PROBING THE IMPACT OF BIOCHAR COMBINED FERTILIZERS ON SOIL NUTRIENT STATUS IN RELATION TO GROWTH AND YIELD OF RICE-WHEAT CROPPING SYSTEM

A Thesis

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By

(ANITA JASWAL)

(41700110)

Supervised By
Dr. Chandra Mohan Mehta

Co-Supervised by
Dr. Anaytullah Siddique

LOVELY PROFESSIONAL UNIVERSITY
PUNJAB2020

DECLARATION

I do here by declare that this thesis entitled **“PROBING THE IMPACT OF BIOCHAR COMBINED FERTILIZERS ON SOIL NUTRIENT STATUS IN RELATION TO GROWTH AND YIELD OF RICE- WHEAT CROPPING SYSTEM”** is a bonafied record of the research work carried out by me and no part of the thesis has been submitted earlier to any University or Institute for the award of any degree or diploma.

Anita Jaswal
30/10/2020

Date: 30-10-2020 **(Anita Jaswal)**

Certificate-I

This is to certify that this thesis entitled ""**PROBING THE IMPACT OF BIOCHAR COMBINED FERTILIZERS ON SOIL NUTRIENT STATUS IN RELATION TO GROWTH AND YIELD OF RICE- WHEAT CROPPING SYSTEM"** being submitted by Anita Jaswal for the award of Degree of Doctor of Philosophy (Agronomy) to the Lovely Professional University is a record of bonafied research work carried out by her under our supervision and guidance. The thesis has reached the standard fulfilling the requirements of the regulation relating to the degree.

(Dr. Chandra Mohan Mehta) **(Dr. Anaytullah Siddique)**

CERTIFICATE- II

This is to certify that the thesis entitled "**PROBING THE IMPACT OF BIOCHAR COMBINED FERTILIZERS ON SOILNUTRIENT STATUS IN RELATION TO GROWTH AND YIELD OF RICE- WHEAT CROPPING SYSTEM"** submitted by Anita Jaswal to the Lovely Professional University, Phagwara in partial fulfilment of the requirements for the degree of Doctor of Philosophy (Agronomy) has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

Dr. Chandra Mohan Mehta
Associate Professor
School of Agriculture

(   )
External Examiner

Dr. Anaytullah Siddique
Assistant Professor
School of Agriculture

Head of the Department

Dean, School of Agriculture

Abstract:

Agricultural production of farmers in Punjab is facing the problem of soil fertility degradation and in consequence, crop yields decline because of the imbalances of nutrient supply. After the harvest of crops the residual portion above ground removed from field during land preparation for the succeeding crop. The mineralization rate increased due to high temperature and release mineral nutrients which lost from fallow lands prior to sowing of succeeding crop. Farmers used mineral fertilizers to crops for the self –sufficiency of food .The cropping period could prolong with the supply of irrigation water, but crop yields are reducing year by year. The maintenance of the threshold level of organic matter for improving physico -chemical and biological properties of soil for sustainable crop production is very crucial. Proper use of crop biomass by transforming into beneficial source of soil amendment is one option to maintain soil health and fertility. The recent availabilty of crop biomass in India is approximately 500 Million tonnes per year. So, these residues may or may not utilize properly. 93 million tonnes of residue burnt in India every year. Residue burning is the traditionally a fast and cheap way to clear the field from residues and ease in land preparation. Although the burning of residual biomass not only deplete the soil from nutrients but also release toxic gases i.e. greenhouse gases. Regarding to this context, biochar which is a pyrolysis product of crop biomass provides a significant, multidimensional opportunity to convert the residual part of the agricultural crop from economic and environmental liability to valuable assets. The application of biochar to soils is one of the suitable options which can increase rates of C sequestration in soil, decrease farm waste and increase the soil fertility by improving its quality. Effect of biochar prepared from crop residue on soil parameters and crop production have been found inconsistent in different studies. Along with that the rate of biochar also poorly understood. So, in present investigation two experiments- field and pot were conducted to check the consequences of rice straw biochar along with manures and NPK on crop yield and soil properties within rice-wheat cropping system during 2018-19 and 2019-2020 at agricultural fields of Lovely Professional University, Phagwara.

Biochar used in the experiment were produced from locally available raw material rice straw at temperature above 600°C under oxygen limited conditions. Field experiments were conducted on sandy loam soil. The treatments were T0 Control (no fertilizer), T1 100%RDF,T2 50%RDF + Biochar, T3 -50%RDF +25%FYM +Biochar,T4 50%RDF+50%FYM+Biochar,T5 50%RDF+ 25%Vermi-compost + Biochar,T6 50%RDF+

50%Vermi compost+ Biochar,T7 50%RDF+ 25%poultry manure+ Biochar,T8 50%RDF+50% poultry manure+ Biochar. Effects of biochar applications together with manures and NPK fertilizers were compared with NPK fertilizer (without biochar) application and therefore the control (without biochar and NPK fertilizers). However, fertilizer rates were different with respect to the crops. Crop growth data, yield attributing parameters data and yield data of each treatment were recorded. Soil samples were taken from top soil before starting the experiments, after harvesting rice and wheat crop, respectively and analysed. The results from the experiment indicate that there was improvement in pH of soil, porosity (%), bulk density, cation exchange capacity, availability of nutrients, organic carbon(%), POC, labile carbon, microbial biomass carbon and microbial quotient. Reduction in soil bulk density observed in biochar treated plots as compared to control and RDF application treatments. Positive changes in carbon fractions of soil and availability of nutrients in soils were recorded in biochar treatments as compared to unamended plots. Application of 50%RDF+50%PM+biochar showed the very positive response towards crop growth, yield attributes and yield in rice crop during both years. But in case of wheat application of 50%RDF+50%FYM+biochar showed the best response in case of plant growth parameters, yield parameters and yield. The lowest crop growth and yield was observed from the control in rice and wheat during both years. The findings of the study suggested that biochar combinations with manures and fertilizers had different effect on soil properties and crop yields under different growing conditions and cultivated crops. The expansion and yield of tested crops were above that of the control and NPK fertilizer application. Rice straw biochar and farmyard manure mixture + NPK fertilizer application are considered as an appropriate soil amendment application under upland crop cultivation i.e. Wheat. Rice straw biochar + 50% Poultry manure + 50% NPK fertilizers should be applied in rice crop as best amendment. Application of Biochar increased total exchangeable cations, reduced bulk density, increased organic carbon, regulated soil pH and, can easily be accessed by farmers by promising crop yields for sustainable agricultural production. Rice straw biochar + NPK fertilizers + FYM in wheat and Rice straw biochar + NPK fertilizers + PM in rice also showed positive influences on soil fertility, enzymatic activities, carbon fractions and nutrient uptake. Therefore, in the pot study, the experiment was conducted to check the leaching of nutrients. So, maximum leachate volume, leached NO3-N and P recorded in 100% RDF (T1) and control. Minimum leachate volume, leached N and P recorded in biochar amended plots. From the result of the study it could be concluded that Biochar application increased crop yields compared to conventional NPK fertilizer *application and non-fertilizer application. Addition of fertilizers with manures and biochar had positive impact on crop biomass and measured soil parameters which clearly reflects the capacity of biochar to be used as substitute to synthetic fertilizers. Thus, converting rice straw to biochar for its application as soil amendment reduces straw burning in open field. It will be better to decide the biochar dose based on the crop type, soil type and the purpose of biochar use: whether to improve soil properties or for the improvement of crop yields, etc. For practical field application, not only beneficial effects of biochar on crop production and soil quality considered, but also economics should be considered because farming objectives of the most of farmers are food security and profit. Research on type of biochar, method of production, biochar application rates which are economically feasible will therefore be required.*

Key words: *Rice straw biochar, poultry manure, FYM, carbon fractions, particulate organic carbon, labile carbon, soil enzymes and soil physico-chemical properties.*

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Anita Jaswal

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Abbreviations/ Acronyms

Ag.	Agriculture
&	And
AAS	Atomic absorption spectrophotometer
BD	Bulk density
C	Carbon
CV	Coefficient of Variance
DHA	Dehydrogenase activity
dSm^{-1}	Deci Siemens per meter
^{o}C	Degree centigrade
Dist.	District
E	East
EC	Electrical conductivity
Fig.	Fig.
FAO	Food and Agricultural Organization
FYM	Farm yard manure
g	Gram
>	Greater than
ha	Hectare
ICAR	Indian Council of Agricultural Research
IISS	Indian Institute of Soil Science
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
M	Molar
µg g^{-1} TPF g^{-1} d^{-1}	microgram TPF/gm soil/day
Max.	Maximum

µg g-1 h-1	Micro gram/gram soil/hour
Mg C g-1	Micro gram carbon per gram
m	Meter
mg kg-1	mega gram per kilogram
min	Minimum
mm	Milli meter
'	Minutes
viz	Namely
N	Nitrogen
N	North
N	Normality
No.	Number
OC	Organic carbon
OM	Organic matter
ppm	Parts per million
%	Per cent
K	Potassium
P	Phosphorus
RDF	Recommended Dose of Fertilizer
SMBC	Soil microbial biomass carbon
SOC	Soil organic carbon
SIC	Soil inorganic carbon
SOM	Soil organic matter
pH	Soil reaction
Temp.	Temperature
TPF	Triphenyl Formazon
t ha^{-1}	Tonnes per hectare
USDA	United States Department of Agriculture
Vol.%	Volume percentage
vs	Verses
PM	Poultry manure
VC	Vermicompost

et al.	And co-workers
DMRT	Duncan’s multiple range test
LSD	Least significant difference
CGR	Crop growth rate
RGR	Relative growth rate
NAR	Net assimilation rate
SPAD	Soil plant and development
LA	Leaf area

CHAPTER 1

INTRODUCTION

Cereals play an important role to meet the food demands of growing population specifically in developing countries where cereal based cropping system is only source of nutrition and calorie intake (Nikos et al., 2012). Rice (*Oryza sativa*)-wheat (*Triticum aestivum*) are the major staple food crops consumed in Asian countries. Rice-wheat cropping system is the major cropping system that is followed in India (Gangwar and Singh, 2011) and Rice is cereal crop belongs to family Poaceae, originated from the Indo Burma region. The domestication of Oryza sativa was dated back from ten thousand to fourteen thousand years ago .The source was wild grass known as *Oryza rufipogan* .Rice is a monocot and annual plants with semi aquatic in nature. The world total production of rice account 496.67 million metric tonnes estimated by United State Department of Agriculture. (World Agriculture production 2019-2020).The top producer of rice is China followed by India and Indonesia. The rice contain twenty three percent calories .As rice are intake by half of population in the world, the daily consumption of calories is sixty percent from rice products (Khush, 2003) and Yao *et al*.,2017 .The rice cultivation in Punjab is 2.4 million hectare which account of six percent of total cultivated area. With average rice husk productivity Punjab rank first in India (FAOSTAT, 2009). The area, production and productivity of rice in Punjab which had increased by 3.9 times (Aulakh KS, 2004) and Yadav *et al*.,2017.Wheat (*Triticum aestivum*) is one of the primary cereal crop cultivated worldwide and food for 2.5 billion world population (USDA, 2019). Wheat crop originated from South-western Asia and many species of wheat cultivated with common genus *Triticum.* Wheat crop can be cultivated as spring and winter season also. Winter wheat cultivated in cold countries like Europe, USA and spring wheat in Asia. India is the second largest producer of wheat worldwide. 30 million hectare acreage under the cultivation of wheat which produced 99.7 million tonnes with average productivity of 337 kg ha^{-1}(USDA, 2019).The trend of last five years of rice and wheat production in India was recorded as given in table no.1.

In 21st century agriculture faced various challenge i.e., it has to fulfill food and industrial demands of growing population as well as protecting environment as well. The world population was 7.85 billion in 2018, but up to 2050 it would reach up to 9.72 billion (UN, 2018). Thus from its recent scenario food production must increase by 70% to satisfy food needs by 2050 (FAO, 2016).

