion in potassium availability in soil due to application of biochar and organic manure.

From the Table 4.15 and fig. 4.27 it can be observed that the incorporation of RDF, biochar and pig manure (treatment T_9) on available sulphur was found to be significantly enhanced over control treatment (T_1). The highest available sulphur in soil after harvest during 2019 was recorded in T_9 (15.67 kg ha^{-1}) and during 2020 it was recorded in treatment T_{11} (15.85 kg ha^{-1}) and pooled value of 15.68 kg ha^{-1}while the lowest values were recorded in T_1.Further, from the pooled data it can be observed that application of treatment T_{11}enhanced available sulphur in soil to the extent of 28.4% over control(T_1) and 11.5% over sole RDF treatment (T_2). A critical examination of the data revealed that T_8, T_9, T_{10} and T_{11} were at par to each other during both the years of experimentation. The increase in available sulphur status of the soil may be due to the addition of biocharthat can alter soil microbial populations or providing habitat for them especially those which are actively giving a contribution to transformations of nutrients including N, P, or S while improving the available nutrient content in soil (DeLuca *et al*., 2015). Similar results wereobserved by Alburquerque*et al.* (2014) who reported that addition of biochar to the soil increase the availability of macronutrients such as sulphur to the soil which are easily accessible to plants.

4.2.5 Effect on exchangeable calcium and exchangeable magnesium

The data obtained on exchangeable calcium is presented on Table 4.16 and fig. 4.28. It can be observed that increasing doses of wood and bamboo biochar along with RDF (T_3-T_6) significantly enhanced exchangeable calcium over control and RDF (T_2) during both the years of experimentation. The highest exchangeable calcium was recorded in treatment T_9 with 4.25 and 4.31 [cmol(p^+)kg^{-1}] respectively, with pooled value of 4.28[cmol(p^+)kg^{-1}] and the lowest was recorded in T_1 with 2.13 and 2.29 [cmol(p^+)kg^{-1}] with pooled value of 2.21 [cmol(p^+)kg^{-1}]. The pooled data further revealed that treatment T_9 enhanced the exchangeable calcium to the extent of 93.6% over control (T_1) and 60.9% over RDF (T_2). A perusal of data further indicatesthat a higher value of exchangeable calcium was observed in wood biochar treated plots. Pig manure application (T_7) also significantly enhanced exchangeable calcium content of the post harvest soil over control and RDF (T_2). The increase in exchangeable calcium in the biochar amended soils might be due to high specific surface area and a number of carboxylic groups of the biochar (cheng *et al*., 2006). Similar results were recorded by (Carvalho *et al*., 2013; wang *et al*., 2014) who observed significant increases of Ca and Mg in the soil after the addition of biochar.

Further, the data on exchangeable magnesium content of soil is presented in Table 4.16 and fig. 4.29 The maximum exchangeable magnesium content was recorded in T_9 with 1.18 and 1.20 [cmol(p^+)kg^{-1}],with pooled value of 1.19 [cmol(p^+)kg^{-1}] and the lowest exchangeable magnesium content was recorded in T_1. However during 2020 the effect of treatments had non-significant effect on exchangeable magnesium content. Further, from the pooled data it can be observed that treatment T_9 (RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB) enhanced the exchangeable magnesium content in soil by 7.2% over control and 3.4% over RDF (T_2).

This increment in exchangeable magnesium content in soil after harvest may be due to increase in pH of the soil during organic matter decomposition leading to the formation of anions which consumed acidity causing protons and solubilise inherent Ca and Mg, thus making it available in the soil (Narambuye and Haynes, 2006).Furthermore, addition of biochar in the soil lead to enrichment

Table 4.16: Effect of biochar and pig manure on exchangeable calcium and exchangeable magnesium of post harvest soil

Treatments	Exchangeable calcium [cmol(p^+)kg^{-1}]			Exchangeable magnesium [cmol(p^+)kg^{-1}]		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	2.13	2.29	2.21	1.08	1.13	1.11
T_2- RDF(20:40:30)	2.67	2.65	2.66	1.14	1.16	1.15
T_3- RDF+2.5t ha^{-1} WB	3.34	3.39	3.37	1.16	1.17	1.16
T_4 -RDF+5.0 t ha^{-1} WB	3.38	3.42	3.40	1.17	1.18	1.17
T_5 -RDF+2.5t ha^{-1} BB	3.25	3.35	3.30	1.15	1.17	1.16
T_6- RDF+5.0 t ha^{-1} BB	3.27	3.39	3.33	1.15	1.17	1.16
T_7- RDF+2.0 t ha^{-1} PM	3.92	3.87	3.90	1.15	1.18	1.17
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	4.24	4.26	4.25	1.17	1.19	1.18
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	4.25	4.31	4.28	1.18	1.20	1.19
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	3.94	3.90	3.92	1.16	1.18	1.17
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	3.99	4.02	4.01	1.17	1.19	1.18
SEm±	0.09	0.06	0.05	0.02	0.01	0.01
CD (P=0.05)	0.26	0.19	0.15	0.049	NS	0.030
Initial values	2.12	2.27		1.09	1.11	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

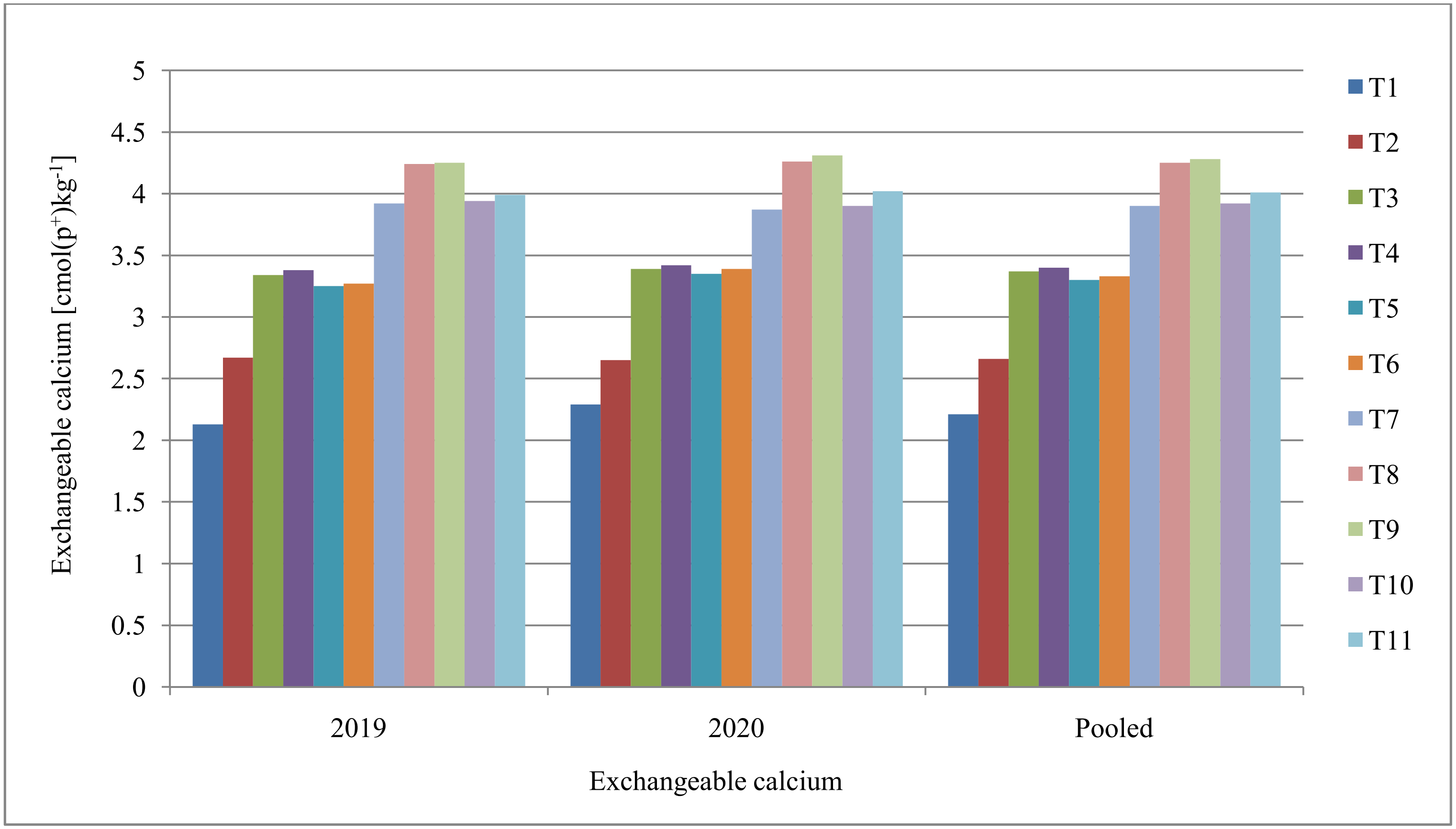


Fig 4.28: Effect of biochar and pig manure on exchangeable calcium of post harvest soil

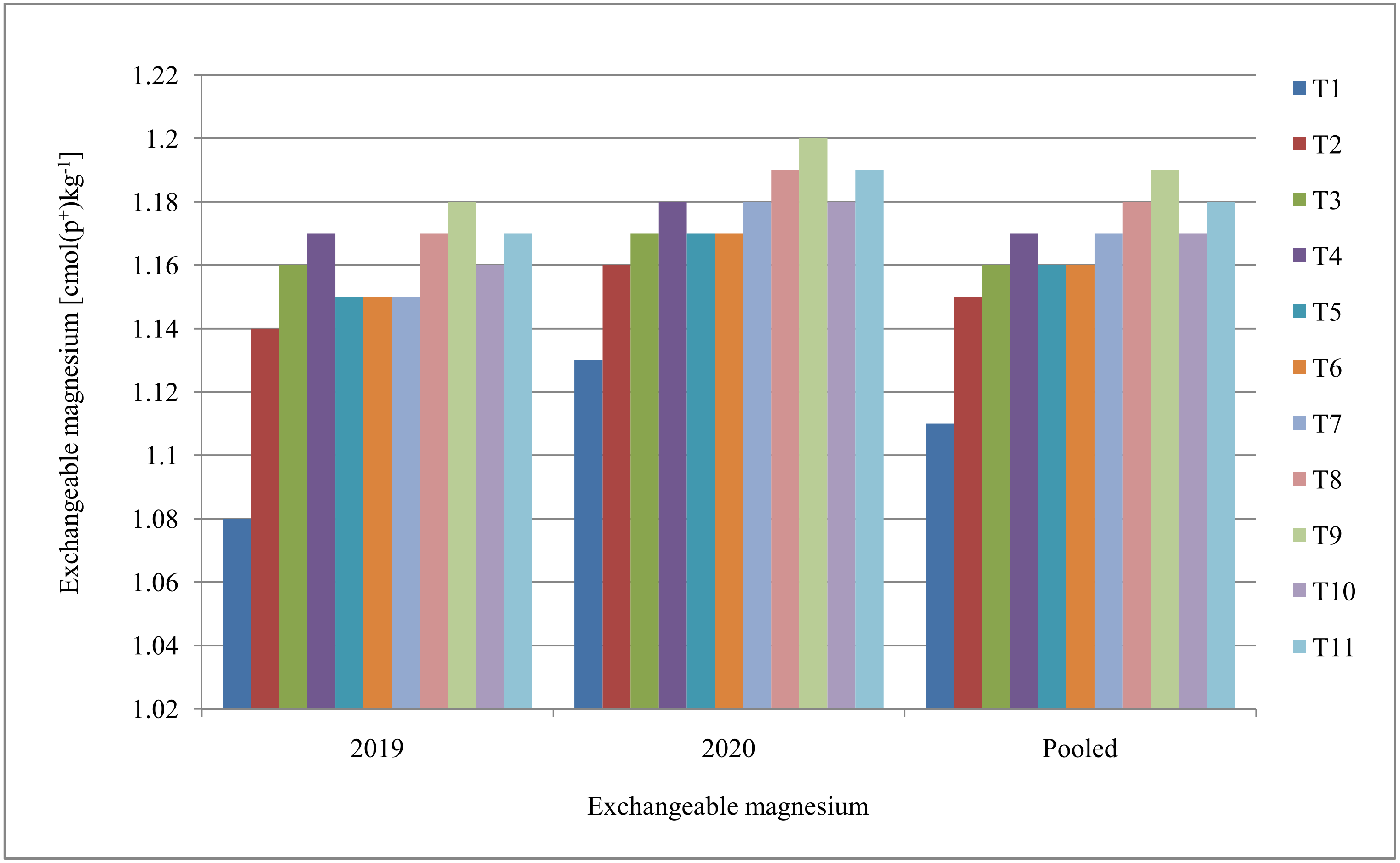


Fig 4.29: Effect of biochar and pig manure on exchangeable magnesium of post harvest soil

in organic matter thereby improving fertility and quality of the soil. Biochar also adds some macro (P, K, N, Ca, Mg) and micronutrients (Cu, Zn, Fe, Mn) to the soil. These results are in close conformity with the findings of Novak*et al*., 2009; Carvalho *et al*., 2013; Agegnehu *et al*., 2015 where the biochar amendment exhibited considerable improvement in soil P, K, Ca and Mg.

4.2.6 Effect on exchangeable aluminium and exchangeable hydrogen

The data pertaining to exchangeable aluminium and exchangeable hydrogen is presented in Table 4.17 and depicted in fig. 4.30 and fig. 4.31. It can be observed that effect of types of biochar application along with RDF or combined with pig manure (T_3 to T_6 and T_8 to T_{11}) on exchangeable aluminium was found to be significantly decreased over control treatment (T_1) and sole RDF (T_2) during both the years of experimentation. It was also noted that wood biochar was more effective than bamboo biochar in reducing the exchangeable aluminium. The highest values of exchangeable aluminium during 2019 and 2020 was recorded in control (T_1) with 2.32 and 2.28 [cmol(p^+)kg^{-1}] respectively, with pooled value of 2.30 [cmol(p^+)kg^{-1}] and the lowest value was recorded in (T_9) treatment with 1.71 and 1.68 [cmol(p^+)kg^{-1}] with pooled value of 1.70 [cmol(p^+)kg^{-1}]. From the pooled data it can be noted that exchangeable aluminium showed a decline of 26.0% in T_9 when compared to T_1 treatment. The reason for decline in soil exchangeable aluminium might be due to the release of base cations and the higher $CaCO_3$ content of biochars that can increase the pH and decrease the Al saturation of acid soil Yuan and Xu (2011). Similar outcomes were reported by (Narambuye and Haynes, 2006; Opala *et al*., 2012: Shetty and Prakash, 2020).

Similarly for exchangeable hydrogen, it is evident from the Table 4.17 and fig. 4.31 the maximum exchangeable hydrogen during 2019 and 2020 was observed in control treatment (T_1) with 0.75 and 0.73 [cmol(p^+)kg^{-1}] with pooled

Table 4.17: Effect of biochar and pig manure on exchangeable aluminium and exchangeable hydrogen of post harvest soil

Treatments	Exchangeable aluminium [cmol(p^+)kg^{-1}]			Exchangeable hydrogen[cmol(p^+)kg^{-1}]		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	2.32	2.28	2.30	0.75	0.73	0.74
T_2- RDF(20:40:30)	2.31	2.27	2.29	0.77	0.76	0.77
T_3- RDF+2.5t ha^{-1} WB	1.76	1.70	1.73	0.47	0.45	0.46
T_4 -RDF+5.0 t ha^{-1} WB	1.73	1.69	1.71	0.44	0.42	0.43
T_5 -RDF+2.5t ha^{-1} BB	1.79	1.75	1.77	0.48	0.46	0.47
T_6- RDF+5.0 t ha^{-1} BB	1.75	1.76	1.76	0.45	0.44	0.45
T_7- RDF+2.0 t ha^{-1} PM	2.30	2.25	2.28	0.49	0.46	0.47
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	1.72	1.69	1.71	0.39	0.37	0.38
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	1.71	1.68	1.70	0.37	0.36	0.37
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	1.78	1.77	1.78	0.40	0.38	0.39
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	1.79	1.78	1.78	0.41	0.39	0.40
SEm±	0.05	0.03	0.03	0.03	0.03	0.02
CD (P=0.05)	0.154	0.095	0.087	0.076	0.079	0.053
Initial values	2.30	2.26		0.71	0.73	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

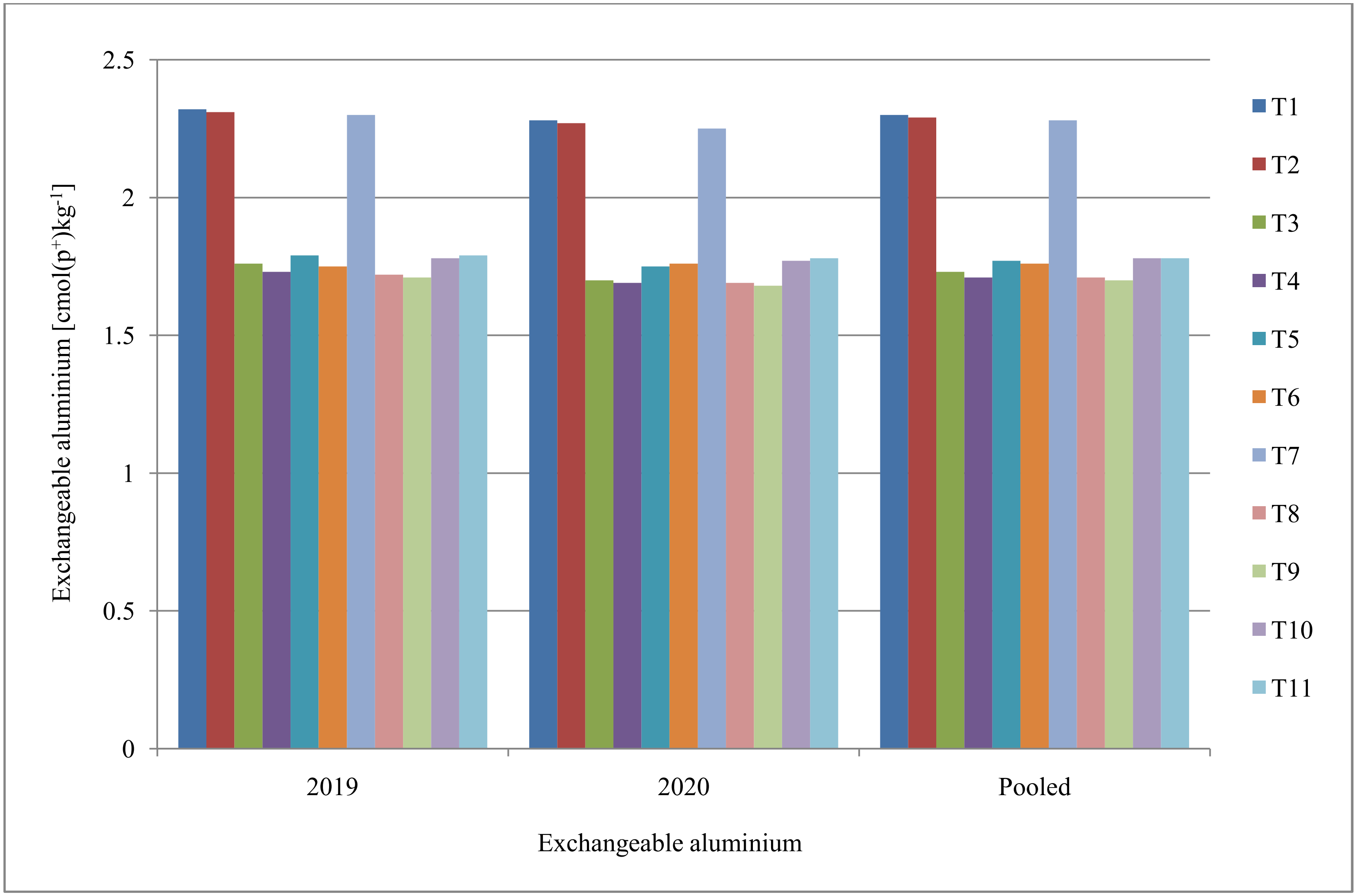


Fig 4.30: Effect of biochar and pig manure on exchangeable aluminum of post harvest soil

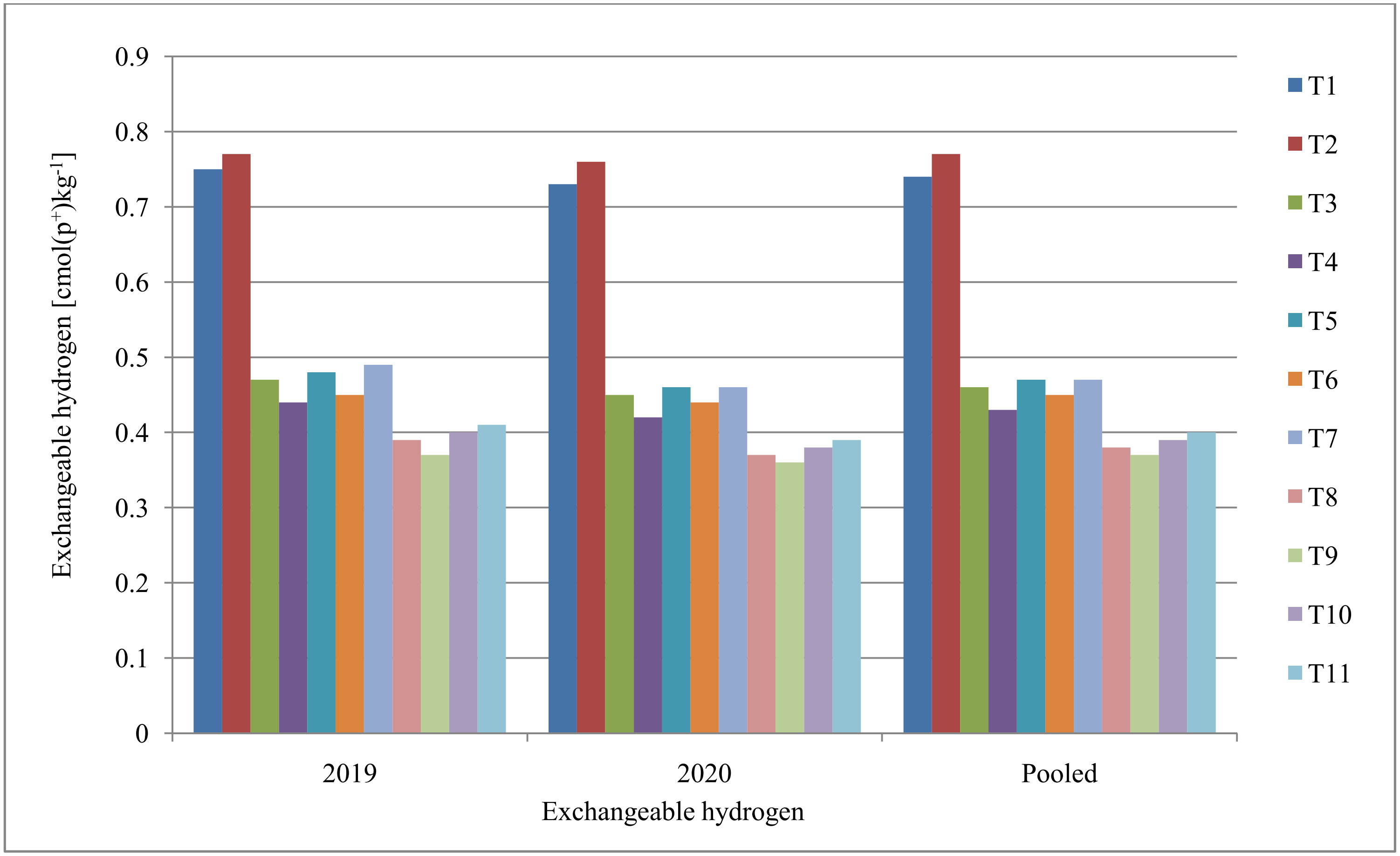


Fig 4.31: Effect of biochar and pig manure on exchangeable hydrogen of post harvest soil

value of 0.74 [cmol(p^+)kg^{-1}] while minimum exchangeable hydrogen was observed in T_9treatment with 0.37 and 0.36 [cmol(p^+)kg^{-1}] with pooled value of 0.37 [cmol(p^+)kg^{-1}]. A significant decline in exchangeable hydrogen was recorded with sole or combined application of wood and bamboo biochar along with RDF and pig manure (T_3 to T_{11}) when compared to control treatment (T_1) and RDF (T_2). Further, from the pooled data it can be considered that exchangeable hydrogen decreased to the extent of 50.0% in T_9 when compared to T_1 and 51.9% over RDF (T_2). These decline in exchangeable hydrogen may be due to increase in pH and presence of base cations in biochars when released to the soil (Yuan *et al*., 2011) This is likely because calcium, magnesium, potassium, and sodium base ions exist in biochar in the form of oxides and soluble carbonates, which dissolve in water and become alkaline, thus neutralizing soil acidity (Tan *et al*., 2017).Another reason may be the presence of abundant carbonate content in biochar that can lead to precipitation of exchangeable Al^+ and neutralization of exchangeable H^+ in the soil thus correcting soil acidity Shetty and Prakash(2020).

4.2.7 Effect on exchangeable acidity and total potential acidity

The data obtained on exchangeable acidity is presented on Table 4.18. It is apparent from the Table 4.18 and fig. 4.32 that combined application of biochar, fertilizer and pig manure had significant effect on exchangeable acidity during both the years of experimentation. It is evident that exchangeable acidity in soil after crop harvest was highest in control treatment (T_1) with 3.06 and 3.01 [cmol(P^+)kg^{-1}] during 2019 and 2020. Lowest values of exchangeable acidity was observed in treatment T_9 (RDF + 2.0 t ha^{-1} Pig manure + 5.0 t ha^{-1} Wood biochar) with 2.08 and 2.04 [cmol(p^+)kg^{-1}]. Application of pig manure (T_7) did not reduce exchangeable acidity significantly over control. Wood and bamboo biochar was at par in reducing exchangeable acidity during both the year of experimentation. It was also observed that T_9 treatment reduced exchangeable acidity by 32.2% over control.

According to Novak *et al*. (2009) biochar possess acid neutralizing effect as it adsorbs cations especially Al^{3+} onto its negatively charged surfaces and therefore, it can be one of the possible reason for the decline in exchangeable acidity of the soil. The ability of biochar particles to absorb the H^+ ions, as well as decarboxylation processes, are probably the main factors in soil acidity neutralization. Similar results were reported by Yamato *et al*. (2006) wherein wood biochar bark of (*Acaia mangium*) application was found to reduce the exchangeable acidity significantly under highly acidic soil.

Further, Table 4.18 and fig. 4.33 embodies the data on total potential acidity. It is evident from the Table 4.18 that biochar amended treatments significantly decreased the total potential acidity of post harvest soil. The maximum reduction was recorded in T_9 with 14.03 and 13.52 [cmol(p^+)kg^{-1}] during first and second year of experimentation with pooled value of 13.78 [cmol(p^+)kg^{-1}]. Pig manure application (T_7) also significantly reduced total potential acidity during both the years of experimentation. But, at same dose of biochar, effect of type of biochar was insignificant. It was also observed that treatment T_8 was statistically at par with T_9 and T_{10} was par with T_{11}. Further, analysis from the pooled data revealed that T_9 decreased total potential acidity to the extent of 21.4% over control (T_1) and 21.3% over RDF (T_2). According to Yuan *et al*. (2011) the biochar particles in soil are subjected to gradual oxidation leading to the production of functional groups containing oxygen (such as COO– carboxylate) reacts with H^+ and Al^{+3} ions in the soil significantly contributes to the alkalinity of soil leading to further decrease in acidity parameters such as total potential acidity. These results are in accordance with those of Masulili Agusalim *et al*. (2010) and Yuan and Xu (2011).