Rice			
Year	Area(m ha)	Production(m ton)	Yield(kg ha^{-1})
2013-2014	44.14	106.65	2416
2014-2015	44.11	105.48	2391
2015-2016	43.39	104.32	2404
2016-2017	43.19	110.15	2550
2017-2018	43.79	112.91	2578
Wheat			
2013-2014	30.47	95.85	3145
2014-2015	31.47	86.53	2750
2015-2016	30.42	92.29	3034
2016-2017	30.79	98.51	3200
2017-2018	29.58	99.70	3371

Table1: Area, production and yield of rice and wheat from 2013-2018(Source; Directorate of economics and statistics and DAC &FW)

Undoubtedly the production of agricultural crops increased at exponential rate since green revolution in Indian (Ladha et al., 2003). There were many reasons behind the cause of green revolution in which one of the causes is the use of synthetic fertilizers (Biswas et al., 2006). Though the production of grain yield was increased as compare to previous one but nowadays many other issues related to production, productivity, soil health and pollution are emerging around the world in which emission of N_2O is one of them because of the overuse of urea fertilizer (Foresight, 2011).

Nowadays, reduction of soil fertility has been recognized as a main biophysical root cause for diminishing per capita food availability because the loss of soil fertility and productivity are the classical constraint for reduction of yield potential (Gichuru et al., 2013). The increase of production through the application of fertilizers reached at stationary point and it seems that further increase of production, is not possible by fertilizer application because crop response to fertilizers depends upon many factors like soil pH, electrical conductivity, organic matter, humus content and cation exchange capacity, results soil acidity, nutrient imbalance and physical degradation of soil (Jat et al., 2011).

Sustainable agriculture is an important aspect that focus towards the make balance between soil health and healthy food supply for human being around the world (Hira, 2009; Humphreys et al., 2010). Low nutrient status and quick mineralization of organic matter in the soil is one of the challenging tasks before the sustainable agriculture because decrease of soil organic matter leads to reduce cation exchange capacity as well as efficacy of applied fertilizers lead to nutrient deficiencies and ultimately limit both crops production and productivity (Glasei et al., 2012).

To sustain the crop production, the use of nitrogen base fertilizers is essential because of high demand nitrogen by high yielding varieties of rice and wheat (Das et al., 2013) Hence, the use of nitrogen base fertilizer is continues increasing in India onwards from green revolution. As per the consecutive use of nitrogen base fertilizer, it is assumed that the use of fertilizer will reach up to 23.6 million tonnes by 2030 (Peters et al., 2013). The negative impact of nitrogen in terms of residual effect is not appear in paddy field because out of all nitrogen, some amount is mobilized by microbes into soil fractions and some amount fixed by clay minerals such as illite and vermiculite while the rest amount of nitrogen lost through denitrification, leaching and volatilization (Sun and Lu, 2014).Regarding the nutrient uptake by rice plant is absolutely different from other plant because as per the growth stage is concerned; the absorption of nitrogen by rice plant at seedling stage is low while maximum before heading stage. More application of nitrogenous fertilizers shows better results in terms of crop production but their negative effect is also reflecting on environment (Jeffery et al., 2014). Therefore, for sustainable agriculture the use of chemical fertilizers should be address and assessed not only on the basis of crop production but also for environmental and climate change (Spokas et al., 2009, Singh et al., 2010). The use of intensive agriculture and variation in climatic conditions both with together resulted soil degradation and declined global food security (Krishna Kumar et al., 2014). While the organic matter of soil significantly improves soil physical, chemical health, sequestration of carbon, control land erosion and protect land from degradation (Golantini and Rossel, 2006**)**.The rapid decomposition of organic matter means the nutrient retention is a limiting factor in soil productivity therefore organic matter influences almost all the composition of soil related to crop production. Maintenance of soil organic matter is also necessary because it improves productivity of soils as well as reduces emission of CO_2 to atmosphere (Rogovska et al., 2010)

The traditional crop management practices like repeated tillage, less use of organic nutrients, minimum use of soil amendments, single use of inorganic fertilizers, growing same cropping pattern resulted to fast soil organic matter degradation (Rahman et al., 2016). Establishing an appropriate level of soil organic matter and ensuring efficient biological cycling of nutrients is vital to the success of soil management and agricultural productivity strategies. These practices comprised with the application of organic and inorganic fertilizers based on knowledge, how to adapt these practices according to local conditions (Vanlauwe et al., 2010). The implementation of techniques to enhance the carbon storage capacity in agricultural soils is the main issue of consideration because soil organic carbon is a major pool of soil organic matter (Sitch et al., 2008). Fast decomposition of organic matter is one of the constraints in the practical application of organic fertilizers. Crop residue incorporation is one of the best practices to increase soil organic matter, fertility and productivity which lead to produce good quality as well quantity of grain yield along with huge amount of nutrient rich crop residue consequently improve physical chemical and biological properties of soil by proper recycling of available crop residues (Doran, 2002). The long time nutrient retention in soil due to elemental cycling provides food and living place for soil biota, especially microorganisms and earthworms (Karmakar et al., 2013). The soil organic carbon pool may be group into four different categories on the basis of its lability i.e. very labile, labile, less labile and non-labile depending on the degree of oxidation by sulphuric acid (Nguyen et al., 2009). The very labile and labile carbon pools are active pools and are directly related with mineralizable nitrogen and water stable aggregate stability (Mishra et al., 2010). Less labile and non-labile is the part of passive pools contributing 35% of total organic carbon and 30-40% of soil organic carbon in passive pools (IPCC, 2013)

The non-labile carbon is chemically recalcitrant in nature due to presence of alkyl carbon chain and aromatic structure in lipids and phenolic. On the other hand, labile carbon having short chain aromatic carbon and carboxyl carbon contributed by degradation of cellulose, hemicellulose, lignin, protein and tannin originated from plant (Majumder et al., 2008). The fractions of soil organic carbon into active, slow and passive group is also based upon the mean retention times i.e. 1-5, 20-40 and 400-2000 years (Zhang *et al,* 2015*)*. The proportion of soil organic carbon is determined by various factors such as type of organic matter, soil type and climatic conditions etc. (Gougoulias et al., 2014).

Increase in soil organic carbon pool by crop residue management practices based upon the management techniques used in combination with crop residues (Thies and Rillig, 2009). The fertilization application in wheat residues with N, increases humification of biomass and increase the carbon sequestration rate of soil. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide are the main gases of greenhouse effect which escape both through burning of fossils and biomass fuel along with decomposition of organic matter (Woolf et al., 2010) . Imbalance conditions created between carbon releases to atmosphere and fixed in soil results in the increase in atmospheric CO_2 (IPCC, 2017).

A number of new techniques have been adapted to limit the production of greenhouse gas emission from various resources in which most of the efforts have been made by using non-fossil fuel sources of energy such as nuclear energy wave, wind power and geothermal sources as well as sequestering carbon in soil by enhancing the size of earth's biomass carbon pools (Aslund, 2012). Most of the soils contain up to 100 tonnes ha^{-1} carbon as organic matter based on land use and climate. It is an urgent need to maintain equilibrium between the rate of addition and emission of CO_2 from soil (Novak *et al.* (2012). If this equilibrium is maintained then the amount of organic matter is also maintained even though the soil has double capacity to hold organic carbon as compared to atmosphere. Instead of increasing amount of external organic matter as inputs, we may go through the use of zero tillage by giving minimum disturbance to soil or by selecting recalcitrant and lignin rich compounds (Palm et al., 2001 and Skjemstad et al., 2014).

Biochar is a very powerful soil amendment to enrich the soil in respect to carbon, nutrients and water because it is a product of vegetation or agriculture waste fire through pyrolysis or gasification under complete or partial absence of oxygen even though a solid carbon rich residue generally referred as char (Yu et al., 2013). The conversion of biomass to

Biochar is based on the type of feedstock but not on the pyrolysis temperature. Biochar is neither a new term nor a new substance because the use of Biochar recorded at least 2000 years back (Lehman et al., 2006; Sohi et al., 2010; O'Neill et al., 2009 and Ameeloot et al., 2013). Biochar not only hold carbon in soil more than hundred years but also act as a source of plant nutrient that helps to combat climate change as well as reduce emission of nitrous oxide. Carbon sequestering in soil through Biochar amendment derived black carbon to the soil that prefer both large and long term carbon sink (Marris, 2006 and Smith et al., 2010). Biochar is recalcitrant in nature due to the stable type of soil organic carbon. To produce CO_2 and combustible gases mainly CO, H_2, CH_4, thermal decomposition of Biochar can be adopted. It is a carbon rich residue which is chemically same as charcoal but it is distinguished from charcoal due to its use as a soil amendment (Chan et al., 2007, 2008; Major et al., 2010; Van Zweiten et al., 2010).

Most of the fraction of carbon is lost by respiratory processes in soil during the conversion of biomass to humus and also from humus to resistant soil (Zhang *et al*. 2012). Around 2-20% of carbon added to soil organic carbon pool by humification while rest is converted to CO_2 due to oxidation however, the additional carbons are only sequester in soil after maximum soil carbon achieved (Ahmed et al., 2017 and Lat et al., 2004). The soil C capacity is increased by continuous supply of biomass. The conversion of biomass to Biochar is based on the type of feedstock but not on the pyrolysis temperature because it depends on the types of biomass feedstock (Alling et al. 2014). The products made after pyrolysis of biomass is environmental friendly, stable and improve soil properties (Lehman et al., 2006 and Zimmerman, 2010). The Biochar incorporation is also influenced by type of soil and other environmental conditions. It can be applied within various climates and agriculture systems, which indicate that one type of Biochar, may increase nutrient holding capacity and production in one system, but not in another (Verheijen et al., 2010 and Atkinson et al., 2010).

Biochar is porous in nature, so it has the ability to absorb plant nutrients and enhance the water holding capacity of soil consequently soil quality and crop yield (Steiner et al., 2008 and Brockhoff et al., 2010). Moreover combined application of Biochar with fertilizers increases the crop yield as compared to fertilizers alone (Chan et al., 2007). The characteristics of Biochar also had a positive effect on the soil quality, porosity, density, particle size and mineral contents even though the application of Biochar improves microbial population in the soil that help in nutrient recycling and release of nutrient from the difference sources available in the soil (Downie et al., 2009; O' Neill et al., 2009; Liang et al., 2010; Rillig and Mummey, 2006; Warnocle et al., 2007 Thies and Rillig, 2009). The status of carbon and nitrogen are changed through the process such as mineralization, nitrification and denitrification which is also based upon the soil moisture and temperature (Buttabach et al., 2013). Basically the application of Biochar influence the mechanism of interaction in the soil and react with physical, chemical and edaphic characteristics of soil like pore space, water holding characteristics, pH, EC and available nutrients, mineralization, nitrification (Jones et al., 2011). Although, Biochar have been shown positive effects on soil, but itself have a limited amount of nutrient due to its relatively low nutrient composition and recalcitrant nature but the application in combination with organic or inorganic fertilizer shows positive effect in respect to the crop growth and yield of different crops (Partey et al., 2014 and Dou et al., 2012). It has the capacity to retain NH_3, NH_4^+ and NO_3^- in animal manures however, the application of FYM, Poultry manure and vermicompost applied along with Biochar reduce the loss of nitrogen and accelerate the humification process (Steiner et al., 2010 and O kazaki and Ishizaki, 2004). Different types of Biochar have different nutrient status therefore, the amendment of Biochar not only improves the physical, chemical and biological properties of soil but also enhance the availability of macro and micro nutrient to the plant especially carbon, nitrogen, phosphorous and potassium (Chan and Xu 2009; Soliman et al., 2010 and Ahmed et al., 2017).

The decomposition, degradation, humification, mineralization and nitrification needs enzymatic involvement in the soil for successful completion of specific reaction because dehydrogenase enzyme consider as a quality indicator and polyphenol oxidase as a bio-degrader while urease and phosphatase as a nutrient recycler especially for carbon, nitrogen and phosphorus. The efficacy of soil enzymes activity depends upon the availability of many soil factors including substrate. Furthermore, it depends on the interaction between Biochar, enzymes and substrate (Paz-Ferreiro et al., 2012; Segu and Oladele, 2019 and Waldrop et al., 2004). Among the community of scientific group, it is still an issue that needs to clarify that the effect of Biochar on soil related enzymes and their associated reactions because the literature shows contradictory information published by various scientists (Park et al., 2011; Kumar et al., 2013; Paz-Ferreiro et al., 2012; Bailey et al., 2011; Lehmann et al., 2011; Wu et al., 2013 and Lammirato et al., 2011)

So that present piece of experiment has been conducted to find out the effect of Biochar combined fertilizers on soil nutrient status in relation to growth and yield of rice-wheat crop under field and pot conditions by considering the following objectives.