Table 4.18: Effect of biochar and pig manure on exchangeable acidity and total potential acidity of post harvest soil

Treatments	Exchangeable acidity [cmol(p^+)kg^{-1}]			Total potential acidity [cmol(p^+)kg^{-1}]		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	3.06	3.01	3.04	17.60	17.45	17.53
T_2- RDF(20:40:30)	3.08	3.03	3.06	17.59	17.43	17.51
T_3- RDF+2.5t ha^{-1} WB	2.23	2.15	2.19	15.04	14.98	15.01
T_4 -RDF+5.0 t ha^{-1} WB	2.17	2.11	2.14	14.87	14.72	14.80
T_5 -RDF+2.5t ha^{-1} BB	2.26	2.20	2.23	15.52	15.26	15.39
T_6- RDF+5.0 t ha^{-1} BB	2.20	2.20	2.20	14.99	14.67	14.83
T_7- RDF+2.0 t ha^{-1} PM	2.79	2.70	2.75	16.29	16.07	16.18
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	2.11	2.06	2.09	14.58	13.62	14.10
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	2.08	2.04	2.06	14.03	13.52	13.78
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	2.18	2.15	2.17	15.36	15.21	15.29
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	2.20	2.17	2.18	14.77	14.55	14.66
SEm±	0.07	0.04	0.04	0.30	0.40	0.25
CD (P=0.05)	0.19	0.13	0.11	0.89	1.17	0.71
Initial values	3.01	2.99		17.58	17.43	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

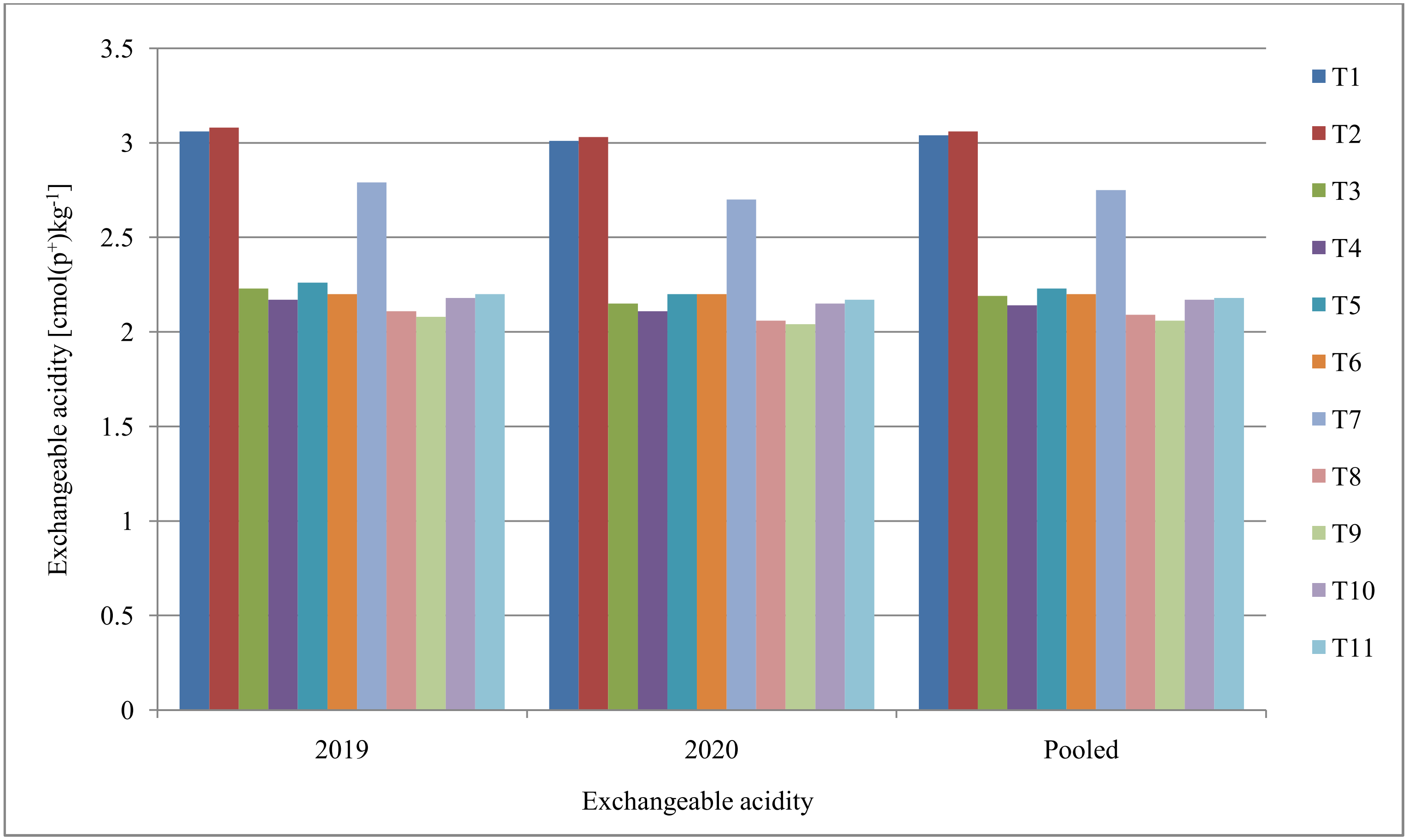


Fig 4.32: Effect of biochar and pig manure on exchangeable acidity of post harvest soil

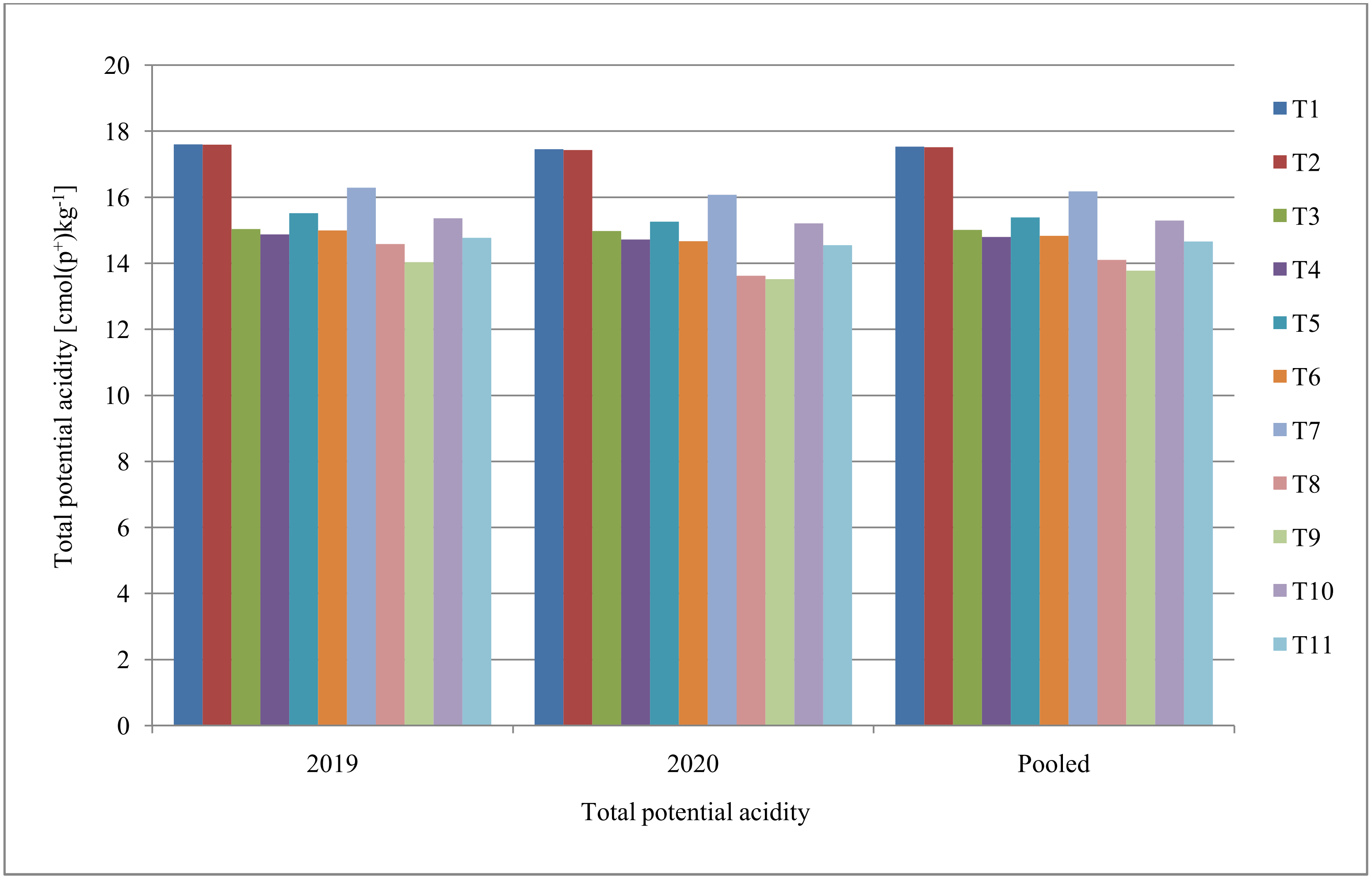


Fig 4.33: Effect of biochar and pig manure on total potential acidity of post harvest soil

4.2.8 Effect on dehydrogenase activity and microbial biomass carbon

The Table 4.19 and fig. 4.34 and 4.35 signify the data on dehydrogenase activity and microbial biomass carbon under different treatments. It was observed that application of types of biochar with fertilizer and pig manure (T_7 to T_{11}) significantly increased dehydrogenase activity in the soil after crop harvest over control (T_1). Application of wood biochar treatment (T_3 and T_4) significantly increased the dedydrogenase activity in soil when compared to sole fertilizer treatment (T_2). However bamboo biochar (T_5 to T_6) along with RDF did not show any significant effect on dehydrogenase activity as compared to control. Among the biochars, wood biochar treated soil showed significantly maximum dehydrogenase activity over bamboo biochar at similar application rate. The highest dehydrogenase activity was found under T_9 with 21.88 and 23.03 (µg TPF g^{-1} h^{-1}) during 2019 and 2020 respectively, with pooled value of 22.46 (µg TPF g^{-1} h^{-1}) and the lowest was recorded in T_1 with 18.25 and 19.38 (µg TPF g^{-1} h^{-1}). A critical examination of the data showed that effect of T_9 was at par with T_8, T_{10} and T_{11}. Application of pig manure (T_7) also significantly enhanced dehydrogenase activity over control and RDF (T_2).

Dehydrogenase activity serves as an important intracellular index for soil microbiological activity due to its role in organic matter decomposition. The enhanced dehydrogenase activities in biochar amended soil may be attributed to addition of labile organic matter, biochar's specific surface area, pore space and its ability to absorb various substrates on its surface (Gasco *et al*., 2016). The highly porous nature and high surface area of biochar act as a favorable habitat for diverse soil biota (Jaafar *et al*., 2014). Similar results have also been reported by (Demisie *et al*., 2014; Mierzwa-Hersztek *et al*., 2016; Irfan *et al*., 2019).

The data pertaining to microbial biomass carbon determined after harvesting of ricebean are presented in the Table 4.19 and fig. 4.35. Wood and

Table 4.19: Effect of biochar and pig manure on dehydrogenase activity and microbial biomass carbon of post harvest soil

Treatments	Dehydrogenase activity (µg TPF g^{-1} h^{-1})			Microbial biomass carbon (µg g^{-1} soil)		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	18.25	19.38	18.81	221.26	224.01	222.63
T_2- RDF(20:40:30)	18.74	19.95	19.34	265.93	273.89	269.91
T_3- RDF+2.5t ha^{-1} WB	20.65	21.51	21.08	323.02	330.62	326.82
T_4 -RDF+5.0 t ha^{-1} WB	21.51	22.55	22.03	310.78	320.13	315.45
T_5 -RDF+2.5t ha^{-1} BB	18.89	19.52	19.21	320.27	325.70	322.99
T_6- RDF+5.0 t ha^{-1} BB	19.51	20.84	20.18	308.62	318.03	313.33
T_7- RDF+2.0 t ha^{-1} PM	20.54	21.31	20.93	327.43	332.94	330.18
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	20.80	22.43	21.61	421.28	429.89	425.58
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	21.88	23.03	22.46	415.63	422.14	418.89
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	20.58	21.50	21.04	418.97	423.97	421.47
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	20.66	21.70	21.18	413.63	420.64	417.13
SEm±	0.54	0.54	0.38	6.98	4.45	4.14
CD (P=0.05)	1.59	1.61	1.09	20.58	13.12	11.83
Initial values	19.21	19.35		217.78	220.33	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

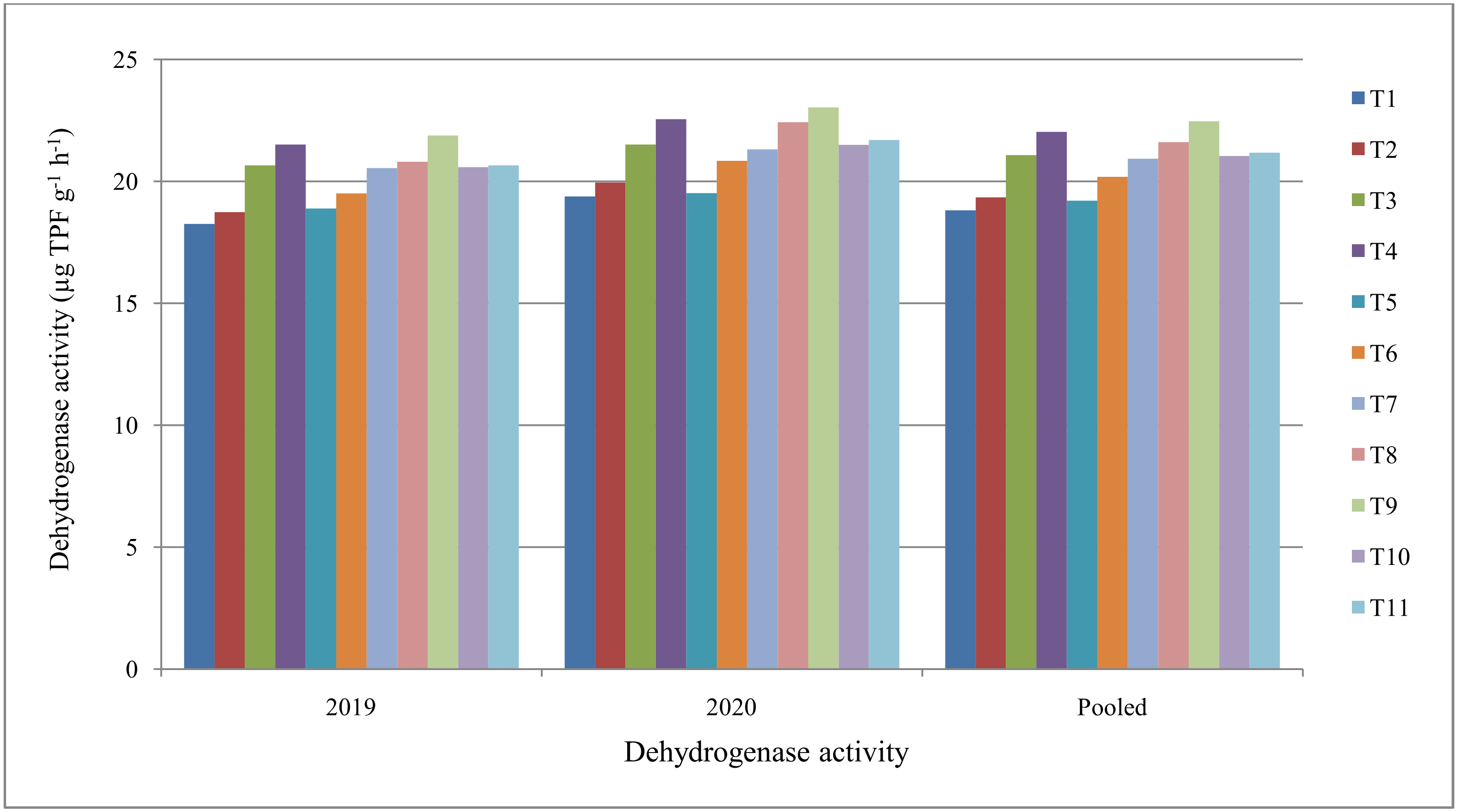


Fig 4.34: Effect of biochar and pig manure on dehydrogenase activity of post harvest soil