1. To determine the impact of Biochar combined with organic and inorganic amendments on soil carbon pools.
2. To analyze the effect of Biochar nitrogen use efficiency
3. To correlate soil carbon fraction change with other soil nutrient dynamics, plant growth and yield.
4. To assess the impact of different Biochar based amendments on important soil biological indicators.

CHAPTER2

REVIEW OF LITERATURE

An existing technique to reduce C from atmospheres is store carbon in plant biomass or in soil organic matter (Srinivas araro *et al*, 2013). The continuous burning of crop residues not only responsible for loss of essential nutrients accumulated in straw but also decrease the total C in surface soil (0-15cm layer). Along with this if residues of crops are incorporated in soil, most of the carbon quickly decompose and very little return to atmosphere. So, transform crop residues to form Biochar by pyrolysis process has been a valid option which increase carbon sequestration in soil, declined agriculture waste and enhance soil quality and productivity(Lackner,2003). But, the results of Biochar as amendment have not proven universal. Some Biochar applications showed adverse effects on soil properties and plant growth because all Biochars not behave in same manner. Thus the effect of application of Biochar on soil properties and plant growth under different areas need to be study .The literature related to study has been enlisted under following main headings:

2.1 Rice –wheat cropping system

2.2 What is Biochar?

2.2.1 Historical perspective of Biochar

2.2.2 Emerging awareness of Biochar

2.2.3 Problem of present scenario

2.2.4 Biochar and carbon sequestration

2.2.5 Preparation of Biochar

2.2.6 Biomass feedstock

2.2.7 Stability of Biochar

2.3. Soil organic carbon, carbon pools and carbon fractions

2.4 Effect of Biochar on soil organic carbon, carbon pools and carbon fractions

2.5 Effect of Biochar on soil physical, chemical and biological properties

2.6 Effect of Biochar on soil nutrient, nutrient uptake and crop yield

2.7 Effect of Biochar combined with fertilizers and manures on soil nutrient status and plant growth and productivity.

2.1 Rice- wheat cropping system: In Asian – subtropical countries such as China, India, Nepal, Bangladesh and Pakistan rice-wheat is the most dominant double cropping system where it is cultivated on about 24 million hectares (Mahajan, 2006). Rice is grown in 111 countries and wheat in 92 countries (Anonymous, 2005). Wheat ranks first and rice ranks second in case of harvested area whereas rice ranks number one in case of calories per hectare. More than half of world’s rice produced by India and China and provide employment opportunities for rural population. These crops are rich source of carbohydrates and good source of proteins. In India rice-wheat is a traditional and most preferable cropping system. This cropping system covers 9.77 million hectares and is the dominant cropping system in India mostly in Punjab, Bihar, Haryana, U.P and M.P contributes. Rice-wheat cropping system helps in social-economic development of rural population in India. Rice-wheat cropping system is new in India and with the introduction of dwarf wheat from CIMMYT Mexico in 1960 it was started in India. As compared to tall wheat dwarf wheat required less temperature for the germination (Chenkual et al., 1990) on the other hand rice needs separate climatic conditions like wet tropical, humid to subtropical (Fujisaka et al., 1994). The developmental conditions of soil and environment are different for rice- wheat cropping system. In rice-wheat cropping system there is conversion of soil from anaerobic to aerobic condition (Mahajan, 2006). Rice is cultivated in puddled soils and stagnant water conditions whereas wheat required pulverized and friable seed bed with proper moisture. Puddling / wet tillage in rice is responsible for hard pan formation in sub soil and due to this the infiltration rate decreased (Greenland and De data, 1985 and Mahajan et al., 2007).This system suitable for rice but not for wheat (Sharma et al., 2003). In post rice soils wheat yield decreased due to poor infiltration, lack of aeration and rough seed bed (Regmi et al., 2002). Stagnating water in rice field change the chemical properties of soil like pH, EC, CEC and affect the availability of nutrients (Ladha et al., 2003). Most of the changes are modified with proper drainage which promotes the implication of proper nutrient management strategies in rice-what cropping system.

2.2 What is Biochar?

Biochar is a fine grained charcoal high in organic carbon and resistant to decomposition. It is produced when biomass (crop residues, wood and leaves) heated through the process of pyrolysis in anaerobic condition (Lehmann et al., 2006). Biochar is term normally linked with plant biomass (Verheijen et al., 2010). Biochar differs from charcoal because of its purpose of use which is not for fuel but for capture of atmospheric carbon (Jeffery et al., 2011 and Sohi et al., 2010). Biochar has specific characters with potential applications in agriculture (Schmidt, 2012).Biochar and mineral char is different because Biochar can be produced from available organic material but mineral char is a black combustible sedimentary rock which extracted from underground(Lehman and Joseph,2009). The "bio" term has environmentally friendly meaning but burning mineral char for the production of energy add carbon dioxide to atmosphere and increase the greenhouse gas emission. On the other hand, if we use the biomass for the production of energy than CO_2 is fixed by photosynthesis in organic material and came back to the atmosphere by pyrolysis (Sohi et al., 2010). As a soil amendment, Biochar creates a recalcitrant soil carbon pool that is carbon negative, serving as a net with drawl of atmospheric carbon dioxide stored in highly recalcitrant soil carbon stocks. The enhanced nutrient and moisture retention capacity of Biochar amended soil not only reduce the total fertilizer requirements but also the climate and environmental impact of croplands.

2.2.1 1Historical perspective of Biochar

The most primitive and common use of Biochar in agriculture dates back to the ancient Amazonians 7000 yr. BP. The scientific attention towards Biochar started from the interest in Biochar grew out of research on rich, dark soils in Amazon known as "Terra Preta" or "Amazonia Dark" Earth (ADE). Many researchers have stated that these soils were made by Amerindians adding large quantities of Biochar and other forms of organic matter 7000 to 500yr.BP (Verheijen *et al*,2 010). Whether intentional or just the result of habitation, there was a large scale C- sequestration and long lasting improvement to poor and highly weathered tropical soils, thereby permitting permanent agriculture and human settlement(Smith,1980).Terra Preta soils are considered to be 'anthrosols', anthropogenically formed soils unique from native soils(Glaser et.al,2002). Biochar has been utilized by other cultures like Japanese farmers were using a method called 'haigoe' whereby human waste was mixed with rice husk Biochar and was allowed to prior application to crops (Sombrek,1966).

In same manner, use of Biochar in green house and on farms to improve plant growth has been found over a hundred years in several western countries (Ogawa, 1994).Today Biochar will typically be applied in large quantities and often to soils receiving high amounts of synthetic and organic fertilizers. Also the feedstock of Biochar, pyrolysis condition and Biochar quality are different from charcoal applied in previous times. Terra Preta soils receive small amount of charcoal repeatedly over a long period of time and that's why microbial community has been adapted to input. The charcoal in "Terra Preta soils have been altered by biotic and abiotic oxidation process over centuries (Lehman *et al*, 2009).

2.2.2 Emerging awareness of Biochar: The application of charcoal for soil fertility maintenance is an old practice from thousand years, but the scientifically interest in Biochar is totally new which is increasing with the awareness of climate change. The practice of using Biochar for the sequestration of C and building soil fertility has gained attention politically, publically and scientifically. The emerging awareness about Biochar is reflected in increasing initiatives related to Biochar like- The international Biochar initiative (IBI, 2006), Terra- The Earth Renewal and Restoration Alliance (Terra, 2009), Carbon Zero project(C Zero, 2009), Biochar C sequestration (BCS, 2006) and the Biochar Fund (Biochar fund, 2008). NGO's and private companies in India are busy in Biochar research. A project named "Use of Biochar on soil health enhancement and green house mitigation in India" is a project handled by 'National Initiative on Climate Resilient Agriculture is also worth mentioning.

2.2.3 Problem of present scenario: The atmospheric CO_2 levels have raised from 278 parts per million by volume (ppmv) in industrial era to around 400ppmv today due to fossil fuel burning ,deforestation and industrial activities like cement production(IPCC,2007 and Tans,2014). Up to 1900 the planet has warmed up to 0.8^0 C as a result of increase CO_2, methane and nitrous oxide (N_2O). If the human beings continuously doing industrial emission than planet warming probability increased up to 2 ^{0}C, a level which is considered safe threshold level of warming. But beyond this, the earth system cannot manage the warming (Demirbas, 2004). To reduce carbon dioxide emission from energy generation and industrial processes, it may be urgent to remove CO_2 directly from the atmosphere which is known as carbon sequestration. Sequestering carbon means enhancing the size of soil C sink. To sequester carbon in soil techniques include no tillage, conservation tillage, cover cropping, decomposition of manures and other carbonaceous material in soil (Lal 2004). Soil carbon sequestration commonly used as a vital technique for mitigate climate change and handling the food security. Soil C sequestration has also other benefits like increasing agronomic productivity and food security (Lal 2004).

Although C sequestration has disadvantages and limitations. First is the slow accumulation of C in soil due to finite holding capacity (Lal, 2009). Secondly, accumulated C has lost rapidly in atmosphere (Six et al., 2001). Thirdly, N may be necessary due to nutrient mobilization so extra nutrient inputs required (Rasmussen et al., 1998). Fourth C leakage occurs by greenhouse gasses emissions. Fifth, C sequestration techniques like no-till and minimum tillage increased nitrous oxide emission (Li et al., 2008). Currently the use of Biochar as a soil amendment has been proposed. Biochar having large C sequestration capacity as compared to conventional soil C management methods due to its recalcitrant nature (Hansen *et al*, 2008). The application of Biochar rapidly increased the soil carbon. The physico chemical recalcitrant nature of Biochar inhibit rapid decomposition .Biochar increased nutrient and water holding capacity and reduce the quantity of additional inputs. In some of the researches, it has been found that Biochar reduce soil emissions of CH_4 and N_2O. So, due to these properties Biochar can play important role in mitigating climate and C sequestration.

2.2.4 Biochar and carbon sequestration: Removal of atmospheric CO_2 through photosynthesis to form organic matter, which is stored in soil for long time in stable form known as C sequestration. Terrestrial, atmospheric, ocean and geological are important pools of carbon. These C pools have different life time and flow takes place between them. C in the active pools moves quickly between pools (Glaser, 2007). To lower the C in atmosphere active pools should be changed to passive pools containing stable C. Biochar has ability to convert active pools to passive pools (Glaser et al., 2001). As compared to burning, controlled carbonization has more ability to convert huge quantity of biomass organic matter into stable C pools which remain in soil for long time (Schmidt and Noack, 2000). The transformation of biomass C to Biochar contributes 50% in carbon sequestration (Lehmann et al., 2006). The potential of C conversion of biomass to Biochar is mainly dependent upon the type of feedstock but not affected by pyrolysis temperature (Gaunt and Lehman, 2008). From the Terra Preta soils the idea came that Biochar can have C storage performance in soil for thousands of years. Biochar mineralizes in soil, a part of it remains for longer time in soil in stable form (Schmidt and Noack, 2000). So, due to this characteristic Biochar has the potential of major C sink. Biochar is a C rich, very fine, highly porous, charcoal like product of biomass to energy called pyrolysis. When Biochar incorporated to soil it has been found to increase soil quality and crop yield along with sequestration of atmospheric C for thousands of years. These benefits offer Biochar as a strategy to deal with global challenges (Lehmann and Joseph, 2009).

2.2.5 Preparation of Biochar: From the past history, heating the wood for the purpose of Biochar preparation has been practiced (Emrich, 1985). Carbonization is practiced from the civilization time (Brown, 1917). There are many different methods for Biochar preparation but in all the methods the feedstock is heated with or without oxygen to take off volatile gases, leaving C behind. This process is called thermal decomposition which is achieved by pyrolysis or gasification. Pyrolysis is the thermal decomposition of C-rich material under anaerobic conditions. 'Pyro' word derived from Geek word which means fire and 'lysis' meaning decomposition of material into small parts (Demir bas, 2004). When Biochar prepared commercially three steps are performed- first step- moisture and volatile lost, second- unreacted residues converted to volatiles gases and Biochar, third slow rearrangement of Biochar.