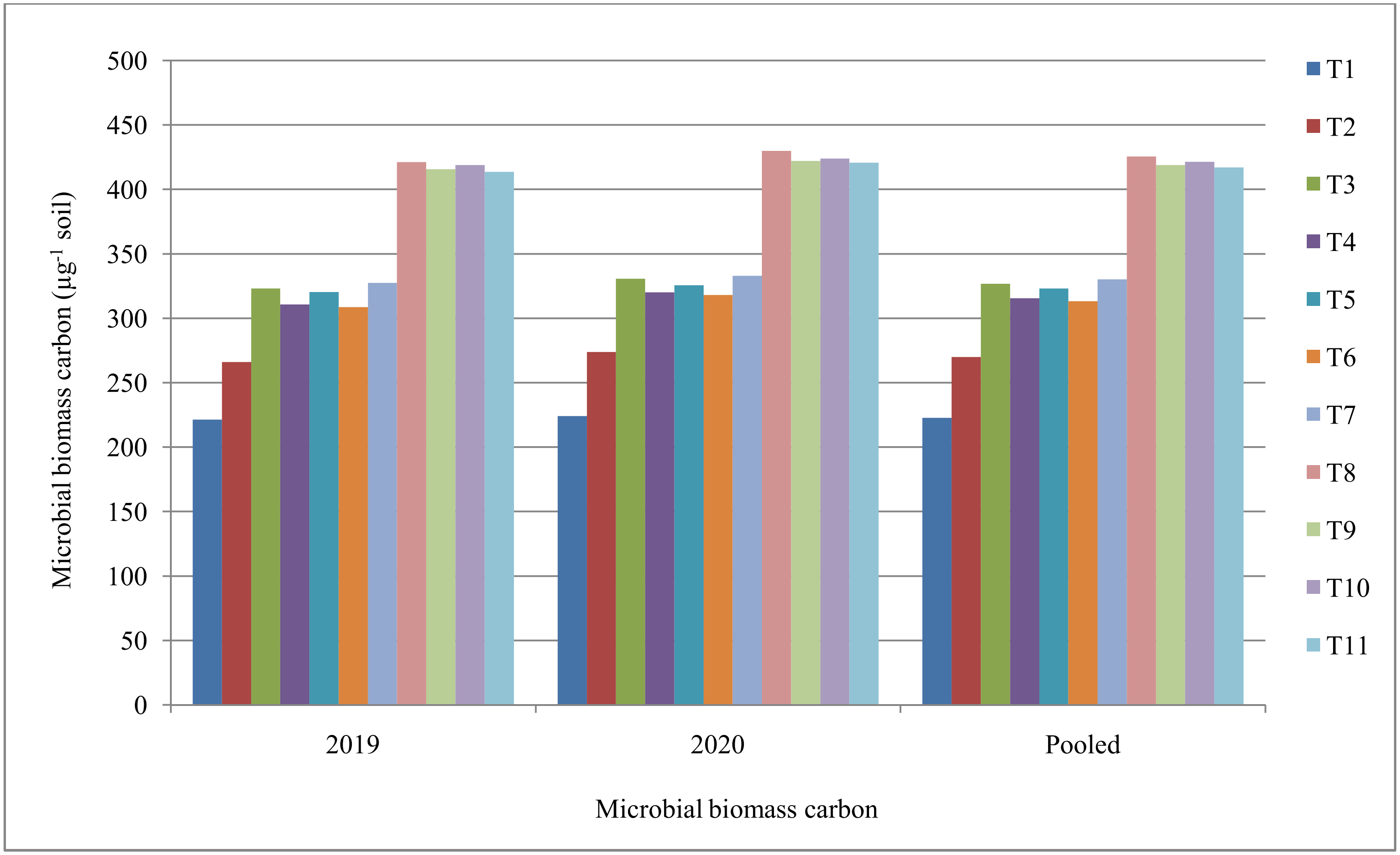


Fig 4.35: Effect of biochar and pig manure on microbial biomass carbon of post harvest soil

Bamboo biochar amended soil along with fertilizer and pig manure significantly increased MBC in the soil when compared with control and fertilizer only treatments. Higher amount of MBC was observed in wood biochar treated plots but values were at par to bamboo treated plots. However it was also observed that T_8 was statistically at par with T_9 and T_{10} was at par with T_{11}. The maximum MBC was recorded in T_8 with 421.28 and 429.89 µg g^{-1} soil during 2019 and 2020 respectively, with pooled value of 425.58 µg g^{-1} soil and the minimum was recorded in T_1 with 221.26 and 224.01 µg g^{-1} soil. From the pooled data it was noted that there was an increase of 91.1% in T_8 in compare to T_1 and 57.6% over RDF (T_2). Biochar is loose and porous material, providing excellent living conditions for the growth of microorganisms (Yamato *et al*., 2006). In addition, the surface structure and carbon content of biochar promotes soil microorganism growth. Biochar can retain water and reduce nutrient leaching by adsorbing cations and anions (Grossman *et al*., 2010) which indirectly improve microbial nutrient utilization, leading to an increase in MBC.

4.2.9 Effect on acid phosphatase activity and alkaline phosphatase activity

Data related to acid phosphatase activity and alkaline phosphatase activity is presented in Table 4.20 and fig. 4.36 and 4.37. It was perceived that biochar application along with fertilizer and pig manure significantly increased the acid phosphatase activity when applied at the rate of 2.5 t ha^{-1}rather than 5.0 t ha^{-1}. The highest acid phosphatase activity was recorded in T_8 treatment with 175.13 and 177.04 µg p-nitrophenol g h^{-1}during 2019 and 2020 respectively, with pooled value of 176.09 µg p-nitrophenol g h^{-1} while lowest was recorded in T_1 with 137.27 and 142.30 µg p-nitrophenol g h^{-1}. Higher doses (5 t ha^{-1}) of wood and bamboo biochar significantly decreased acid phosphatase activity in comparison to lower doses (2.5 t ha^{-1}) of respective biochar. It was also observed that pig manure (T_7) application remarkably enhanced acid phosphates acticity over control (T_1)

and RDF (T_2). Thus, from the pooled data an increase in 25.9% in T_8 over control (T_1) and 19.2% over RDF (T_2)was observed. The reason for the decrease in acid phsophatase activity at higher rate of biochar may be due to the presence of numerous micro-pores on the surface of biochar including surface functional groupswhich can physico-chemically immobilize soil enzyme activityand decrease the soluble substrate available for soil enzymes ultimately hindering soil enzyme activity(Masto*et al*., 2013). Similar results were also reported by Bhaduri *et al*., (2016).

Further, Table 4.20 and fig. 4.37 also signifies the data on alkaline phosphatase activity under different treatments. Increasing the dose of biochar (2.5 to 5.0 t ha^{-1}), significantly increased the alkaline phosphatase activity in soil after harvest. Among the biochars, wood biochar treated soil showed significantly higher values over bamboo biochar at similar application rate. Sole application of pig manure (T_7) significantly enhanced alkaline phosphatase activity over control and RDF (T_2). It is evident that in both the years maximum alkaline phosphatase activity was recorded in T_9 with 113.24 and 115.78 µg p-nitrophenol g h^{-1} and the minimum was recorded in T_1 with 80.65 and 83.08 µg p-nitrophenol g h^{-1}. A critical examination of the data shows that the effect of T_9 was at par with T_8 and that of T_{10} was at par with T_{11}. The T_9 increased pooled alkaline phosphatase activity to the extent of 39.8% over control (T_1) and 27.5% over RDF (T_2). The raise in alkaline phosphatase activity through the biochar application might be due to chemical improvement in enzyme activity which occurred by interaction with biochar, fertilizer and pig manure. Soil holds some quantity of organic phosphorus, so the microbes inhabiting in the biochar pore can liberate the biochar-phosphorus also from the organic matter thereby leading to increased enzyme activity. Similar results were reported by (Das *et al*., 2021).

Table 4.20: Effect of biochar and pig manure on acid phosphatase activity and alkaline phosphatase activity of post harvest soil

Treatments	Acid phosphatase activity (µg p-nitrophenol g^{-1} h^{-1})			Alkaline phosphatase activity (µg p-nitrophenol g^{-1} h^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1-Control	137.27	142.30	139.78	80.65	83.08	81.87
T_2- RDF(20:40:30)	144.93	150.41	147.67	87.20	92.37	89.79
T_3- RDF+2.5t ha^{-1} WB	159.45	162.35	160.90	93.97	96.66	95.31
T_4 -RDF+5.0 t ha^{-1} WB	148.52	157.52	153.02	109.02	111.06	110.04
T_5 -RDF+2.5t ha^{-1} BB	158.29	165.65	161.97	89.99	98.74	94.36
T_6- RDF+5.0 t ha^{-1} BB	146.54	151.50	149.02	101.81	108.66	105.24
T_7- RDF+2.0 t ha^{-1} PM	161.56	166.58	164.07	106.65	109.17	107.91
T_8-RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} WB	175.13	177.04	176.09	111.64	113.20	112.42
T_9- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} WB	165.42	173.42	169.42	113.24	115.78	114.51
T_{10} -RDF+2.0 t ha^{-1} PM+2.5 t ha^{-1} BB	171.20	171.27	171.24	109.57	110.66	110.11
T_{11}- RDF+2.0 t ha^{-1} PM+5.0 t ha^{-1} BB	163.30	172.69	167.99	110.46	111.85	111.16
SEm±	2.95	2.62	1.97	2.32	2.55	1.73
CD (P=0.05)	8.70	7.74	5.64	6.86	7.53	4.93
Initial values	135.76	141.45		79.12	80.45	

WB- Wood biochar, BB- Bamboo biochar, PM- Pig manure

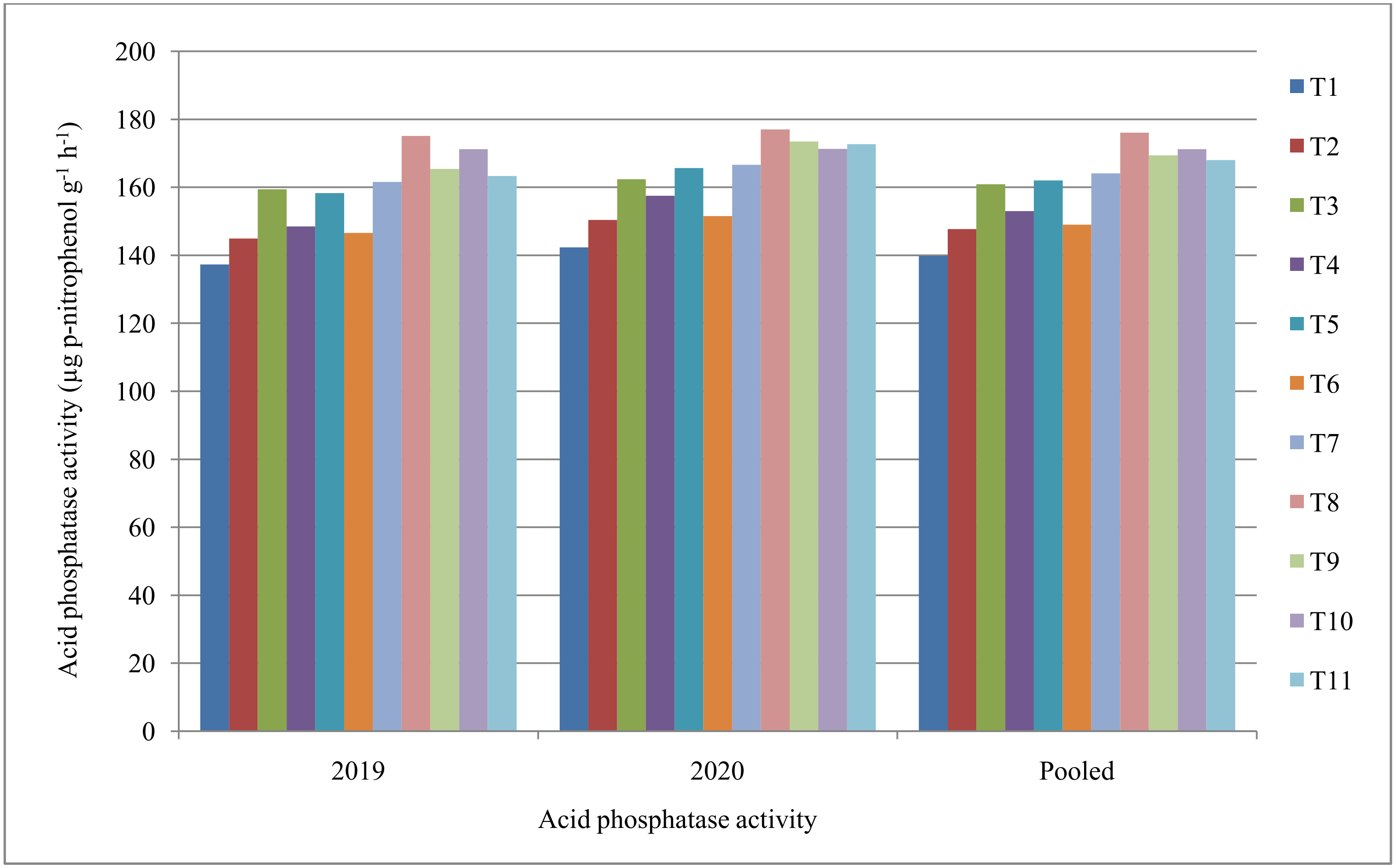


Fig 4.36: Effect of biochar and pig manure on acid phosphatase activity of post harvest soil