2.2.5.1 Methods of pyrolysis: The basic process of pyrolysis is heating a C-containing raw material in oxygen limited condition. The process is same for all, but the different methodologies are there with different result. Rather than feedstock, the pyrolysis temperature and the residence time of material in pyrolysis unit are variables which often modified. Temperature in itself has a major effect on the end product of feedstock. The different types of products like char, gas and oil and tar preparation based upon the amount of heating. Based upon the heating pyrolysis is of different types:

2.2.5.1.1 Slow pyrolysis: It is a low technique and robust technology which is useful for Biochar production. The most widespread application for charcoal production in ancient times was slow pyrolysis of biomass in traditional kilns (Antal and Gronil, 2003). In these processes liquid and gas products escape as smoke in atmosphere led to environmental pollution. Lower heating rates used in slow pyrolysis as compared to fast pyrolysis (Peacocke and Joseph, 2009) and commonly low temperature. In recent time slow pyrolysis takes place in continuous reactors like drum pyrolysers and rotary kilns (Joseph, 2009). These reactors along with charcoal also collect bio-oil and syngas are highly efficient as compared to traditional kilns.

2.2.5.1.2 Fast pyrolysis: These pyrolysis plants designed for continuous process by using high-technology to provide more fractions of liquid product (Yanik et al., 2007). In few seconds, biomass converts into Biochar by fast pyrolysis using high heating rates ($>200^0$ C s^{-1}) and high temperature around 500^0C. For the instant conversion of biomass, the biomass must be dried (<10% moisture), and particles of biomass must be ground to <2mm to avoid any barrier during manufacturing (Verheijen et al., 2010).

Biochar is made into two general reaction pathways during the pyrolysis of lingo cellulosic biomass. In first pathway devoltalization occurs, in which primary Biochar left behind. In second pathway at high temperature above 500-550 ^{0}C organic vapours decompose on the surface to form secondary Biochar inform of coke. At temperature up to 700-800^0C the reaction occurs at fast rate and condensable volatiles quantity increased. In fast pyrolysis, there is an optimization in temperature for maximization of liquid product yield or different feed stocks (Brown 2009).

2.2.5.1.3 Gasification: It is a thermo-chemical conversion process in which there is complete conversion of organic fractions of biomass into gases and avoids the formation of Biochar and bio oil. It is an endothermic process in which carbonaceous compounds convert into gas and heat is required to speed up this process. By the combustion of biomass heat is generally supplied and temperature range is 600-1300^0 C (Brown 2009).

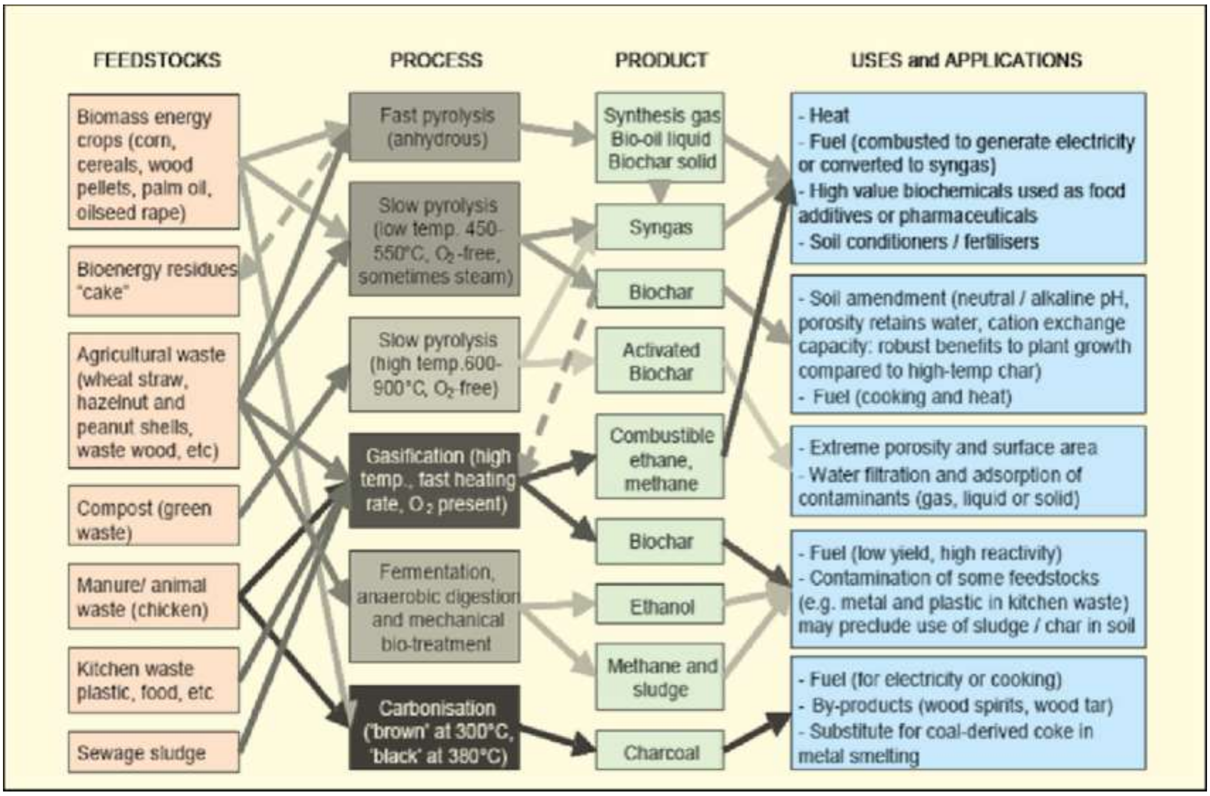


Fig. 2.2 Summary of pyrolysis processes in relation to their common feed stocks, typical products, and the applications and uses of these products (Sohi et al., 2010).

2.2.6 Biomass feed stock: Feed stock and pyrolysis conditions are the most vital factors which controlled the physical and chemical properties of freshly made Biochars (affected by the feedstock material (Downie et al., (2009). Organic waste example household waste, urban waste, industrial by products can be used as feedstock during pyrolysis with some cautions to prevent the contamination of the Biochar product. The particular feedstock properties affect the physico-chemical quality of Biochar. The application of Biochar to soil made from different feed stocks has different impact on soil properties, crop yield. It is important that the applied feedstock should be easily available and cheap. Different feed stocks used to produce Biochar are presented in table form:

S.No.	Feed stock material	Sources
1.	Wheat straw	Mahinpey et al.,2009 and Abel S. et al.,2009
2.	Maize stover	Mullen et al.,2010
3.	Sewage sludge	Hosain et al.,2010
4.	Rice husk	Hao et al.,2010
5.	Poultry litter	Kim et al.,2009
6.	Rice straw	Fu et al.,2010
7.	Pine saw dust	Wang et al.,2008
8.	Pine needles and covers	Tritici et al.,2007
9.	Wood chips	Spokas et al.,2009
10.	Wood wastes	Asai et al.,2009
11.	Bagasse of sugarcane	Chen Y et al.,2010

Table 2.2.6 : Different feedstocks used to produce Biochar

2.2.6.1 Biochar production: Biochar can be prepared at a small scale by the use of low –cost stoves/kilns or at large scale by pyrolysis process. It is made up of the elements such as carbon, hydrogen, sulphur, oxygen and nitrogen minerals in fractions of ash. It is manufactured by pyrolysis process through thermal decomposition in an oxygen limited environment. Biochar is a stable biomass which is mixed to soil to enhance crop production, to control pollution and changes the properties of soil. The dry biomass waste cut into small pieces less than 3cm. the biomass is heated with or without oxygen at temperature 350-700 degree Celsius(Sullivan et al., 2012) The produced Biochar based on two factors- the feedstock temperature and rate of heating. The Biochar produced at low temperature has amorphous carbon structure with low aromaticity than Biochar produced at high temperature

(Joseph SD et al., 2010). The process of pyrolysis affects the quality of Biochar in case of agronomic performance.

2.2.6.2. Rice husk Biochar: Rice husks, remains of woods and residues of crop considered as agriculture waste but recently convert into Biochar for carbon sequestration purpose. The use of rice husk and rice straw has been come under use from some time (Ponamperuma, 1982). Researchers has shown that incorporation of rice straw and rice husk can significantly improve soil properties by reducing soil bulk density, enhancing soil pH , adding organic C ,increase availability of nutrients(Yamato et al.,2006). Asia is a main rice growing region has vast rice residues estimated 560 million tons of rice straw and 112 million tons of rice husk. These residues could be valuable resources for production of Biochar to increase soil fertility. Carbonized rice husk comprised with very light material having micro porous structure and bulk density of 0.15gcm^{-3}(Haefele et al., 2009). Carbonization processes of rice husk formation increase the water holding capacity (Oshio et al., 1981).Traditional practice of burning rice straw in field refers that black carbon from incompletely burned rice residue might be important source of organic matter in rice soils(Schmidt and Noavk,2000). Though the burning of straw, portions of rice residues are indirectly applied to soil by means of composting. To maintain sustainable soil productivity straw needs to supply yearly. The transformation of straw into Biochar is promoted by local governments to improve the fertilizer efficiency and support the use of cost effective, recycled agricultural waste such as rice straw (FAO, 2004).

2.2.6.3 Characteristics of Biochar: Characteristics of any material is the first point to understand its effectiveness and mechanism of action. The characteristics of Biochar are judged by its physical and chemical constituents. The feedstock temperature and heating affect the quality and efficient use of Biochar (Sohi et al., 2010). It has been confirmed by many authors that the biomass used for the production of Biochar and the pyrolysis temperature are most important processes that affect the physico-chemical properties of Biochar.

2.2.6.3.1 Physical characteristics: Soil productivity for crop production based on the physical condition of soil (Benjamin et al., 2003).The physical structure of Biochar is determined by scanning electron microscopy. Biochar produced from the cellulosic plant material has macro porous structure is necessary for water holding and adsorption capacity of soil (Yu et al., 2006, Day et al., 2005). It was found that if the temperature increased from

400-900^{0}C the surface area of Biochar increased from 120 to 460m^{2}g^{-1}(Ogawa et al., 2006). Biochar can increase plant growth by improving soil physical characteristics (bulk density, water holding capacity, permeability) (Sun and Lu, 2014). The high recalcitrant nature of Biochar improves agronomical efficiency of crop (Abujbhah et al., 2016). As the pyrolysis temperature increased from 400-600^{0}C reduced N component and volatility of Biochar but increased carbon and ash content (Purakayastha et al., 2012). The rice and wheat Biochar prepared at 400^{0}C temperature has low bulk density as compare to maize and bajra Biochar. The water holding capacity of wheat Biochar was more as compared to maize stover Biochar (Purakayastha *et al*. (2013a)).

2.2.6.3.2 Chemical characteristics: Biochar composition is heterogeneous in nature which contains stable and labile components, volatile compounds, ash and moisture (Amonette and Joseph, 2009). It is commonly formed of amorphous and graphene C. It has high organic carbon content which is a conjugation of six C atoms linked together in rings. The C structure changes from amorphous to aromatic and to graphene sheets as pyrolysis temperature increased (Cao and Harris, 2010). Biochar addition to soil has been proven a boon for fertility and productivity (Lehmann and Joseph, 2015). The proportion of quartz, sylvite and calcite in Biochar makes it crystalline in nature due to this proportion the pyrolysis temperature changes (Cao and Harris, 2010). The researchers concluded that by increase in pyrolysis temperature the ratio of large to small aromatic ring structures increased and oxygen functional groups decreased (Li et al., 2006). There was a lot of variation in N content of Biochar material produced from different biomass. The concentration of other elements in Biochar increased with increase in pyrolysis temperature except N. Biochar rich with Ca, Mg, K and P. Due to its high pH, Ca and Mg it has ability to use as liming material for acid soils. pH of Biochar ranged from 8.2-13.0 of different feed stocks .Total carbon content increased with increase in pyrolysis temperature from 33-82.4%. Biochar which was produced at high temperature depleted with N and S (DeLuca et al., 2009). High temperature produced Biochar has high pH, EC and extractable No_3^- (DeLuca et al., 2009)

Table2.2.6.3.2: Chemical properties of Biochar samples prepared from different feed stocks (Jha et al., 2010)

Material used for producing Biochar	**pH**	**Total C (%)**	**Total N (%)**	**C:N**	**Ca**	**Mg**	**P**	**K**	**CEC**	**References**
					(c mol /kg)					
Paper mill waste	9.4	50.0	0.48	104	6.2	1.20	-	0.22	9.00	Zwieten et al.,2010
Green waste (grass clippings, cotton trash and plant pruning's	9.4	36.0	0.18	200	0.4	0.56	-	21.00	24.00	Chan et a l.,2007
Eucalyptus Biochar	-	82.4	0.57	145	-	-	1.87	-	4.69	Noguera et al.,2010
Cokking Biochar	-	72.9	0.76	96	-	-	0.42	-	11.19	Noguera et al.,2010
Poultry litter(450^0 C)	9.9	38	2.00	19	-	-	37.42	-	-	Chan et al.,2008
Poultry litter(550^0C)	13	33	0.875	39	-	-	5.81	-	-	Chan et al.,2008
Wood Biochar	9.2	72.9	0.76	120	0.83	0.20	0.10	1.19	11.90	Major et al.,2010
Hardwood saw dust	-	66.5	0.30	221	-	-	-	-	-	Spokas et al.,2010

2.2.7 Stability of Biochar: The chemical and physical properties of Biochar, temperature and rainfall affect the decomposition rate of Biochar (Lehmann et al., 2009). The Biochar stability is due to the change of native C structures of biomass to aromatic ring structure that takes place during the pyrolysis of organic matter (Glaser et al., 2001). Bladock and Smernik, 2002 reported that black C is highly stable due to its polycyclic aromatic C structures and resistance to physical and microbial breakdown permit it to persist in soil. There is a difference between producing Biochar for the betterment of crop growth and maximizing soil C sequestration. As the pyrolysis temperature increased it increased total elemental C content, ash content, aromaticity and stability (Krull et al., 2009). The Biochar recalcitrant nature makes it more resistant to degradation and release of nutrients from Biochar is inhibited and less benefit to growth of plants. Biochar formed at lower temperature have more bio available C and nutrients availability to plants (Laird et al., 2009).The bio available C degrade rapidly and resulted less sequestered C.

Biochar has macro molecular structure covered by six aromatic carbon atoms recalcitrant to microbial decomposition (Steinbeiss et al., 2009). 0.5% black C was decomposed per year under optimal conditions (Kuzyakor et al., 2009). The studies found that if black carbon decomposes ten times slower under natural conditions than 2000 years was the mean residence time and 1400 years was life of black C. The black C mean residence time in soil is in range of millennia. Knolblauch et al., 2010 reported that addition of carbonized rice husk resulted in increase in C mineralization rates as compared to control. The addition of organic matter stimulates the mineralization of labile compounds of Biochar (Zimmerman et al., 2011). The application of Biochar to soil increases the respiration rate (Jones et al., 2011). The most of CO_2 produced after Biochar addition came from equal breakdown of organic C and release of inorganic C contained in the Biochar.

2.3 Soil organic carbon, carbon pools and carbon fractions:

2.3.1 Soil organic carbon and soil organic carbon fractions: Soil organic matter (SOM) is commonly comprised with the various organic remains in soil like plant and animal residues, less than 2mm size materials and soil organisms during decomposition. The transformation of soil organic matter plays a critical role in soil ecosystem functioning and global warming. Soil organic matter is crucial for the maintenance of soil structure, holding and releasing plant nutrients and improved water holding capacity which increased agricultural productivity. When SOM decomposed it released mineral nutrients and making them available for plant growth (Vanderwal and De Boer, 2017).

Soil organic carbon (SOC) is the main part of soil organic matter. Soil organic carbon is the important indicator of soil health. Total organic Carbon (TOC) is the carbon stored in soil organic matter. Organic carbon enters the soil through the plant, animal residues, root exudates and soil biota decomposition. The carbon cycle is a fundamental part of life on earth (Zhang et al.,2015). For the achievement of sustainable development goals, mitigation and adaptation to climate change SOC plays important role. High soil organic matter content enhances the soil fertility and improves food productivity by providing nutrients to plants and increase water availability (Kirkby et al.,2013).SOC modify the soil structure by improving aggregate stability, porosity ,aeration and water infiltration of soil. Soil organic matter divided into different pools depends upon the time of decomposition and retention of the products in soil (Gougoulias et al., 2014). Active pools changes in months or few years and passive pools changes in thousands of years. Soil organic matter is made up of 4 major pools- plant residues, particulate organic carbon, humus and recalcitrant organic carbon. These pools different in their chemical composition, time of decomposition and role in soil functioning. Plant residues are shoots and root residues found on the surface of soil. They decompose rapidly and provide important source of energy for the microorganisms present in the soil. Plant debris whose size is 0.053-2 mm categorized as particulate organic carbon. It decomposes in years to decade and provides important source of energy for soil microorganisms. It helps in maintaining soil structure and providing soil nutrients. Plant residues and particulate organic carbon considered as labile carbon. Humus is formed from the decomposition plant materials having size less than 0.053mm in size. This type of carbon may take decades to centuries to decompose and become unavailable to microorganisms. It is important in retention of nutrients. Recalcitrant organic carbon is the organic material resistant to decomposition. It takes centuries to thousands of years to decompose. Burning soils and highly weathered soils have more recalcitrant organic carbon.

Soil organic matter comprised with 55-60% C by mass (FAO and ITPS, 2015). Similar to soil organic matter, SOC is divided into different pools (O, Rourke et al., 2015). Fast pool (Labile or active pool) made after the addition of fresh organic carbon to soil the decomposition results large proportion of biomass which is being lost in 1-2 years. Intermediate pools comprised with microbially processed organic carbon which is partially stabilized and turnover in 10-100 years. Slow pools (Stable pools) are highly stabilized SOC and turnover in100 to1000 years.

Soil organic carbon shows the balance between addition of organic carbon from different sources and its losses through different pathways. SOC changes according to land use, soil types and climatic zones (Swarup et al., 2000). Intensive cropping adoption on one side disturb the C balance by oxidation losses due to continuous cultivation and on second side add the C to soil by addition of crop residues resulted either a net build up or depletion of SOC stock(Kong et al.,2005). The SOC stock is made up of labile or active pools and passive pools with different residence time in soil. Labile carbon pool is that fraction of soil organic carbon which rapidly turns over. The oxidation of labile C derives the flux of CO_2 from soil to atmosphere (Mandal et al., 2007). This type of pool act as a fuel for soil food web and affect the nutrient cycling and soil quality (Chan et al., 2001 and Mandal 2005).

2.3.2 Active and Passive carbon pools:

2.3.2.1 Active carbon pools: Active pools of C represent the accumulation of C in labile form for short period of time. Parton et al., 1987 found that living microbes and microbial products were major constituents of active pools of C. Active C fractions are act as energy source for soil food web and affects nutrient cycling (Majumder et al., 2008). The labile fractions of soil organic carbon showed positive response to change in supply (Chan et al., 2001). Microbial biomass C, water soluble organic C and carbohydrates are the major fractions of active pools of SOC (Mandal, 2005). 5-20% of TSOC (Total soil organic C) comprised with carbohydrates which formed from plants, animals and microorganism (Stevenson, 1994). Soil carbohydrates are formed from polysaccharides which plays a vital role in stability and aggregation of soil structure (Vivek, 2008).1-5% in TSOC contributed by soil MBC. The C: N ratio of MBC is 5-10 gave mineral nutrient and life to soil (Vivek, 2008). Water soluble organic carbon (WSOC) refers to rapid organic substrate for soil micro-organisms (Swarup and Singh, 2009).

2.3.2.2 Passive carbon pools: Recalcitrant fractions of soil organic matter responsible for passive pools of SOC. Humic acid(HA) and Fulvic acid (FA) are recalcitrant fractions with the long residence time in soil(Rajkishore,2013) . These recalcitrant fractions of humic substances are stable fractions of SOM pool and resist microbial decomposition. These humic acid substances are chemically reactive in nature which contribute in productivity of crops (Stevenson, 1994).Passive pools have C; N ratio of 7:1 to 9:1 and very slowly affected by microbial activities (Swarup and Singh, 2009). Humification means the turnover of biologically derived C to chemical complex form is a complex process for driving C sequestration (Sherrod et al., 2005). In rice and sugarcane crops organic carbon formed within phytoliths which are important fractions of SOC and remain in soil for more time (Parr and Sullivan, 2005). Phytoliths are silica bodies formed by plant bio mineralization process. So by enhancing phytoliths production in crop plants, terrestrial C sequestration C can be greatly achieved.

The main purpose of soil C sequestration is to transform atmospheric CO_2 into stable long lived soil carbon pools which helps to mitigate global warming. It is observed in current past that soil C sequestration is less demanded area due to the absence of real and quantifiable assessment of C capture in the process. It might be due to the controversies in humic and Fulvic acid formation which are main components of passive pools. Most importantly, the accurate procedures for measurement of these pools are not satisfactory (Raj kishore et al., 2015).

2.3.3 Relationship between different C pools: Soil organic C influenced by agriculture management practices. The extractable pools of TOC are referred as early indicators of change in TOC (Blair et al., 1995). Soil organic matter formed of labile, less labile and recalcitrant C pools (Chan et al., 2001). Labile and less labile pools decompose quickly and act as nutrient source whereas less labile and recalcitrant C pools are important for C sequestration in soil (Benbi et al., 2012). Among the labile C pools water extractable organic carbon (WEOC), MBC and potassium permanganate oxidizable C ($KMnO_4$-C) and organic fractions are essential (Benbi et al., 2015 a). The change in C input to soil affect the TOC (Chan et al., 2001). Energy source for microbes is the labile pools (Bolinder et al., 1999) and give better management of C dynamics. 20-40% organic C presents as slow pool which takes decades to turn over and 5% exists as rapidly cycling active pools with turn over time from hours to months (Benbi et al., 2015b). The characterization of SOM based on the reagents and chemicals used for the extraction of labile C pools (Shafer et al., 2001).

2.4 Effect of Biochar on soil organic carbon and Carbon dynamics: Total soil organic carbon is one of the main indicators of soil quality (Prabha et al., 2013). The increase in soil organic carbon by application of Biochar might be the nature of carbon found in Biochar (Lehmann *et al*, 2003). The mineralizable soil organic carbon which is easily oxidized is mainly responsible for flux of CO_2 from soil to environment. Soil organic carbon can be categorized as very labile, less labile and non- labile based upon degree of oxidation with H_2SO_4(Cheng et al.,2006 and Iqbal et al.,2009). Very labile and labile pools have direct correlation with mineralizable N and water aggregate stability. Less labile pools and non-labile pools contribute 35% of total organic carbon and responsible for passive pool (Nguyen et al.,2009 and Chan et al., 2001). To improve the C status in agriculture systems Biochar is an alternative soil management strategy and as a tool to increase soil organic carbon. The use of Biochar for the C sequestration in soil for long time under different management strategies has been suggested by the literature since last two decades (Zimmermen et al.,2011).Recalcitrant nature of Biochar makes it stable type of Biochar that is mainly formed of alcohols, phenols and organic acids(Jindo et al.,2014). The active C pools are more susceptible to microbial attack which contributes in soil C mineralization. But by the addition of Biochar a C rich amendment a balance between active and passive C pools may be formed. Biochar acts as a priming agent during mineralization (Kuzyakov et al., 2009 and Luo et al., 2011). Some of previous studies concluded that soil microbial activity enhanced by the improvement of microbial habitat environment and increased C mineralization (Lehmann et al., 2011, Quillicam et al., 2013 and Smith 2010). These results confirmed that C mineralization occurred after Biochar addition. Huge rate of rice husk Biochar resulted high C mineralization when determined in terms of cumulative emission of CO_2 (Deenik et al., 2010). On the other hand application of 90 tonne ha^{-1} oak Biochar reduced C mineralization by 2%, grass Biochar decreased 5% in C mineralization and sugarcane Biochar reduces by 25% C mineralization within 2 weeks of Biochar application to soil (Zimmermen et al., 2010). The lower rate of rice husk Biochar also reduces the C mineralization rate may be due to strong adsorption of soluble soil C , nutrients and microbes on the surface of Biochar resulted in increasing C use efficiency (Jose et al.,2018 and Bailey et al., 2011). Rice husk Biochar (RHB) significantly affects the microbial biomass carbon. As the rate of rice husk Biochar increased microbial biomass carbon also increased. The microbial biomass content in soil is directly correlated with the total carbon in soil (Singh et al., 2014). Microbial quotient is a key point of microbial C use efficiency (Costanzo et al., 2011).The sequestration of C by application of RHB also increased. The incorporation of Biochar to soil gave benefit in C sequestration (Marris et al., 2006 and Herath et al., 2015).