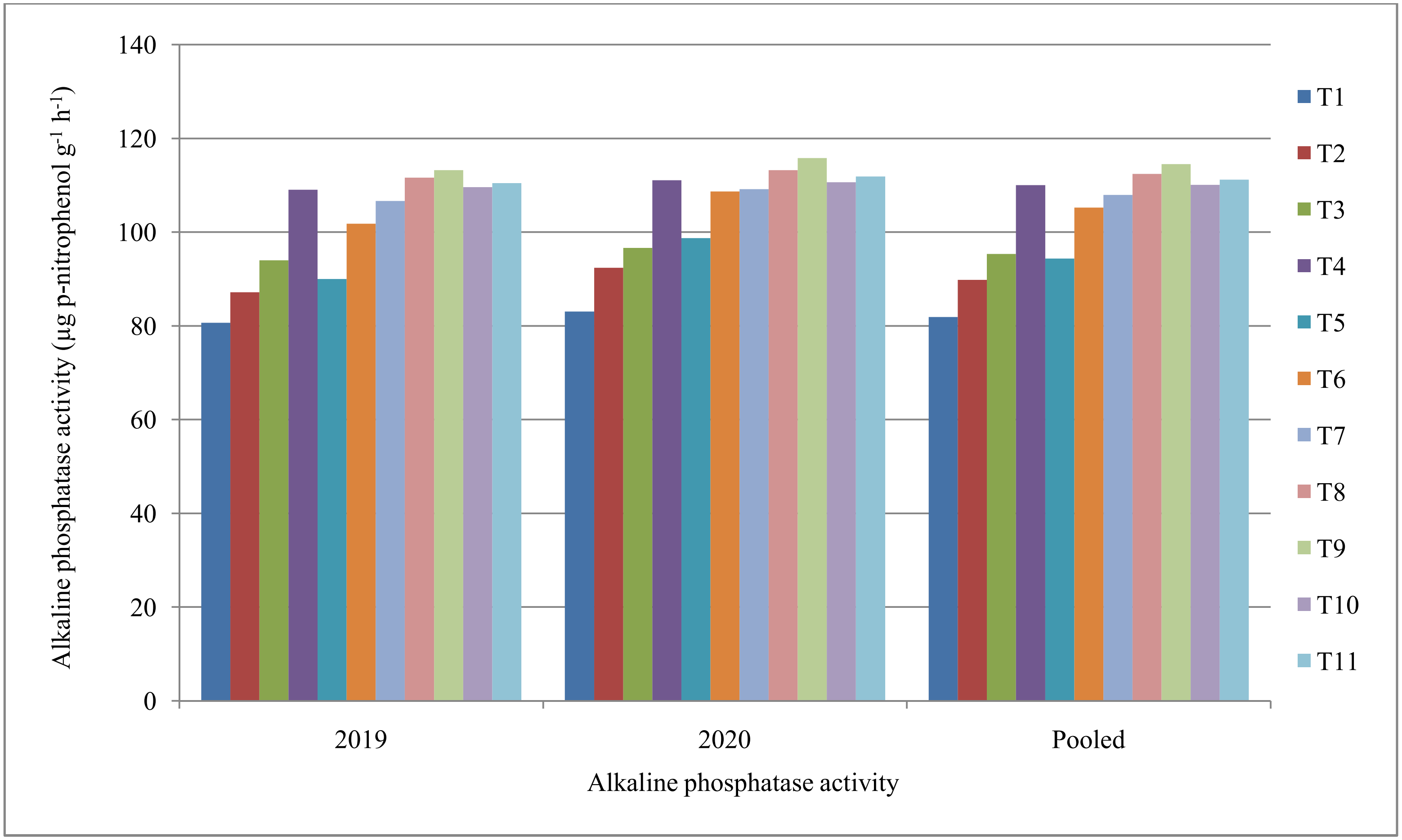


Fig 4.37: Effect of biochar and pig manure on alkaline phosphatase activity of post harvest soil

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A research investigation entitled "Effect of Biochar and Pig Manure on Performance of Ricebean [*Vigna umbellata* (Thunb) Ohwi and Ohashi] and Soil Properties in Dystrudepts" was conducted during the *kharif* season of 2019 and 2020 at the Experimental Farm of the Department of Agricultural Chemistry and Soil Science, School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema, Nagaland. The main findings of the investigation are summarized below:

Effect of biochar and pig manure on growth and yield of ricebean

1. Application of RDF, biochar along with pig manure @ RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB significantly enhanced the plant height at different growth stages. Irrespective of year and treatment, plant height of ricebean varied from 28.84 to 48.12 cm, 70.22 to 131.68 cm and 75.23 to 155.41 cm at 40, 80 DAS and at harvest respectively. Further, it was observed that at 40 DAS biochar and pig manure alone did not increase the plant height significantly over control but at 80 DAS and at harvest plant height was increased significantly with the application of biochar and pig manure. However, combine application of RDF, biochar and pig manure significantly enhanced the plant height over RDF (T_2) treatment.
2. Significantly higher number of branches per plant was recorded at all the growth stages. At 40, 80 DAS and at harvest maximum number of branches per plant was observed at T_9 treatment (7.91 and 7.98, 9.84 and 9.63, 10.60 and 10.65) with pooled value of 7.94, 9.74 and 10.63 at 40, 80 DAS and at harvest during both the years of experimentation. Minimum number of

branches per plant was recorded from control treatment (T_1) during both the year and pooled.

3. Number of pod per plant was increased significantly with RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB application. Maximum number of pod per plant was recorded in T_9 (31.21 and 32.55 with pooled value of 31.88) and minimum number of pod per plant was recorded in T_1 (18.22 and 20.87) during 2019 and 2020. Further from the pooled data it was observed that number of pod per plant increased by 63.1% and 24.8% over control (T_1) and RDF (T_2) with application of T_9 treatment.
4. Effect of RDF, biochar and pig manure on pod length was significant and maximum pod length was recorded in treatment T_9 with 8.14 and 8.22 cm during first and second year of experimentation respectively, while the pooled value was 8.18 cm. The minimum pod length was observed in control treatment T_1 with 5.54 and 5.88 cm with pooled value of 5.71 cm. A critical examination of the data inferred that application of biochar at lower rate (2.5 t ha^{-1}) along with fertilizer and pig manure showed statistically similar pod length as recorded with higher dose of biochar (5.0 t ha^{-1}). However, pod length of ricebean obtained from wood biochar treatments along with pig manure and RDF (treatment T_9) was statistically at par with treatment T_8, T_{10} and T_{11}.
5. The highest number of seed per pod 7.18 and 7.20 was recorded with application of treatment T_9 (RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB) during 2019 and 2020 respectively, with pooled value of 7.19. This was followed by treatment T_8, T_{11} and T_{10} with pooled value of 7.18, 6.93 and 6.91. A critical examination of data indicates that treatment T_9 was at par with treatment T_8, T_{10} and T_{11} with regard to pooled number of seeds per pod. A further examination of the data revealed that treatment T_8, T_9, T_{10} and T_{11} in

case of pooled values enhanced the number of seed per pod to the extent of 18.4, 18.6, 14.0 and 14.3%, respectively over control while these treatments enhanced seed per pod by 14.3, 14.5, 10.0 and 10.3% respectively over lone RDF treatment.

6. Effect of biochar, RDF and pig manure had significant effect on seed yield. The highest seed yield was recorded in treatment T_9 with the value of 1264.42 and 1277.12 kg ha^{-1} during 2019 and 2020 respectively, with pooled value of 1270.77 kg ha^{-1}. The lowest seed yield was found in control treatment T_1 with 678.43 and 725.22 kg ha^{-1}, with pooled value of 701.82 kg ha^{-1}. Application of treatment T_9 (RDF + 2.0 t ha^{-1} PM + 5.0 t ha^{-1} WB) enhanced seed yield by 86.3% and 76.1% during first and second year of experimentation, respectively while pooled seed yield enhanced to the extent of 81.0% over control. The T_9 treatment enhanced pooled seed yield by 38.7% over RDF (T_2 treatment) while application of RDF (T_2 treatment) increased pooled seed yield to the extent of 30.5% over control (T_1).

7. Stover yield of the ricebean increased significantly with combined application of RDF, biochar and pig manure (treatment T_9) during both the years of experimentation. Maximum stover yield was recorded in treatment T_9 with the value of 2567.31 and 2590.82 kg ha^{-1} during 2019 and 2020 with pooled value of 2579.08 kg ha^{-1}. Treatment T_9 increased the stover yield to the extent of 55.6%, 56.8% during the first and second year of experimentation over control with pooled value of 56.2%. Further, analysis of the data also indicated that application of biocar and pig manure (treatment T_3 to T_{11}) increase stover yield significantly over RDF (T_2) during both years of experimentation.

Effect on quality

1. Effect of RDF, biochar and pig manure on nitrogen content in both seed and stover had significant result. In seed, the highest nitrogen content was observed in treatment T_9 with 3.44 and 3.46% during 2019 and 2020 respectively, with pooled value of 3.45% and the lowest nitrogen content was recorded in T_1 with value of 3.13 and 3.15% respectively, with pooled value of 3.14%. Application of RDF (T_2) significantly enhanced nitrogen content in seed as compared to control. In stover the nitrogen content was observed maximum in treatment T_9 with 1.36 and 1.38% during 2019 and 2020 respectively, with pooled value of 1.37%, and minimum nitrogen content was recorded in T_1 with the value of 1.14 and 1.15% respectively, with pooled value of 1.15%. A significant improvement in stover nitrogen content was observed with fertilizer application (T_2) over control. Combined application of biochar and pig manure (T_8 to T_{11}) significantly increased the nitrogen content in stover in comparison to RDF (T_2) during both the years of experimentation.
2. Effect of RDF, biochar and pig manure indicated significant increase in phosphorus content as compare to control treatment in case of both of seed and stover. The highest phosphorus content in seed was recorded in T_9 with 0.40 and 0.42% with pooled value of 0.41%, whereas the lowest phosphorus content in seed was observed in T_1 with 0.24 and 0.25% during 2019 and 2020 respectively, with pooled value of 0.24%. From the pooled data it was observed that P content in seed was found to be increased by 70.8% over control with application of T_9. Similarly in stover, the phosphorus content was highest in T_9 with 0.20 and 0.21% during 2019 and 2020 respectively, with pooled value of 0.21%. The lowest phosphorus content was observed in T_1 with 0.11 and 0.12% with pooled value of

0.12%. Further evaluation of pooled data indicated that P content in stover increased to the extent of 75.0% over control.

3. Effect of RDF, biochar and pig manure on potassium content in seed and stover of ricebean was significant as compare to control. Combined application of biochar and pig manure (T_8 to T_{11}) significantly enhanced potassium content in seed in comparison to sole RDF treatment (T_2) and control (T_1) during both the years of experimentation. In seeds, maximum potassium content 0.96 and 0.97% was recorded in treatment T_9 during 2019 and 2020 with pooled value of 0.97%, while minimum potassium content was recorded in T_1 with 0.81 and 0.82% with pooled value of 0.82%. Similarly, maximum potassium content in stover was recorded in treatment T_9 with 1.55 and 1.56% with pooled value of 1.55%, respectively during both the years of experimentation, while minimum potassium content was recorded in T_1. Treatment T_9 improved the potassium content in stover of ricebean by 11.5%, over control.

4. Application of RDF, biochar and pig manure on sulphur content in seed and stover of ricebean showed significant effects. Maximum sulphur content in seed and stover was recorded in treatment T_9 while minimum was recorded in control treatment (T_1) during 2019 and 2020. Sulphur content in seed during both the years of experimentation was found to be non-significant, pooled value influenced significantly. The pooled data reflected that combined of application of bamboo biochar along with pig manure and RDF treatment (T_{10} and T_{11}) did not increase sulphur content in seed significantly over RDF (T_2) Further, evaluation indicated an increase in sulphur content in seed by 19.2% on combined application of RDF + 2.0 t ha^{-1} Pig manure + 5.0 t ha^{-1} Wood biochar (T_9). The minimum sulphur content in seed was recorded in control treatment (T_1) during both the years of experimentation.

5. Significant effect of RDF, biochar and pig manure on calcium content in seed and stover was recorded highest in T_9 and lowest in control (L_1) during both the years of experimentation. Treatment T_9 enhanced pooled calcium content in seed to the extent of 36.4% over control and 25.0% over RDF (T_2). Treatment T_4 was statistically at par with T_3 while T_6 was at par with T_5, signifying that application of two different biochar at same rate had almost similar effect on calcium content in seed. Application of treatment T_9 enhanced the calcium content in stover to the extent of 19.0% over control and 8.6% over RDF (T_2). Further, the pooled data also revealed that the effect of T_9 was statistically at par with T_8 and $T_{11.}$
6. Application of RDF, biochar and pig manure on magnesium content in seed and stover was found to be non- significant during both the years of experimentation. Maximum magnesium content was recorded in T_9 with 0.19% and minimum was recorded in T_1. It was also observed that application of T_9 treatment was statistically at par with T_8, T_{10} and T_{11}.
7. The nitrogen uptake in both seed and stover showed significant effect among the treatments. Maximum nitrogen uptake in seed (43.53 and 44.13 kg ha^{-1}) was recorded with treatment T_9 during 2019 and 2020 respectively, with pooled value of 43.83 kg ha^{-1}. Treatment T_9 augmented pooled nitrogen uptake in seeds by 98.5% over control while 47.4% over RDF (T_2). Maximum nitrogen uptake in stover varied from 18.81 to 35.65 kg ha^{-1} with pooled value of 35.25 kg ha^{-1}. Application of treatment T_9 significantly augment nitrogen uptake in stover by 86.2%, over control and 46.8% over RDF (T_2). Treatment T_9 was statistically at par with T_8 while T_{11} was at par with T_{10}.

8. The effect of RDF, biochar and pig manure on phosphorus uptake was significant which recorded maximum in T_9. The highest P uptake in seed (5.01 and 5.36 kg ha^{-1}) during 2019 and 2020 was recorded under T_9 treatment, with pooled value of 5.19 kg ha^{-1}, while minimum P uptake was recorded in control treatment (T_1). Application of biochar and pig manure (treatment T_3 to T_{11}) showed significant increment in phosphorus uptake of seed over RDF (T_2). In stover the phosphorus uptake was observed maximum in T_9 with 5.14 and 5.44 kg ha^{-1} during 2019 and 2020, respectively with pooled value of 5.29 kg ha^{-1}. Phosphorus uptake of pooled stover was enhanced by 174.0% in stover with application of T_9 over control and 98.1% over RDF (T_2).
9. The potassium uptake in seed and stover of ricebean was significantly influenced by the combined application of RDF, pig manure and biochar. Maximum potassium uptake in seed was (12.11 and 12.43 kg ha^{-1}) recorded with T_9 treatment with pooled value of 12. 27 kg ha^{-1} while minimum potassium uptake was recorded in control treatment (T_1). Treatment T_9 enhanced potassium uptake in seed by 114.1% over control and 55.5% over RDF (T_2). In stover potassium uptake ranged from 22.71 to 40.42 kg ha^{-1}. Treatment T_9 enhanced potassium uptake in stover by 75.0% over control and 45.8% over RDF (T_2).
10. The combined application of RDF, biochar and pig manure significantly influenced sulphur uptake. The maximum sulphur uptake in seed was recorded in T_9 with 3.84 and 3.95 kg ha^{-1} during 2019 and 2020 respectively, with pooled value of 3.90 kg ha^{-1}. The sulphur content in seed was enhanced by 117.8% with application of treatment T_9 over control (T_1) and 55.3% over RDF (T_2). In stover the sulphur uptake ranged from 1.87 to 3.76 kg ha^{-1} and 2.03 to 4.06 kg ha^{-1} during first and second year

respectively. Combined application of RDF, biochar and pig manure (T_8 to T_{11}) significantly enhanced sulphur uptake in stover over sole RDF (T_2) application during 2019 and 2020. The treatment T_9 enhanced sulphur uptake in stover by 100.5% over control treatment (T_1) and 62.9% over RDF (T_2), furthermore treatment T_9 was statistically at par with T_8, T_{10} and T_{11}.