Prabha et al., 2013 concluded that the addition of Biochar to soil increased the total C content which is measured after 500 days incubation in soil column as compared to control. Similarly increased in soil organic carbon by addition of Biochar in rice crop also reported by Laird et al., 2010.Soil organic carbon concentration is 4.6% as compared to control. Maximum organic carbon 4.6% recorded with 35g of Biochar. Zhang et al., 2012also reported that the Biochar rates from 0-40 tonne ha^{-1}, the soil organic carbon also increased. Jones et al., 2012 also observed the same result in fodder maize and hay grass. Only the measurement of soil organic carbon not reflect the changes in soil quality and nutrient status (SafFigna et al., 1989) but the measurement of active pools of carbon like particulate organic C that changes in the quality of soil and increase the productivity is also essential (Franzluebbers et al., 1995).Due to the changes in management practices there is a rapid change in the particulate organic carbon fractions of soil organic carbon between active and slow fractions (Chan et al.,2013 and Bayer et al., 2001) . Prabha et al., 2013 in their research experiment in rice crop observed that by the addition of Biochar higher doses to lower doses

(B 35 >B25 >B15 >B0 tonnes)particulate organic carbon decreased. Water soluble carbon fraction is the sensitive indicator of labile organic matter could be used as a measure of sol quality (Zhang et al., 2012). The labile C content increased with different doses of Biochar (Ghani et al., 2003). The dissolved organic carbon content increased with Biochar addition (Jones et al., 2012).

2.5 Effect of Biochar on soil physical, chemical and biological properties: Soil organic matter is one of the vital factors affecting the physical properties of soil (Benjamin et al., 2013). The soil structure is improved by the organic matter. Organic matter increases the soil aggregation, soil porosity, nutrient and water retention due to high adsorption capacity and high surface area. Soil rich with organic matter resulted good physical properties of soil and gave more yield (Abdallah et al., 1998). But in recent scenario to increase the soil organic carbon, there is a need to add the Biochar and manure to soil. Compost, manure, biogas slurry used these days as a source of carbon but decomposition rate is very high (Palm et al., 2001).

2.5.1 **Effect of Biochar on soil physical properties:**

2.5.1.1 Surface area: Biochar has high surface area which influences Biochar interaction with soil. High surface area increases the total soil specific surface of Biochar amended soils (Chen et al., 2013).If the surface area is more the absorption rate is more. Biochar has high specific surface area which affects the soil interaction with other substances and increase specific surface area of soil [Gundale and De Luca, 2006).

2.5.1.2 Bulk density: Bulk density is a measurement of how tightly soil particles are pressed together. It is a ratio of mass of oven dry soil to bulk volume. Biochar has high specific area and highly porous structure .Biochar has low bulk density. The range of Biochar bulk density range from0.08 gcm^{-3} to 0.43 gcm^{-3} (Chaudhri et al., 2013) which is based on the feed stock used for biomass and pyrolysis temperature. When Biochar applied to soil it reduces the bulk density of soil due to its high porosity (Lim et al., 2016 and Downie et al., 2009). Mukherjee et al., 2013 reported that Biochar due to its more porosity decreased the bulk density of soil (Abel et al., 2013).

2.5.1.3 Permeability and water holding capacity: Biochar due to its highly porous structure not only improves soil water movement but also improves soil water retention characteristics (Novak et al., 2012) .The maximum amount of water that a soil can hold is known as soil water retention capacity. It is a very important property for plant growth. Huge amount of water hold by soil decreases irrigation frequency of crop (Sun and Ku, 2014). Uzoma et al., 2011 reported that Biochar boost up the available water content up to 97% and 56% of saturated water content up to 97% and 56% of saturated water content. The Biochar amended soils retain 15% more moisture as compared to unamended soils (Laird et al., 2010) .The increase in water retention capacity by addition of Biochar also based on soil texture (Tryon,1948). Addition of Biochar increased the water holding capacity of sandy soil as compared to loamy or clayey soil. The water holding capacity of soil increased by Biochar addition due to its more porosity and adsorption capacity (Herth et al., 2013). The surface of graphyne sheet of Biochar contains hydrophilic functional groups (Uzoma et al., 2011). Biochar increases the soil water retention capacity due to its more porous nature (Downie et al., 2009).Biochar amended soils represented an increase in available soil moisture (Liu et al.,2012). Remarkable changes in aggregate stability and water retention capacity has been observed by addition of Biochar (Sun and Lu, 2014).

2.5.1.4 Soil Porosity: The ratio of pore volume to total soil volume is known as porosity of soil. It is very vital attribute of soil which affects the plant growth. Macro, meso and micro pores present in soil. The pores are important for the exchange of gases, mobility of nutrients and movement of water in soil. The porosity of soil increased with the application of Biochar (Herth et al., 2013).The increase in soil porosity was due to high porous nature of Biochar (Leonard Githinji, 2013).

2.5.1.5 Soil aggregation: Soil colloidal particles combine together due to net attractive forces among them is called soil aggregation. A soil which is fully aggregated has well structure and provide good medium for nutrients and water movement into soil (Soinne et al., 2014). Borselli et al., 1996 reported that microorganisms secreted polysaccharides increase the adherence of soil colloidal particles (Lehmann and Joseph, 2009).

2.5.2 **Effect of Biochar on soil chemical properties:** Addition of Biochar to soil has been reflected as an effective opportunity for improvement in soil fertility and nutrient use efficiency (Lehmann and Joseph, 2015).The probability of enhancement in soil fertility and plant growth after Biochar amendment raised from Terra Preta soils of central Amazonia(Glser et al., 2002) which were rich with black carbon(Cheng et al., 2008). Biochar application influenced the chemical properties of soil i.e. pH, EC, CEC and nutrient contents (Beiderman and Harpole, 2013).

2.5.2.1 Effect of Biochar on pH of soil: Biochar has the ability to improve the chemical properties of soils. Soil pH is important property of soils in terms of availability of nutrients to plants (Fagria and Baligar, 2008). Granatstein et al., 2009 found that when different types of Biochar applied to soil they show different effect. Biochar has ability to increase pH of soil by decreasing amount of exchangeable Al^{3+} (Brewer and Brown, 2012Commonly pH of Biochar ranged from acidic to alkaline range (pH 8-10). Various research studies concluded that Biochar addition increase soil pH (Luo et al., 2011, Wu et al., 2012, Xu et al., 2013). The reclamation in pH of soil was due to the addition of alkali and alkaline *metal o*xides by Biochar or decreased the availability of acidic ions from soil matrix (Kumar et al., 2013). Van Zwieten et al., 2010 reported that application of paper mill Biochar @10 tha^{-1} increase pH, CEC, exchangeable Ca, total C and reduce aluminium availability. Biochar application to soil may improve nutrient supply to plants. The study concluded that pH increase from 7.1-8.1 with application of $39tha^{-1}$ Biochar formed from herbaceous feedstock in sandy soil. The Biochar used in study having pH 6-9.6 based on pyrolysis temperature and feedstock material (Steiner et al., 2007). The increase in pH of soil might be due to high cation exchange capacity (CEC) and buffering capacity (Lashari et al., 2013). An increase in pH of soil by Biochar application is reported for many soils it may be due to alkaline nature of Biochar which is mostly linked with pyrolysis temperature and types of biomass used for Biochar preparation(Glaser et al., 2002, Amelot et al., 2013 and Chintal et al., 2014). The reason behind increase in pH of Biochar amended soil is the presence of negative charged phenolic, carboxyl and hydroxyl groups on Biochar surfaces which bind H^+ ion in soil solution so reducing H^+ ion concentration in soil solution and enhance soil pH (Masto et al., 2013).The silicates, carbonates and bicarbonates originating from Biochar can bind to H^+ ions and remove from soil solution also increase in pH of soil (Farrel et al., 2013). The effect is more pronounced on acid soils and soils with organic matter because soil organic matter related to pH buffering capacity (Chintala et al., 2014). Rodriguez et al., 2009 stated that soil pH was increased from 4-4.5 by addition of Biochar. Matsubra et al., 2002 conducted a greenhouse experiment and found that the soil pH of the treatments receiving Biochar increased as compared to control.

2.5.2.2 Effect of Biochar on cation exchange capacity of soil: Cation exchange capacity of soil is the capacity of soil to retain the exchangeable cations in soil and reduce the leaching losses (Sohi et al., 2009). Surface oxidation and negative charge surface functional groups of Biochar increase CEC which readily provide the nutrients for growth of plants (Downie et al., 2009). Porous structure, large surface area and negative surface charges functional groups of Biochar enhance CEC and retention capacity of nutrients (Laird et al., 2010).).Biochar amendment to soil has been reported to decrease the mobility of toxic elements in acid soils (Major et al.,2010) and increase K and P availability(Jeffery et al.,2011). Literature findings show that changes in soil quality including increasing pH, organic carbon, cation exchange capacity and N fertilizer use efficiency at high Biochar rate greater than 50 tha^{-1}(Chan et al., 2008 and Bera et al., 2016). Soils having more CEC has potential to hold the plant nutrients to surface of Biochar particles and nutrients are retained in soil for long time rather than leached down.(Glaser eta., 2002, Liard et al., 2010a). Cornelissen et al., 2013 observed in their study that Biochar of wood increase the soil CEC might be due to the oxidation of Biochar. The Increased CEC resulted more productivity (Liang et al., 2006). Uzoma et al., 2011 noticed that CEC of soil increased by 50% by addition of charcoal. Topoliantz et al., 2002 reported that CEC positively influenced by addition of Biochar.

2.5.2.1 Effect of Biochar on nutrient retention, nutrient availability and other properties:

Li et al., 2015 reported that by use of wheat Biochar there was increase in soil pH, organic carbon, and total nitrogen and reduced N_2O emission. Jaffar et al., 2015 b and Hardle et al., 2014 reported that by use of acacia whole tree green waste there was increase in microbial activity ,enhance porosity and improve aggregate stability. Gaskin et al., 2010 found that by use of peanut hull as source of Biochar increased K, Ca and Mg in 0-15 cm surface soil and increase the uptake of K in plant tissue. Beiderman and Harpole 2013 and Thies et al., 2015 used different Biochar sources in different soils. They observed that microbial biomass carbon, rhizobia nodule formation, pH of soil, P, K, N and C increased with the addition of Biochar. Rajkovich et al., 2012 conducted an experiment on alfisols by use of manure, corn stover wood chips as Biochar source. They concluded that tissue N concentration, K and Na content of soil increased with Biochar. Abel et al., 2013 stated that by use of wood and manure based Biochar there was increase in soils saturated hydraulic conductivity, total nitrogen concentration, CEC, field capacity and reduce the leaching. Similar findings also supported by Ajayi et al., 2016 and Atkinson et al., 2010).Madiba et al., 2016 used wood and pea nut shell as Biochar source. They stated that by use of this Biochar the availability of phosphorous in soil is increased. This result is also supported by Warnock et al., 2010. Novak et al., 2009 reported that Biochar produced from poultry litter at high pyrolysis temperature increased soil pH and enhance the availability of P and Na. Oguntndane et al., (2008) used charcoal site soil as Biochar which increased the total porosity of soil from 46% to 51%, 88% increase in hydraulic conductivity and 9% decrease in bulk density. Giierena et al., 2015 reported that increase in total N by 78% by addition of Biochar. Chan et al., 2007 used wood Biochar as experimental material. They found that increase in soil C content, pH value and available P by use of Biochar. The leaching of fertilizers also reduced. The same result also found by Randon et al., 2007.

Schulz and Glaser, 2012 reported that Biochar increase in pH of soil, available K, Ca, Mg and CEC. Inyang et al., 2010 stated that sugarcane bagasse Biochar addition increased the CEC of soils and increase nutrient holding capacity. Chan et al., 2007 noticed significant interaction of Biochar and nitrogen and presenting the role of Biochar in improving N fertilizer use efficiency. Jin Hue et al., 2011 observed significant increase in pH, organic carbon and exchangeable cations. Sukartono et al., 2011 reported that the use of Biochar enhanced the contents of available P, exchangeable K, Mg and Ca as compared to control. Ali Et al.2015 found that integrated use of Biochar with FYM and N improves wheat nutrient uptake and soil total N content. Castaldi et al., 2011 found that Biochar enhances CEC which also increased nutrient retention capacity. Zhang et al., (1998) noticed that Biochar improve soil pH, organic C and total N. Steiner et al., 2007 observed improved nitrogen use efficiency in Biochar containing soils. Steiner et al., 2004 observed that Biochar is important for increasing soil biology which affects the microbial biomass and composition. The similar result also supported by Randon et al., 2007. Lehmann and Joseph 2009 reported that application of Biochar can increase C sequestration and improves soil quality. Zwieten et al., 2010, Schulz and Glaser 2012 and Zhang et al., 2013 reported that Biochar improved the soil properties like CEC, nutrient absorption and soil water retention capacity. Pietikainen et al., 2000 stated that Biochar having high porous structure and large surface area due to this it act as habitat for the beneficial microorganisms.

Gundale and De Luca (2006) stated that Biochar addition to soil increased the nutrient availability by changing its physico chemical properties.Major et al., 2010 demonstrated that application of Biochar@ 20tha^{-1} significantly increased the availability of Ca, Mg, Mn and Mo over control. Lair et al., 2010 demonstrated that Biochar amendments @5,10 and 20g kg^{-1} soil improved the availability of total N,P,K, Mg and Ca. Lehmann et al., 2003 reported that by the addition of Biochar the nutrient availability to plants become high due to more retention capacity. Rodriguez et al., 2002 stated that Biochar can be used by farmers to reclaim the pH of soil and decrease the lime application. De Gryze et al., (2010) considered that increase in pH of soil by addition of bio chat based on soil texture. As compared to clayey soil increase in pH in sandy and loamy soils found.

2.5.3 **Effect of Biochar on soil biological indicators:** Soil physical- chemical properties increase microbial density and activities by giving them habitats. The direct useful effects of Biochar on quality of soil and microorganisms can result in providing more habitats and niches to microorganisms as litter and roots. Most of the processes of soil may be altered by addition of Biochar (De Luca et al., 2009). Nutrient transformation and C mineralization were demonstrated to increase or decrease in presence of Biochar (Kuzzyakov et al., 2009). This might be due to response of transforming C sources, nutrient availability, adsorption of organic-inorganic compound including enzymes or transforming pore structure (Liang et al., 2010). Soil extracellular enzymes are responsible for organic matter decomposition and nutrient cycling (Daquan et al., 2012). The effects of Biochar on soil enzyme activities based on the interaction of substrates and enzymes (Masto et al., 2013). The greater porosity and surface area of Biochar is supposed to reduce the extracellular enzyme activities (Ameeloot et al., 2013). Pyrolysis temperature during preparation of Biochar plays important role on enzymatic activities. If Biochar produced at 700 degree C than dehydrogenase activity decreased and if produced at 350 degree C than dehydrogenase activity increased (Bailey et al., 2011). Dehydrogenase enzyme activity in soil reflects the overall scenario of microbial metabolism. The dehydrogenase activity in soil and microbial biomass carbon in soil were increased by addition of different types of Biochar (Liang et al., 2010). Soil microbial biomass carbon is a key factor for the response of microbial biomass to change in soil management which affects the turnover of organic matter (Nanniperi et al., 1990).Addition of Biochar responsible for increase in microbial biomass. There was more decomposition of soil C which was responsible for enhancing microbial biomass in presence of Biochar (Wardle et al., 2008). Microbial activity stimulate within short time after addition of Biochar due to labile compounds in Biochar (Das et al., 2008). Kolb et al., 2009 considered that fresh Biochar prepared from dairy manure enriched with N, P and labile C enhanced the total respiration and metabolic quotient. Jin 2010 reported that after addition of Biochar to soil the activities of two mineralization enzymes decreased. These findings also supported by Bailey et al., 2010, Paz –ferreiro et al.,2012 and Lammirate et al.,2011. Bailey et al., 2010 reported that by addition of Biochar the activity of alkaline phosphatase, amino peptidase and N-acetyl-glucosamindase were increased. They also reported that uptake of N and P by plants and growth of root hairs in Biochar pores rate fastens the production of organic N and P mineralizing enzymes. Jin, 2010 demonstrated that Biochar amendment to soil increased alkaline phosphatase activity by 61% and amino peptidase by 15%.Dempster et al., 2012 reported that specific surface area of soil increased by Biochar application which increased microbial activity of soil. Atkinson et al., 2010 and Lehman et al., 2011 demonstrated that micro biological properties of soil increased due to the improvement in physico chemical properties.

Chan et al., 2008 and Steiner et al., 2008a reported that high doses of Biochar decreased the microbial biomass C in soil. This result also supported by Kolb et al., 2009.Park et al., 2011 found that increased dehydrogenase activity with application of Biochar. De Roy et al., 2005 reported that there was increase in dehydrogenase activity by application of wheat straw Biochar. Zomuner et al., 2008 demonstrated that Biochar containing substantial amount of P which increased the acid phosphatase and alkaline phosphatase activity in soil. Kumar et al.2013 findings conclude that alkaline phosphatase and acid phosphatase activity with high doses of Biochar decreased. Wang et al., 2011findings conclude that high acid phosphatase activities in soil over control. Same findings also found by Masto et al., 2013.Deng and Tatabati, 1997 concluded that the residue and charcoal application to soil supplied organic P which increased the acid and alkaline phosphatase activity in soil. Khare and Goyal, 2013 findings conclude that increment in the urease activity by Biochar application over control might be the result of high microbial biomass. Wu et al., 2013 and Knicker et al., 2008 reported that with increased rates of Biochar there was reduction in urease activity might be due to presence of N as pyrrole and indole form in Biochar.

2.6 Effect of Biochar on soil nutrient, nutrient uptake and crop yield: Biochar is a carbon based co-product containing nutrients such as N, P, K, Mg and Ca. When added in soil it increased soil organic matter, water retention and soil biological activity as well as decreased fertilizer requirement (Uzmo et al., 2011). The Biochar application to soil significantly improve crop yield directly or indirectly. Directly in this manner that Biochar prepared from biomass during pyrolysis contain high amount of nutrients and indirectly by improvement in soil physical, chemical and biological properties due to Biochar application. Fox et al., 2014 reported that Biochar amended soils increased N and P uptake efficiency. The result was also supported by Subedi et al., 2016.Deluca et al., 2009 demonstrated that the increase in nutrient content in Biochar amended soils. Kanmann et al., 2012 reported increase in soil organic carbon content. Clough et al., 2013 demonstrated significant increase in total N content with rye grass Biochar. Wang et al., 2015a reported that the available phosphorous content in soil amended with Biochar increased as compared to control. Sachs, 2004 observed that the exchangeable K content improved by addition of Biochar application. Guererna et al., 2013 and Zha et al., 2014 found that the Biochar amendment decreases soil NO_3^- N and NH_4^+ - N leaching. The N retention capacity increased due to less leaching and crop N uptake increased. Beiderman et al., 2013 observed that Biochar amendment increased the total soil N concentration and rice yield. Glaser et al., 2002 found that the water holding capacity increased due to that bulk density reduced and NO_3^- N and NH_4^+ - N leaching reduced. Vaccari et al., 2011 stated that application of Biochar prepared from wheat straw @1.9tha^{-1} along with recommended N:P:K increased the production of maize crop. They concluded that this application was superior to crop residue incorporation and burning. Purakayastha (2010) was conducted an experiment to evaluate the effect of Biochar made from different materials. The rate of Biochar application is 3 and 6 tonnes ha^{-1} along with NPK. They found that Biochar application increased grain yield of wheat and pigeon pea.

Oguntunde et al., 2004 reported that grain yield and biomass yield of maize increased on charcoal soils. They also observed that the uptake of K, Cu, Mn also increased with high Biochar application. The same result found by Major et al., 2010.Zhang et al., 2012 stated that increase in rice yield by 9-28%over control with Biochar application @0, 10 and 20t ha^{-1}.Atkinson et al., 2002 found that increased in plant growth and yield by application of Biochar has been found due to the modification in soil physical properties. Glaser et al., 2002 reported that soil structure and water holding capacity improved by application of Biochar due to which nutrient availability increased. Jeffery et al., 2010 concluded that Biochar amendment to soil increased productivity. Lehmann and Joseph, 2015 reported that there was significant increase in crop yield by Biochar application. Lehmann et al., 2003b found that Biochar application with combined use of fertilizers increased crop yield due to improvement in soil properties.

Crane –Drosech et al., 2013 demonstrated that there was increase in crop yield by Biochar application due to improvement in soil aggregation increasing nutrient retention and improve soil water holding capacity. Biederman and Harpole, 2013 concluded that Biochar application increases plant productivity by 10%. The same result supported by Liv et al., 2013.Uzoma et al., 2011 reported that increase in maize, cowpea and peanut yield by Biochar along with recommended fertilizers. They reported that soil pH, CEC, nutrient availability increased and reduced exchangeable Al^{3+} content. Yamato et al., 2006 attributed 98% increase in maize grain yield due to modification in soil physical and chemical properties

.Bridle and Pritchard, 2004 has been explored the significant increase in soil C: N ration by Biochar application.

Zhang et al., 2012a, find out the effect of Biochar on quality of soil, yield of rice crop in China. They found enhancement in rice yield due to increase in pH of soil, soil organic carbon, total nitrogen and reduction in bulk density of soil. Kloss et al., 2014 concluded the 68% decrease in yield by Biochar application in mustard and barley crop due to decrease in Cu, Fe, Mn and Zn concentration and increase Mo concentration in plant tissues. Jeffery et al., 2011 demonstrated more crop yield in pot as compared to field. The same result also supported by Crane-Drosech et al., 2013. Liu et al., 2013 reported that the crops cultivated with Biochar gave 10.6% more yield as compared to control. Shinchi koyama and Hisayoshi Hayashi 2017 concluded that rice husk charcoal application to soil increasing carbon sequestration. It also increased silicon uptake. Peng et al., 2011 found that Biochar amendment responsible for the changes in total nitrogen , available phosphorous and available potassium based on type and quantity of Biochar. Lin et al., 2016 reported that enhancement in soil available P and available K by application of Biochar. The same results found by Yang et al., 2004.Biederman et al., 2013 demonstrated that superiority of Biochar in enhancing P and K uptake and availability by reduction in leaching losses and liming of soil.

2.7 Effect of Biochar combined with fertilizers and manures on soil nutrient status and plant growth and productivity: The use of organic material as fertilizer for crop production has received major attention for more crop production (Tripathi et al., 2013). Organic matter is the lives of soil and the operations which favors sustainable production and promote organic matter build up (Tejada et al., 2009). Organic manuring by direct application of FYM has been reduced over years due to various problems (Behera et al., 2007). Currently manuring has come in trend again because of high fertilizers prices. The manures like FYM, Vermicompost maintained sustainability for long time. There was a positive interaction noticed between organic manures and urea as nitrogen source (Habtegebrial, 2007). Poultry manure is the excreta of farm fowl which decompose slowly. It contains higher N and P compared to other manures. It contains 3.03%, 2.63% P_2O_5 and 1.4% K_2O. Poultry manure act as substitute to FYM and chemical fertilizers. But the farmers are not aware about this. Here it is necessary to literate the farmers not only about N,P_2O_5 ,K_2O in poultry manure but also that it is a good source of micro nutrients like Zn, Cu, Mn, Fe. Vermicompost is a method of making compost using earthworms. It is the process in which earthworms feed on waste organic substances converts them into compost. Vermicompost is a mixture of faecal excretions and organic matter including humus. Vermi casts are rich in $CaCO_3$ and some content of $MgCO_3$. The exchange of Ca^{2+}, Mg^{2+}, K^+, available N, P, and K is higher in vermicompost due to presence of cations. Vermicompost contain 1.6%N, 5.04% P_2O_5 and 0.8% K_2O.The inorganic fertilizers played a vital role in improving fertility of soil and crop productivity (Khan et al., 2009). N fertilizers improve grain yield (43-65%) and biomass (25-42%) in maize. The application of organic manures along with fertilizers to provide nutrients to plants is a problematic task because organic materials have variable and complex nature. Proper knowledge about chemical composition, nutrient content and C quality of organic materials required (Ogolo et al., 2002). The inorganic fertilizers not only decrease in increment in yield but also deteriorate soil (Castada et al., 2011). To handle this problem of current scenario to enhance yield and nutrient use efficiency is the integrated crop management by use of organic manures and organic materials like Biochar combined with fertilizers (Manqiang et al., 2009).Developing sustainable fertilizer management practices like synchronization in type and quantity of organic sources of nutrients like FYM may improve fertility of soil(Fageria and Baligar, 2005) and FYM should be an alternative to synthetic fertilizer(Ali et al.,2015) . FYM not only provide nutrients but also helps to increase the productivity of soil. It also increase Soil N and organic matter which increased crop yield (Sanchez-Monerdo et al., 2004). The literature related to the combined use of Biochar, manures and fertilizers discussed as.