11. The effect of RDF, biochar and pig manure on calcium uptake in seed and stover was significant which recorded maximum in T_9, while, minimum calcium uptake was associated with control (T_1). Calcium uptake in seed varied from 0.69 to 1.96 kg ha^{-1} however during 2020 the treatment effect was found insignificant. The pooled data in calcium content in stover revealed that RDF, biochar and pig manure application (T_9) increased the calcium uptake in seed by 141.5% over control (T_1) and 70.6% over RDF (T_2). In stover the calcium uptake varied from 3.41 to 6.34 kg ha^{-1} and 3.58 to 6.65 kg ha^{-1} during first and second of experimentation respectively. Further analysis of the data conveyed that treatment T_9 was statistically at par with treatment $T_{8,}$ T_{10} and T_{11}.

12. The effect of biochar and pig manure on magnesium uptake by ricebean in seed and stover was recorded maximum in T_9. The higher uptake of magnesium in seed was influenced by T_9 with 1.01 kg ha^{-1} during 2019, whereas the treatment effect was found non-significant during 2020. The pooled data of treatment T_9 enhanced magnesium uptake in seed by 171.7% over control (T_1) and 76.6% over sole application of RDF (T_2). In stover, maximum magnesium uptake was recorded in T_9 treatment which varied from 2.36 to 4.79 kg ha^{-1} and 2.42 to 5.09 kg ha^{-1} during first and second year respectively. The pooled data conveyed that magnesium uptake in

stover was enhanced to the extent of 106.6% over control and 65.7% over RDF (T_2).

Effect on soil properties

1. Application of wood and bamboo biochar along with RDF and pig manure significantly increased pH of the soil during both the years of experimentation. Maximum pH of the soil was recorded under T_9 treatment with 6.0 and 6.02 respectively, with pooled value of 6.01. Pooled pH of post harvest soil was increased by 14.9% with application of T_9 treatment over control. At lower rate, wood biochar (T_3) significantly increased soil pH as compared to bamboo biochar (T_5). Maximum organic carbon was recorded under T_9 (18.80 and 18.82 g ka^{-1}) with a pooled value of 18.81 g kg^{-1}, while minimum was recorded in T_1 with pooled value of 16.87 g kg^{-1}. Application of treatment T_9 enhanced the pooled organic carbon by 11.4% over control treatment (T_1) and 11.3% over RDF (T_2).
2. Effect of biochar and pig manure was found significant on cation exchange capacity and base saturation. Irrespective of years, cation exchange capacity of post harvest soil varied from 9.72 to 12.62 [cmol (p^+) kg^{-1}. Application of biochar and pig manure along with RDF (T_9) enhanced pooled CEC to the extent of 28.0% over control (T_1) and 23.4% over RDF (T_2). The highest base saturation was recorded in T_9 treatment with 44.98% and 45.65% during 2019 and 2020 respectively, with pooled value of 45.32% and the lowest was recorded in T_1 with 34.92% and 36.14% with pooled value of 35.53%. Combined application of biochar and pig manure (T_8 to T_{11}) indicated significant impact on base saturation in comparison to sole biochar application (T_3 to T_6). Furthermore, pooled base saturation with T_9 application was enhanced by 27.5% over control (T_1) and 15.4% over RDF (T_2).

3. Biochar and pig manure had significant effect on available nitrogen and phosphorus content in the soil after crop harvest. The maximum available nitrogen was recorded in T_9 with 260.50 and 282.30 kg ha^{-1} with a pooled value of 271.40 kg ha^{-1} and the minimum was recorded in control treatment (T_1). Application of wood biochar along with fertilizer and pig manure (T_9) in pooled data amplified available nitrogen by 14.1% over control and 9.0% over RDF (T_2). The available phosphorus in soil varied from 10.07 to 14.38 kg ha^{-1} with pooled value of 13.87 kg ha^{-1}. Highest available phosphorus was observed in treatment (T_9), while minimum was recorded in control treatment (T_1). Due to T_9 treatment pooled available phosphorus improved by 30.97% over control and 9.9% over RDF (T_2).
4. The RDF, biochar and pig manure significantly influenced potassium and sulphur status of post harvest soil. The maximum available potassium in soil after crop harvest was recorded in T_9 with 165.05 and 166.02 kg ha^{-1} during first and second year with pooled value of 165.54 kg ha^{-1}. Application of treatment T_9 enhanced the pooled availability of potassium by 18.3% over control (T_1) and 12.2% over RDF (T_2). The highest available sulphur in soil after harvest during 2019 was recorded in T_9 (15.67 kg ha^{-1}) and during 2020 it was recorded in treatment T_{11} (15.85 kg ha^{-1}) and pooled value of 15.68 kg ha^{-1} while the lowest values were recorded in $T_{1.}$ Due to application of T_9 treatment available sulphur in soil was enhnaced to the extent of 28.4% over control (T_1) and 11.5% over sole RDF treatment (T_2).
5. Effect of biochar and pig manure significantly enhanced exchangeable calcium over control and RDF (T_2) during both the years of experimentation. The highest exchangeable calcium was recorded in treatment T_9 with 4.25 and 4.31 [cmol(p^+)kg^{-1}] respectively, with pooled value of 4.28 [cmol(p^+)kg^{-1}] and the lowest was recorded in T_1 treatment.

The maximum exchangeable magnesium content was recorded in T_9 with pooled value of 1.19 [cmol(p^+)kg^{-1}] and the lowest exchangeable magnesium content was recorded in T_1. However during 2020 the effect of treatments had non-significant effect on exchangeable magnesium content.

6. Effect of types of biochar application along with RDF or combined with pig manure (T_3 to T_6 and T_8 to T_{11}) on exchangeable aluminium was found to be significant over control treatment (T_1) and sole RDF (T_2). Maximum reduction in exchangeable Al was recorded in (T_9) treatment. The maximum exchangeable hydrogen during 2019 and 2020 was observed in control treatment (T_1) with 0.75 and 0.73 [cmol(p^+)kg^{-1}] with pooled value of 0.74 [cmol(p^+)kg^{-1}] while minimum exchangeable hydrogen was observed in T_9 treatment with 0.37 and 0.36 [cmol(p^+)kg^{-1}] with pooled value of 0.37 [cmol(p^+)kg^{-1}].

7. Application of biochar, fertilizer and pig manure had significant effect on exchangeable acidity and total potential acidity. The exchangeable acidity in soil after crop harvest was highest in control treatment (T_1) with 3.06 and 3.01 [cmol (P^+) kg^{-1}]. Lowest values of exchangeable acidity was observed in treatment T_9 (RDF + 2.0 t ha^{-1} Pig manure + 5.0 t ha^{-1} Wood biochar) with 2.08 and 2.04 [cmol(p^+)kg^{-1}]. T_9 treatment reduced exchangeable acidity by 32.2% over control. Biochar amended treatments significantly decreased the total potential acidity of post harvest soil. The maximum reduction was recorded in T_9 with 14.03 and 13.52 [cmol(p^+)kg^{-1}] with pooled value of 13.78 [cmol(p^+)kg^{-1}]. Treatment T_9 decreased total potential acidity to the extent of 21.4% over control (T_1) and 21.3% over RDF (T_2).

8. Application of types of biochar with fertilizer and pig manure (T_7 to T_{11}) significantly increased dehydrogenase activity in the soil after crop harvest over control (T_1). The highest dehydrogenase activity was found under T_9 with 21.88 and 23.03 (µg TPF g^{-1} h^{-1}) during 2019 and 2020 respectively, with pooled value of 22.46 (µg TPF g^{-1} h^{-1}) and the lowest was recorded in T_1 with 18.25 and 19.38 (µg TPF g^{-1} h^{-1}). Wood and bamboo biochar amended soil along with fertilizer and pig manure significantly increased MBC in the soil when compared with control and fertilizer only treatments. Higher amount of MBC was observed in wood biochar treated plots but values were at par to bamboo biochar treated plots. The maximum MBC was recorded in T_8 with 421.28 and 429.89 µg g^{-1} soil during 2019 and 2020 respectively, with pooled value of 425.58 µg g^{-1} soil and the minimum was recorded in T_1 with 221.26 and 224.01 µg g^{-1} soil.

9. Biochar application along with fertilizer and pig manure significantly increased the acid phosphatase activity. The highest acid phosphatase activity was recorded in T_8 treatment with 175.13 and 177.04 µg p-nitrophenol g h^{-1} during 2019 and 2020 respectively, with pooled value of 176.09 µg p-nitrophenol g h^{-1} while lowest was recorded in T_1 with 137.27 and 142.30 µg p-nitrophenol g h^{-1}. An increment of 25.9% with T_8 over control (T_1) and 19.2% over RDF (T_2) was observed. Maximum alkaline phosphatase activity was recorded in T_9 with 113.24 and 115.78 µg p-nitrophenol g h^{-1} and the minimum was recorded in T_1 with 80.65 and 83.08 µg p-nitrophenol g h^{-1}. T_9 treatment increased pooled alkaline phosphatase activity in soil to the extent of 39.8% over control (T_1) and 27.5% over RDF (T_2).

CONCLUSION

The following conclusions can be drawn from the following summary of present investigation

1. Biochar application has the significant potential to boost the agricultural sustainability. Plant growth, yield attributes, yield, nutrients concentration and their uptake by ricebean significantly enhanced with combined application of RDF, biochar and pig manure.
2. Application of biochar enhanced the pH, base saturation, CEC, and available nutrient content of post harvest soil while it reduced the exchangeable acidity, exchangeable aluminium, exchangeable hydrogen, and total potential acidity of the soil.
3. As an environment friendly soil amendment, biochar provides a good living biota for the soil microorganisms thereby promoting soil microbial activity. Dehydrogenase activity, microbial biomass carbon, acid and alkaline phosphatase activity also significantly improved with the application of biochar.
4. As observed from the outcome of the investigation, combined application of RDF + 2.0 t ha^{-1} pig manure + 5.0 t ha^{-1} wood biochar may be recommended for getting better yield of ricebean in Dystrudepts of Nagaland.

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APPENDIX

Appendix I: Effect of biochar and pig manure on plant height of ricebean at 40 DAS

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	77.61	38.80	1.93	12.86	6.43	0.62	3.49	Yr	1	15.84	15.84	1.04	4.08
									R	4	90.47	22.62	1.48	2.61
Treatment	10	611.84	61.18	3.04*	1101.59	110.16	10.58*	2.35	Tr	10	1639.28	163.93	10.73*	2.08
									Y x T	10	74.15	7.41	0.49	2.08
Error	20	402.97	20.15		208.26	10.41			Error	40	611.22	15.28		
Total	32	1092.42			1322.70				Total	65	2430.96			

*Significant at 5%

Appendix II: Effect of biochar and pig manure on plant height of ricebean at 80 DAS

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	210.63	105.31	0.86	267.94	133.97	2.35	3.49	Yr	1	359.24	359.24	4.01	4.08
									Rep	4	478.57	119.64	1.34	2.61
Treatment	10	8383.59	838.36	6.87*	8606.57	860.66	15.10*	2.35	Tr	10	16963.17	1696.32	18.95*	2.08
									Y x T	10	26.99	2.70	0.03	2.08
Error	20	2441.37	122.07		1139.70	56.99			Error	40	3581.07	89.53		
Total	32	11035.59			10014.22				Total	65	21409.05			

*Significant at 5%

Appendix III: Effect of biochar and pig manure on plant height of ricebean at harvest

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	227.00	113.50	1.44	194.95	97.48	0.76	3.49	Yr	1	290.60	290.60	2.80	4.08
									Rep	4	421.96	105.49	1.02	2.61
Treatment	10	12398.54	1239.85	15.73*	12128.44	1212.84	9.42*	2.35	Trt	10	24510.36	2451.04	23.62*	2.08
									Y x T	10	16.62	1.66	0.02	2.08
Error	20	1576.55	78.83		2574.41	128.72			Error	40	4150.96	103.77		
Total	32	14202.10			14897.80				Total	65	29390.50			

*Significant at 5%

Appendix IV: Effect of biochar and pig manure on number of branches per plant of ricebean at 40 DAS

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	1.53	0.77	1.56	2.72	1.36	6.90	3.49	Yr	1	0.62	0.62	1.81	4.08
									Rep	4	4.25	1.06	3.10	2.61
Treatment	10	13.70	1.37	2.80*	14.03	1.40	7.12*	2.35	Trt	10	27.40	2.74	7.98*	2.08
									Y x T	10	0.34	0.03	0.10	2.08
Error	20	9.79	0.49		3.94	0.20			Error	40	13.73	0.34		
Total	32	25.02			20.69				Total	65	46.33			

*Significant at 5%

Appendix V: Effect of biochar and pig manure on number of branches per plant of ricebean at 80 DAS

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.15	0.07	0.15	0.04	0.02	0.07	3.49	Yr	1	0.30	0.30	0.77	4.08
									Rep	4	0.19	0.05	0.12	2.61
Treatment	10	26.11	2.61	5.49*	26.82	2.68	8.94*	2.35	Trt	10	52.09	5.21	13.44*	2.08
									Y x T	10	0.84	0.08	0.22	2.08
Error	20	9.51	0.48		6.00	0.30			Error	40	15.51	0.39	0.77	
Total	32	35.76			32.86				Total	65	68.92			

*Significant at 5%

Appendix VI: Effect of biochar and pig manure on number of branches per plant of ricebean at harvest

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.10	0.05	0.09	1.37	0.68	1.11	3.49	Yr	1	0.03	0.03	0.05	4.08
									Rep	4	1.47	0.37	0.62	2.61
Treatment	10	29.04	2.90	5.00*	28.50	2.85	4.65*	2.35	Trt	10	57.53	5.75	9.64*	2.08
									Y x T	10	0.01	0.00	0.00	2.08
Error	20	11.61	0.58		12.26	0.61			Error	40	23.87	0.60	0.05	
Total	32	40.75			42.13				Total	65	82.91			

*Significant at 5%

Appendix VII: Effect of biochar and pig manure on number of pod per plant of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	20.51	10.25	2.78	13.88	6.94	1.33	3.49	Yr	1	35.17	35.17	7.91	4.08
									Rep	4	34.39	8.60	1.93	2.61
Treatment	10	434.57	43.46	11.80*	368.88	36.89	7.09*	2.35	Trt	10	792.02	79.20	17.82*	2.08
									Y x T	10	11.42	1.14	0.26	2.08
Error	20	73.68	3.68		104.09	5.20			Error	40	177.76	4.44		
Total	32	528.75			486.85				Total	65	1050.78			

*Significant at 5%

Appendix VIII: Effect of biochar and pig manure on pod length of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.30	0.15	0.26	2.80	1.40	4.03	3.49	Yr	1	0.10	0.10	0.23	4.08
									Rep	4	3.10	0.77	1.68	2.61
Treatment	10	14.31	1.43	2.49*	11.57	1.16	3.33*	2.35	Trt	10	25.76	2.58	5.59*	2.08
									Y x T	10	0.12	0.01	0.03	2.08
Error	20	11.48	0.57		6.96	0.35			Error	40	18.44	0.46		
Total	32	26.09			21.33				Total	65	47.52			

*Significant at 5%

Appendix IX: Effect of biochar and pig manure on seed per pod of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.49	0.25	2.47	0.44	0.22	1.60	3.49	Yr	1	0.11	0.11	0.96	4.08
									Rep	4	0.93	0.23	1.97	2.61
Treatment	10	3.82	0.38	3.82*	4.47	0.45	3.26*	2.35	Trt	10	8.14	0.81	6.87*	2.08
									Y x T	10	0.15	0.01	0.13	2.08
Error	20	2.00	0.10		2.47	0.14			Error	40	4.74	0.12		
Total	32	6.31			7.66				Total	65	14.08			

*Significant at 5%

Appendix X: Effect of biochar and pig manure on test weight of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	2.55	1.28	1.21	3.47	1.74	1.11	3.49	Yr	1	0.09	0.09	0.07	4.08
									Rep	4	6.02	1.51	1.15	2.61
Treatment	10	5.37	0.54	0.51	4.33	0.43	0.28	2.35	Trt	10	9.56	0.96	0.73	2.08
									Y x T	10	0.14	0.01	0.01	2.08
Error	20	21.07	1.05		31.25	1.56			Error	40	52.32	1.31		
Total	32	28.99			39.06				Total	65	68.14			

*Significant at 5%

Appendix XI: Effect of biochar and pig manure on seed yield of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	27512.46	13756.23	2.87	2204.74	1102.37	0.30	3.49	Years	1	21562.21	21562.21	5.09	4.08
									Replication	4	29717.20	7429.30	1.76	2.61
Treatment	10	824204.15	82420.42	17.18*	791146.52	79114.65	21.56*	2.35	Treatment	10	1602383.54	160238.35	37.85*	2.08
									Y x T	10	12967.13	1296.71	0.31	2.08
Error	20	95939.79	4796.99		73378.45	3668.92			Error	40	169318.25	4232.96		
Total	32	947656.41			866729.72				Total	65	1835948.34			

*Significant at 5%

Appendix XII: Effect of biochar and pig manure on stover yield of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	17974.11	8987.06	1.75	4350.87	2175.44	0.38	3.49	Years	1	318.17	318.17	0.06	4.08
									Replication	4	22324.98	5581.25	1.03	2.61
Treatment	10	2402523.49	240252.35	46.82*	2418844.99	241884.50	42.43*	2.35	Treatment	10	4818945.41	481894.54	88.97*	2.08
									Y x T	10	2423.07	242.31	0.04	2.08
Error	20	102635.32	5131.77		114010.66	5700.53			Error	40	216645.98	5416.15		
Total	32	2523132.92			2537206.52				Total	65	5060657.61			

*Significant at 5%

Appendix XIII: Effect of biochar and pig manure on nitrogen content in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	1	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.004	0.002	1.02	0.003	4 10	0.87	3.49	Years	1	0.01	0.01	5.02	4.08
									Replication	4	0.01	0.002	0.95	2.61
Treatment	10	0.30	0.03	15.82*	0.24	10 40	13.71*	2.35	Treatment	10	0.54	0.05	29.32*	2.08
									Y x T	10	0.00	0.0005	0.27	2.08
Error	20	0.04	0.002		0.04	65			Error	40	0.07	0.002		
Total	32	0.34			0.28	DF			Total	65	0.63			

*Significant at 5%

Appendix XIV: Effect of biochar and pig manure on nitrogen content in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.004	0.002	1.11	0.005	0.002	0.66	3.49	Years	1	0.01	0.01	1.94	4.08
									Replication	4	0.01	0.00	0.81	2.61
Treatment	10	0.12	0.01	6.63*	0.13	0.01	3.62*	2.35	Treatment	10	0.24	0.02	9.18*	2.08
									Y x T	10	0.002	0.0002	0.08	2.08
Error	20	0.04	0.002		0.07	0.003			Error	40	0.10	0.003		
Total	32	0.16			0.20				Total	65	0.36			

*Significant at 5%

Appendix XV: Effect of biochar and pig manure on phosphorus content in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.0002	0.0001	0.38	0.0001	0.0003	0.75	3.49	Years	1	0.01	0.01	35.20	4.08
									Replication	4	0.001	0.0002	0.58	2.61
Treatment	10	0.06	0.01	20.93*	0.07	0.01	20.83*	2.35	Treatment	10	0.13	0.01	41.38*	2.08
									Y x T	10	0.001	0.0001	0.38	2.08
Error	20	0.01	0.0003		0.01	0.0003			Error	40	0.01	0.0003		
Total	32	0.07			0.08				Total	65	0.16			

*Significant at 5%

Appendix XVI: Effect of biochar and pig manure on phosphorus content in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.0001	0.0001	0.61	0.001	0.0004	1.49	3.49	Years	1	0.002	0.002	8.20	4.08
									Replication	4	0.001	0.0003	1.27	2.61
Treatment	10	0.02	0.002	19.74*	0.02	0.002	5.82*	2.35	Treatment	10	0.04	0.004	18.72*	2.08
									Y x T	10	0.0002	0.00002	0.08	2.08
Error	20	0.002	0.0001		0.01	0.0003			Error	40	0.01	0.0002		
Total	32	0.02			0.02				Total	65	0.05			

*Significant at 5%

Appendix XVII: Effect of biochar and pig manure on potassium content in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.001	0.0003	0.26	0.002	0.001	1.93	3.49	Years	1	0.004	0.004	4.68	4.08
									Replication	4	0.003	0.001	0.82	2.61
Treatment	10	0.07	0.01	6.07*	0.006	0.01	11.20*	2.35	Treatment	10	0.13	0.01	15.48*	2.08
									Y x T	10	0.001	0.0001	0.09	2.08
Error	20	0.02	0.001		0.01	0.001			Error	40	0.03	0.001		
Total	32	0.09			0.07				Total	65	0.16			

*Significant at 5%

Appendix XVIII: Effect of biochar and pig manure on potassium content in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.0005	0.0002	0.52	0.002	0.001	1.28	3.49	Years	1	0.01	0.01	14.90	4.08
									Replication	4	0.002	0.001	0.95	2.61
Treatment	10	0.07	0.01	15.18*	0.08	0.01	12.42*	2.35	Treatment	10	0.15	0.01	27.12*	2.08
									Y x T	10	0.001	0.0001	0.12	2.08
Error	20	0.01	0.0005		0.01	0.001			Error	40	0.02	0.001		
Total	32	0.08			0.001				Total	65	0.18			

*Significant at 5%

Appendix XIX: Effect of biochar and pig manure on sulphur content in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.0001	0.00004	0.09	0.00001	0.000003	0.01	3.49	Years	1	0.002	0.002	5.64	4.08
									Replication	4	0.0001	0.00002	0.05	2.61
Treatment	10	0.01	0.001	2.02	0.005	0.0005	1.28	2.35	Treatment	10	0.01	0.001	3.12*	2.08
									Y x T	10	0.001	0.0001	0.24	2.08
Error	20	0.01	0.0004		0.01	0.0004			Error	40	0.02	0.0004		
Total	32	0.02			0.01				Total	65	0.03			

*Significant at 5%

Appendix XX: Effect of biochar and pig manure on sulphur content in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.00004	0.00002	0.06	0.001	0.0003	0.62	3.49	Years	1	0.002	0.002	5.65	4.08
									Replication	4	0.001	0.0002	0.39	2.61
Treatment	10	0.003	0.0003	0.76	0.004	0.0004	0.80	2.35	Treatment	10	0.01	0.001	1.43	2.08
									Y x T	10	0.001	0.0001	0.14	2.08
Error	20	0.01	0.0003		0.01	0.0005			Error	40	0.02	0.0004		
Total	32	0.01			0.01				Total	65	0.03			

*Significant at 5%

Appendix XXI: Effect of biochar and pig manure on calcium content in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.001	0.004	2.75	0.004	0.002	1.76	3.49	Years	1	0.003	0.003	4.42	4.08
									Replication	4	0.005	0.001	1.89	2.61
Treatment	10	0.005	0.0005	3.05*	0.004	0.0004	0.34	2.35	Treatment	10	0.01	0.001	1.30	2.08
									Y x T	10	0.0005	0.00005	0.08	2.08
Error	20	0.003	0.0002		0.02	0.001			Error	40	0.03	0.001		
Total	32	0.01			0.03				Total	65	0.04			

*Significant at 5%

Appendix XXII: Effect of biochar and pig manure on calcium content in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.002	0.001	2.84	0.002	0.001	4.52	3.49	Years	1	0.001	0.001	2.92	4.08
									Replication	4	0.005	0.001	3.49	2.61
Treatment	10	0.004	0.0004	1.03	0.005	0.0005	1.86	2.35	Treatment	10	0.01	0.001	2.61*	2.08
									Y x T	10	0.0003	0.00003	0.09	2.08
Error	20	0.01	0.0004		0.01	0.0003			Error	40	0.01	0.0003		
Total	32	0.01			0.01				Total	65	0.03			

*Significant at 5%

Appendix XXIII: Effect of biochar and pig manure on magnesium content in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.00002	0.00001	0.03	0.00004	0.00002	0.05	3.49	Years	1	0.001	0.001	2.49	4.08
									Replication	4	0.0001	0.00002	0.04	2.61
Treatment	10	0.003	0.0003	0.76	0.002	0.0002	0.37	2.35	Treatment	10	0.004	0.0004	0.93	2.08
									Y x T	10	0.001	0.0001	0.17	2.08
Error	20	0.01	0.0004		0.01	0.0004			Error	40	0.02	0.0004		
Total	32	0.01			0.01				Total	65	0.02			

*Significant at 5%

Appendix XXIV: Effect of biochar and pig manure on magnesium content in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.001	0.001	1.76	0.001	0.0004	1.46	3.49	Years	1	0.001	0.001	2.14	4.08
									Replication	4	0.002	0.001	1.61	2.61
Treatment	10	0.01	0.001	1.59	0.01	0.001	1.83	2.35	Treatment	10	0.01	0.001	3.28*	2.08
									Y x T	10	0.0004	0.00004	0.13	2.08
Error	20	0.01	0.0003		0.01	0.0003			Error	40	0.01	0.0003		
Total	32	0.01			0.01				Total	65	0.03			

*Significant at 5%

Appendix XXV: Effect of biochar and pig manure on nitrogen uptake in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	41.35	20.67	3.33	2.33	1.16	0.28	3.49	Years	1	34.55	34.55	6.62	4.08
									Replication	4	43.67	10.92	2.09	2.61
Treatment	10	1218.10	121.81	19.62*	1173.69	117.37	27.78*	2.35	Treatment	10	2377.70	237.77	45.58*	2.08
									Y x T	10	14.08	1.41	0.27	2.08
Error	20	124.17	6.21		84.49	4.22			Error	40	208.67	5.22		
Total	32	1383.62			1260.51				Total	65	2678.67			

*Significant at 5%

Appendix XXVI: Effect of biochar and pig manure on nitrogen uptake in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	1.57	0.78	0.52	4.76	2.38	0.66	3.49	Years	1	3.79	3.79	1.48	4.08
									Replication	4	6.33	1.58	0.62	2.61
Treatment	10	700.98	70.10	46.95*	731.80	73.18	20.20*	2.35	Treatment	10	1430.59	143.06	55.93*	2.08
									Y x T	10	2.18	0.22	0.09	2.08
Error	20	29.86	1.49		72.46	3.62			Error	40	102.32	2.56		
Total	32	732.40			809.01				Total	65	1545.21			

*Significant at 5%

Appendix XXVII: Effect of biochar and pig manure on phosphorus uptake in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.29	0.14	1.61	0.11	0.06	0.69	3.49	Years	1	2.90	2.90	34.04	4.08
									Replication	4	0.40	0.10	1.18	2.61
Treatment	10	28.50	2.85	31.85*	31.62	3.16	39.03*	2.35	Treatment	10	59.66	5.97	69.97*	2.08
									Y x T	10	0.46	0.05	0.54	2.08
Error	20	1.79	0.09		1.62	0.08			Error	40	3.41	0.09		
Total	32	30.58			33.35				Total	65	66.83			

*Significant at 5%

Appendix XXVIII: Effect of biochar and pig manure on phosphorus uptake in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.18	0.09	1.48	0.34	0.17	1.23	3.49	Years	1	0.87	0.87	8.73	4.08
									Replication	4	0.52	0.13	1.30	2.61
Treatment	10	28.67	2.87	48.17*	28.18	2.82	20.07*	2.35	Treatment	10	56.78	5.68	56.81*	2.08
									Y x T	10	0.06	0.01	0.06	2.08
Error	20	1.19	0.06		2.81	0.14			Error	40	4.00	0.10		
Total	32	30.04			31.33				Total	65	62.24			

*Significant at 5%

Appendix XXIX: Effect of biochar and pig manure on potassium uptake in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	2.73	1.37	2.12	0.02	0.01	0.03	3.49	Years	1	3.90	3.90	8.23	4.08
									Replication	4	2.75	0.69	1.45	2.61
Treatment	10	107.11	10.71	16.64*	107.01	10.70	35.05*	2.35	Treatment	10	213.03	21.30	44.90*	2.08
									Y x T	10	1.09	0.11	0.23	2.08
Error	20	12.87	0.64		6.11	0.31			Error	40	18.98	0.47		
Total	32	122.71			113.14				Total	65	239.76			

*Significant at 5%

Appendix XXX: Effect of biochar and pig manure on potassium uptake in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	5.31	2.65	1.93	3.35	1.67	0.82	3.49	Years	1	5.54	5.54	3.24	4.08
									Replication	4	8.66	2.16	1.26	2.61
Treatment	10	788.92	78.89	57.33*	822.29	82.23	40.17*	2.35	Treatment	10	1610.71	161.07	94.11*	2.08
									Y x T	10	0.49	0.05	0.03	2.08
Error	20	27.52	1.38		40.94	2.05			Error	40	68.46	1.71		
Total	32	821.75			866.58				Total	65	1693.86			

*Significant at 5%

Appendix XXXI: Effect of biochar and pig manure on sulphur uptake in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.16	0.08	0.79	0.02	0.01	0.09	3.49	Years	1	0.79	0.79	8.41	4.08
									Replication	4	0.18	0.04	0.47	2.61
Treatment	10	11.09	1.11	10.92*	10.12	1.01	11.76*	2.35	Treatment	10	21.02	2.10	22.39*	2.08
									Y x T	10	0.20	0.02	0.21	2.08
Error	20	2.03	0.10		1.72	0.09			Error	40	3.75	0.09		
Total	32	13.28			11.86				Total	65	25.94			

*Significant at 5%

Appendix XXXII: Effect of biochar and pig manure on sulphur uptake in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.13	0.06	0.31	0.32	0.16	0.54	3.49	Years	1	1.27	1.27	5.01	4.08
									Replication	4	0.45	0.11	0.45	2.61
Treatment	10	9.18	0.92	4.44*	11.33	1.13	3.77*	2.35	Treatment	10	20.13	2.01	7.93*	2.08
									Y x T	10	0.38	0.04	0.15	2.08
Error	20	4.13	0.21		6.02	0.30			Error	40	10.15	0.25		
Total	32	13.44			17.68				Total	65	32.39			

*Significant at 5%

Appendix XXXIII: Effect of biochar and pig manure on calcium uptake in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.09	0.05	2.74	0.49	0.24	1.47	3.49	Years	1	0.60	0.60	6.53	4.08
									Replication	4	0.58	0.15	1.59	2.61
Treatment	10	2.51	0.25	15.17*	2.90	0.29	1.74	2.35	Treatment	10	5.32	0.53	5.81*	2.08
									Y x T	10	0.10	0.01	0.11	2.08
Error	20	0.33	0.02		3.33	0.17			Error	40	3.66	0.09		
Total	32	2.93			6.72				Total	65	10.25			

*Significant at 5%

Appendix XXXIV: Effect of biochar and pig manure on calcium uptake in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	1.89	0.95	3.69	1.01	0.51	2.94	3.49	Years	1	0.55	0.55	2.56	4.08
									Replication	4	2.90	0.73	3.38	2.61
Treatment	10	21.86	2.19	8.52*	24.06	2.41	13.97*	2.35	Treatment	10	45.70	4.57	21.32*	2.08
									Y x T	10	0.22	0.02	0.10	2.08
Error	20	5.13	0.26		3.44	0.17			Error	40	8.58	0.21		
Total	32	28.89			28.52				Total	65	57.96			

*Significant at 5%

Appendix XXXV: Effect of biochar and pig manure on magnesium uptake in seed of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.02	0.01	0.26	0.004	0.002	0.04	3.49	Years	1	0.22	0.22	4.42	4.08
									Replication	4	0.02	0.01	0.12	2.61
Treatment	10	1.20	0.12	3.26*	1.01	0.10	1.65	2.35	Treatment	10	2.14	0.21	4.37*	2.08
									Y x T	10	0.07	0.01	0.14	2.08
Error	20	0.74	0.04		1.22	0.06			Error	40	1.96	0.05		
Total	32	1.96			2.23				Total	65	4.41			

*Significant at 5%

Appendix XXXVI: Effect of biochar and pig manure on magnesium uptake in stover of ricebean

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.78	0.39	2.09	0.37	0.19	1.19	3.49	Years	1	0.37	0.37	2.17	4.08
									Replication	4	1.15	0.29	1.68	2.61
Treatment	10	16.07	1.61	8.65*	17.11	1.71	10.95*	2.35	Treatment	10	32.95	3.30	19.27*	2.08
									Y x T	10	0.22	0.02	0.13	2.08
Error	20	3.72	0.19		3.13	0.16			Error	40	6.84	0.17		
Total	32	20.56			20.61				Total	65	41.54			

*Significant at 5%

Appendix XXXVII: Effect of biochar and pig manure on pH of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.01	0.004	2.06	0.003	0.002	0.67	3.49	Years	1	0.007	0.007	2.87	4.08
									Replication	4	0.012	0.003	1.30	2.61
Treatment	10	1.84	0.184	85.20*	1.81	0.181	70.41*	2.35	Treatment	10	3.652	0.365	154.21*	2.08
									Y x T	10	0.003	0.000	0.11	2.08
Error	20	0.04	0.002		0.05	0.003			Error	40	0.095	0.002		
Total	32	1.89			1.87				Total	65	3.77			

*Significant at 5%

Appendix XXXVIII: Effect of biochar and pig manure on organic carbon of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.56	0.28	5.64	0.12	0.06	1.05	3.49	Years	1	0.01	0.01	0.25	4.08
									Replication	4	0.67	0.17	3.19	2.61
Treatment	10	16.38	1.64	33.25*	16.34	1.63	28.99*	2.35	Treatment	10	32.72	3.27	61.94*	2.08
									Y x T	10	0.001	0.0001	0.003	2.08
Error	20	0.99	0.05		1.13	0.06			Error	40	2.11	0.05		
Total	32	17.92			17.59				Total	65	35.53			

*Significant at 5%

Appendix XXXIX: Effect of biochar and pig manure on cation exchange capacity of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.21	0.11	0.89	0.05	0.02	0.18	3.49	Years	1	0.04	0.04	0.35	4.08
									Replication	4	0.26	0.07	0.51	2.61
Treatment	10	27.78	2.78	23.28*	25.08	2.51	18.69*	2.35	Treatment	10	52.80	5.28	41.65*	2.08
									Y x T	10	0.06	0.01	0.05	2.08
Error	20	2.39	0.12		2.68	0.13			Error	40	5.07	0.13		
Total	32	30.38			27.81				Total	65	58.23			

*Significant at 5%

Appendix XXXX: Effect of biochar and pig manure on base saturation of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	18.14	9.07	5.20	25.21	12.60	19.49	3.49	Years	1	3.64	3.64	3.04	4.08
									Replication	4	43.35	10.84	9.06	2.61
Treatment	10	256.09	25.61	14.68*	220.29	22.03	34.07*	2.35	Treatment	10	472.44	47.24	39.51*	2.08
									Y x T	10	3.94	0.39	0.33	2.08
Error	20	34.90	1.74		12.93	0.65			Error	40	47.83	1.20		
Total	32	309.13			258.43				Total	65	571.20			

*Significant at 5%

Appendix XXXXI: Effect of biochar and pig manure on available nitrogen of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	12.13	6.07	0.25	45.72	22.86	1.86	3.49	Years	1	10299.50	10299.50	565.57	4.08
									Replication	4	57.86	14.46	0.79	2.61
Treatment	10	2598.41	259.84	10.78*	2741.47	274.15	22.27*	2.35	Treatment	10	5085.55	508.56	27.93*	2.08
									Y x T	10	254.34	25.43	1.40	2.08
Error	20	482.19	24.11		246.24	12.31			Error	40	728.44	18.21		
Total	32	3092.74			3033.44				Total	65	16425.69			

*Significant at 5%

Appendix XXXXII: Effect of biochar and pig manure on available phosphorus of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.01	0.004	0.68	0.001	0.0003	0.17	3.49	Years	1	17.34	17.34	4377.89	4.08
									Replication	4	0.01	0.002	0.55	2.61
Treatment	10	28.99	2.90	489.72*	28.74	2.87	1435.10*	2.35	Treatment	10	57.72	5.77	1457.36*	2.08
									Y x T	10	0.003	0.0003	0.08	2.08
Error	20	0.12	0.01		0.04	0.002			Error	40	0.16	0.004		
Total	32	29.11			28.78				Total	65	75.24			

*Significant at 5%

Appendix XXXXIII: Effect of biochar and pig manure on available potassium of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	360.74	180.37	3.93	472.38	236.19	3.73	3.49	Years	1	42.72	42.72	0.78	4.08
									Replication	4	833.12	208.28	3.81	2.61
Treatment	10	1894.93	189.49	4.13*	1719.28	171.93	2.71*	2.35	Treatment	10	3605.65	360.57	6.60*	2.08
									Y x T	10	8.56	0.86	0.02	2.08
Error	20	918.24	45.91		1267.73	63.39			Error	40	2185.98	54.65		
Total	32	3173.92			3459.40				Total	65	6676.04			

*Significant at 5%

Appendix XXXXIV: Effect of biochar and pig manure on available sulphur of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	1.71	0.85	1.69	1.34	0.67	1.56	3.49	Years	1	0.14	0.14	0.30	4.08
									Replication	4	3.04	0.76	1.63	2.61
Treatment	10	37.40	3.74	7.39*	29.98	3.00	6.98*	2.35	Treatment	10	67.08	6.71	14.34*	2.08
									Y x T	10	0.30	0.03	0.06	2.08
Error	20	10.12	0.51		8.59	0.43			Error	40	18.71	0.47		
Total	32	49.23			39.91				Total	65	89.28			

*Significant at 5%

Appendix XXXXV: Effect of biochar and pig manure on exchangeable calcium of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.47	0.23	10.14	0.30	0.15	12.52	3.49	Years	1	0.03	0.03	1.75	4.08
									Replication	4	0.76	0.19	10.95	2.61
Treatment	10	13.34	1.33	57.83*	12.11	1.21	102.23*	2.35	Treatment	10	25.39	2.54	145.41*	2.08
									Y x T	10	0.07	0.01	0.38	2.08
Error	20	0.46	0.02		0.24	0.01			Error	40	0.70	0.02		
Total	32	14.27			12.65				Total	65	26.95			

*Significant at 5%

Appendix XXXXVI: Effect of biochar and pig manure on exchangeable magnesium of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.001	0.0005	0.56	0.0005	0.0002	0.47	3.49	Years	1	0.01	0.01	9.59	4.08
									Replication	4	0.001	0.0003	0.53	2.61
Treatment	10	0.02	0.002	2.37*	0.01	0.001	1.84	2.35	Treatment	10	0.03	0.003	4.11*	2.08
									Y x T	10	0.002	0.0002	0.24	2.08
Error	20	0.02	0.001		0.01	0.0005			Error	40	0.03	0.001		
Total	32				0.02				Total	65	0.06			

*Significant at 5%

Appendix XXXXVII: Effect of biochar and pig manure on exchangeable aluminium of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.04	0.02	2.23	0.03	0.02	5.36	3.49	Years	1	0.02	0.02	2.97	4.08
									Replication	4	0.07	0.02	3.09	2.61
Treatment	10	2.05	0.20	25.12*	1.94	0.19	62.77*	2.35	Treatment	10	3.98	0.40	70.81*	2.08
									Y x T	10	0.01	0.001	0.12	2.08
Error	20	0.16	0.01		0.06	0.003			Error	40	0.22	0.01		
Total	32	2.25			2.04				Total	65	4.30			

*Significant at 5%

Appendix XXXXVIII: Effect of biochar and pig manure on exchangeable hydrogen of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.003	0.001	0.71	0.002	0.001	0.40	3.49	Years	1	0.01	0.01	2.56	4.08
									Replication	4	0.005	0.001	0.55	2.61
Treatment	10	0.56	0.06	28.26*	0.59	0.06	27.41*	2.35	Treatment	10	1.15	0.11	55.61*	2.08
									Y x T	10	0.001	0.0001	0.03	2.08
Error	20	0.04	0.002		0.04	0.002			Error	40	0.08	0.002		
Total	32	0.60			0.63				Total	65	1.24			

*Significant at 5%

Appendix XXXXIX: Effect of biochar and pig manure on exchangeable acidity of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.02	0.01	0.75	0.05	0.02	4.47	3.49	Years	1	0.04	0.04	4.46	4.08
									Replication	4	0.07	0.02	1.89	2.61
Treatment	10	4.40	0.44	34.66*	4.28	0.43	76.74*	2.35	Treatment	10	8.67	0.87	94.92*	2.08
									Y x T	10	0.01	0.001	0.09	2.08
Error	20	0.25	0.01		0.11	0.01			Error	40	0.37	0.01		
Total	32	4.67			4.44				Total	65	9.15			

*Significant at 5%

Appendix XXXXX: Effect of biochar and pig manure on total potential acidity of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.36	0.18	0.66	0.95	0.48	1.00	3.49	Years	1	1.36	1.36	3.64	4.08
									Replication	4	1.32	0.33	0.88	2.61
Treatment	10	41.51	4.15	15.06*	51.20	5.12	10.78*	2.35	Treatment	10	91.77	9.18	24.45*	2.08
									Y x T	10	0.95	0.09	0.25	2.08
Error	20	5.51	0.28		9.50	0.48			Error	40	15.01	0.38		
Total	32	47.39			61.66				Total	65	110.41			

*Significant at 5%

Appendix XXXXXI: Effect of biochar and pig manure on dehydrogenase activity of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	0.91	0.45	0.52	5.78	2.89	3.25	3.49	Years	1	18.69	18.69	21.22	4.08
									Replication	4	6.68	1.67	1.90	2.61
Treatment	10	41.13	4.11	4.72*	44.71	4.47	5.03*	2.35	Treatment	10	84.69	8.47	9.62*	2.08
									Y x T	10	1.15	0.11	0.13	2.08
Error	20	17.43	0.87		17.79	0.89			Error	40	35.22	0.88		
Total	32	59.47			68.28				Total	65	146.43			

*Significant at 5%

Appendix XXXXXII: Effect of biochar and pig manure on microbial biomass carbon of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	419.25	209.62	1.44	123.34	61.67	1.04	3.49	Years	1	769.57	769.57	7.49	4.08
									Replication	4	542.58	135.65	1.32	2.61
Treatment	10	138717.49	13871.75	94.99*	140445.45	14044.54	236.54*	2.35	Treatment	10	279100.14	27910.01	271.75*	2.08
									Y x T	10	62.79	6.28	0.06	2.08
Error	20	2920.66	146.03		1187.52	59.38			Error	40	4108.18	102.70		
Total	32	142057.40			141756.30				Total	65	284583.28			

*Significant at 5%

Appendix XXXXXIII: Effect of biochar and pig manure on acid phosphatase activity of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	5.92	2.96	0.11	3.67	1.84	0.09	3.49	Years	1	476.45	476.45	20.37	4.08
									Replication	4	9.59	2.40	0.10	2.61
Treatment	10	4151.66	415.17	15.90*	3711.90	371.19	17.96*	2.35	Treatment	10	7733.39	773.34	33.07*	2.08
									Y x T	10	130.17	13.02	0.56	2.08
Error	20	522.06	26.10		413.33	20.67			Error	40	935.39	23.38		
Total	32	4679.63			4128.91				Total	65	9284.99			

*Significant at 5%

Appendix XXXXXIV: Effect of biochar and pig manure on alkaline phosphatase activity of post-harvest soil

SOV	DF	2019			2020				SOV		Pooled			F tab
		SS	MSS	F Cal	SS	MSS	F Cal	F tab		DF	SS	MSS	F Cal	
Replication	2	103.26	51.63	3.18	115.07	57.54	2.94	3.49	Years	1	186.95	186.95	10.45	4.08
									Replication	4	218.34	54.58	3.05	2.61
Treatment	10	3891.71	389.17	24.00*	3232.28	323.23	16.53*	2.35	Treatment	10	7032.27	703.23	39.32*	2.08
									Y x T	10	91.73	9.17	0.51	2.08
Error	20	324.25	16.21		391.09	19.55			Error	40	715.34	17.88		
Total	32	4319.23			3738.45				Total	65	8244.63			

*Significant at 5%