Naseem khan et al., 2013 conducted an experiment to check the effects of integrated use of Biochar, FYM and nitrogen fertilizer on soil organic fertility. The study concluded that Biochar and FYM accumulate soil organic matter. Biochar along with FYM had no significant effect on accumulation of soil mineral N but Biochar+ FYM+ Fertilizers accumulated more mineral N in soil. Lampkin, 2002 reported that combined use of Biochar with FYM and synthetic fertilizers improved soil properties like soil pH, CEC, soil aggregation, soil water holding capacity and soil microbial activity (Bari et al., 2003).Steiner et al., 2007 emphasized that the use of Biochar with FYM increased the availability of plant nutrients and soil productivity. Ali et al., 2015 observed that combined use of Biochar with FYM and N increase wheat nutrient uptake and soil N content. Castaldi et al., 2011 considered that integrated use of Biochar with FYM and N increased CEC which also enhanced nutrient retention capacity of soil. Liu et al., 2010 reported that with Biochar amendment along with FYM, soil pH, organic carbon and total N was improved. Sukartono et al., 2011 reported that soils amended with Biochar along with FYM had more nitrogen use efficiency. Steiner et al., 2007 reported that soil biology enhanced which affect the microbial biomass and composition by use of manures and Biochar. Rondan et al., 2007 demonstrated improvement in biological nitrogen fixation by Biochar and FYM application. Chan et al., 2007 reported that grain weight of wheat was increased with FYM as compared to control. This result also in confirmity with the findings of Kumar and Puri 2001 who observed that FYM along with N was the best option for increasing maize yield. Uzoma et al., 2011 found that significant increase in maize yield by use of Biochar, FYM and N. Ali et al., 2011 reported that highest number of tillers recorded in FYM amended plots FYM might be due to the release of nutrients from the decomposition. Steiner et al., 2007 observed that the use of Biochar along with manures increased the grain yield 16% over control. Day et al., 2005 concluded that productivity of crop increased by use of Biochar along with manures and synthetic fertilizers. The combined use increased the fertility of soil by reducing leaching of N. The similar results found by Blackwell et al., 2009 and Chan et al., 2007. Atkinson et al., 2010 demonstrated the integrated influence of Biochar, FYM and N fertilizer on wheat. The highest number of spikes m^{-2}, grains per spike, 1000 grain weight, grain yield and straw yield recorded with Biochar @5tha^{-1}+120kg N+10 t FYMha^{-1}.Maqsood and Shehzad ,2013 reported that application of Biochar @25 tha^{-1} and FYM 10 t ha^{-1} increased P grain uptake by 19.9% compared to control. Akmal et al., 2010 concluded that there was increased in soil C by 54.16% due to Biochar, FYM and N level interactions. Iqbal et al., 2002 recorded that application of Biochar with FYM increased soil P and K content. Oya and Iu, 2002 resulted that application of mineral N, Biochar and FYM increased the grain yield of wheat over control. Singh and Aggarwal 2001 reported that enhancement in grain yield might be due to N fertilization and mineralization of organic sources such as Biochar and FYM. Puste et al., 2013 revealed that application of manures along with fertilizers in sunflower crop increased the nutrient uptake. Tripathi et al., 2013 observed that the combination of Biochar, FYM and NPK result highest fibre yield of sun hemp. Lagomarsino et al., 2009 recommended that combination of organic and inorganic source saved 50% of inorganic fertilizers without compromising rice yield and also improved soil fertility. Subehia and Dhankia 2013 revealed that the combined use of organic and inorganic fertilizers improved rice grain yield and straw yield over solely fertilizers treated plots. The maximum rice grain and straw yield was recorded with 50% N supplied through FYM.

Upadhyay et al., 2011 found that use of organic manures along with chemical fertilizers increased soil organic carbon, available N, P and K content as compared to alone chemical fertilizers. Milkha and Aulakh (2004) emphasized that integrated nutrient management increased crop yield over recommended fertilizers due to slow mineralization rate , reduced N losses , improvement in NUE and increased soil fertility. Tilak et al., 2005 recommended that for improving soil fertility optimized use of organic and inorganic sources of plant nutrients required. Yong *et al,* 2006 emphasized that soil organic carbon, available N,P,K content in soil enhanced by application of Biochar, FYM and RDF. Mulan et al., 2014 concluded that the wheat straw Biochar along with manures and NPK increased N and P uptake efficiency. Paul et al., 2014 revealed that with rice husk Biochar incorporation in soil along with FYM increased soil microbial biomass carbon, activities of dehydrogenase enzyme. The plant height, number of tillers, number of panicles and number of grains per panicle also recorded maximum. Naik et al., 2013 resulted that organically + inorganically treated plots recorded highest grain and straw yield of wheat as compared to control. Yaduvanshi et al., 2013 conducted a field experiment to check the effect of inorganic fertilizers alone and in combination with organic manures on soil properties. The study resulted that soil organic carbon, available N, available P increased with the use of FYM+NPK. Nutrient use efficiency increased in wheat due to use of organic manures and inorganic fertilizers. Bahadur et al., 2013 reported that plant height, productive tillers, dry weight per plant, length of spikelet, test weight, grain and straw yield increased by application of FYM, Biochar and RDF. Mavriya et al., 2013 discussed that integrated application of organic manures with RDF and Biochar improved the yield and yield contributing characters of rice and wheat. Bhaduri and Gautam 2013 resulted high yield and B: C ratio with 4.5 tha^{-1} Biochar+ FYM+RDF in rice crop. Meena et al., 2013 recorded highest wheat yield with the use of RDF+ FYM+ Biochar+ Zn. Rathod et al., 2013 stated that FYM and vermicompost along with inorganic fertilizers benefitted the crop by improving the yield of fodder maize. Jat et al., 2012 recommended that combined use of organic and inorganic sources of N is vital to get high yield of wheat maize cropping system and to enhance soil fertility. Bhatnagar et al., 2011 concluded that regular use of fertilizers with manures maintain the sustainability for high production of crops. Nandapure et al., 2011 resulted that integrated use of chemical fertilizers, Biochar and manures, improved the bulk density and aggresivity of crops. Mubarak and Singh 2011 reported that integrated use of Biochar, recommended fertilizer dose and poultry manure significantly increased wheat yield and soil nutrient status. Zahoor 2014 study result that incorporation of Biochar and FYM in soil increase the number of spikes m^{-2}, grain yield and number of grains per spikes and thousand grain weights (g). They recommended that use of FYM with RDF and Biochar before sowing have the ability to increase the yield of wheat. Singh et al., 2015a observed that 75% RDF+25% vermicompost+ Biochar increased the growth and yield attributing characters of wheat. The grain and straw yield also increased with this combination.Devi et al., 2011 stated that 50% RDF +50% vermicompost+ Biochar increased the yield of rice-wheat cropping system and increased the NPK uptake. Mojaddam and Noori 2015 reported that use of manures along with NPK increased leaf area index, crop growth rate and net assimilation rate of pules.

Adekiya et al., 2018 reported that application of Biochar and poultry manure alone or in combination improve soil physical, chemical and biological properties. Partey et al., 2014 reported that there was a positive interaction of Biochar and poultry manure which increased the potential of Biochar to enhance the utilization efficiency of nutrients in poultry manure. Steiner et al., 2010 recommended that the combination of 50t ha^{-1} Biochar and 5t ha^{-1} poultry manure increased the reddish yield. Dou et al., 2012 stated that application of Biochar to soil in combination with chemical fertilizers has shown a positive effect on plant growth. Ishizaki and Okazaki 2004 observed that combination of bulky manures with Biochar decreased N loss along with that increased humification and fertilizers value. This combination increased the yield of crops. Chan et al., 2007 observed synergistic interaction of Biochar with nitrogen .The high yield and nutrient use efficiency was observed with Biochar and nitrogen fertilizer. Arif et al., 2012 stated the combination of Biochar, FYM and mineral nitrogen increased the maize productivity. Mizuta et al., 2004 observed the improvement in soil chemical properties due to the positive interaction of Biochar and poultry manure. This results confirmed by the findings of Lehmann et al., 2002 and Radovic et al., 2001.Downie et al., 2009 reported that inculsion of Biochar with poultry manures and fertilizers decreased leaching and improve nutrient holding capacity of soil and increase yield. Lehmann et al., 2003 and Lehmann et al., 2006 reported that the direct nutrient additions by Biochar and greater nutrient retention results more nutrient availability for plants. Zhang A. et al., 2012 reported that rice yield was increased by 10-12% during first year and 10-28% during second year by application of 10 mg and 40 mg Biochar per kg soil as compared to control. Jia et al., 2012 studied the effect of maize stover Biochar on growth of vegetables. They reported that 30 mg Biochar application per kg soil along with chemical fertilizers and manures was most effective combination as compared to control and sole application

CHAPTER 3

MATERIALS AND METHODOLOGY

To achieve the proposed objectives of research field experiment was conducted during 2018-2019 and 2019-2020 at agronomy research fields, School of agriculture, Lovely professional University, Phagwara and Punjab. The used materials and methods during course of experimentation in conducting field experiment as well as pot experiments are briefly discussed in this chapter under following headings:

3.1 Location of the experimental site: The experiment was conducted at Agronomy research fields of Lovely Professional University, Phagwara, and Punjab to probe the impact of Biochar combined fertilizers on soil nutrient status in relation to growth and yield of rice-wheat cropping system. The agriculture farm is located at latitude 31.25^0N and longitude 75^0 E along with altitude of above mean sea level. Generally Rice-wheat cropping system followed in this area. The experiment was carried out an area of $600m^2$ having uniform topography with gentle slope and proper drainage.

3.2 Climate and weather conditions: The experimental site enjoys subtropical climate where hot winds during summer flow for longer time during day time and temperature remain high during night. The hottest months are May, June and July (mercury touches 49^0 C) and temperature falls down in last week of July. The winter comes in October. December and January months are the coldest month’s .Minimum temperature sometimes touches to freezing point at night and early morning. Winter rains are irregular and erratic. The annual rainfall of the region is 1150 mm and maximum portion received in July, August and September. The weather remains humid in most of the months of year. The meteorological data recorded during study period from 2 years study period are presented in Fig 3.2(a), 3.2.(b), 3.2.(c).

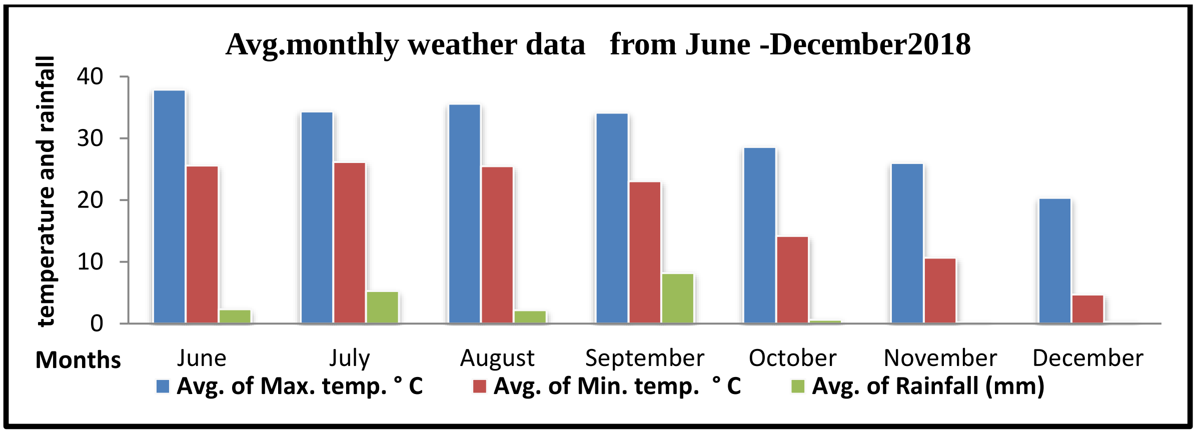


Fig. 3.2(a): Standard Meteorological monthly average weather data from June-December 2018

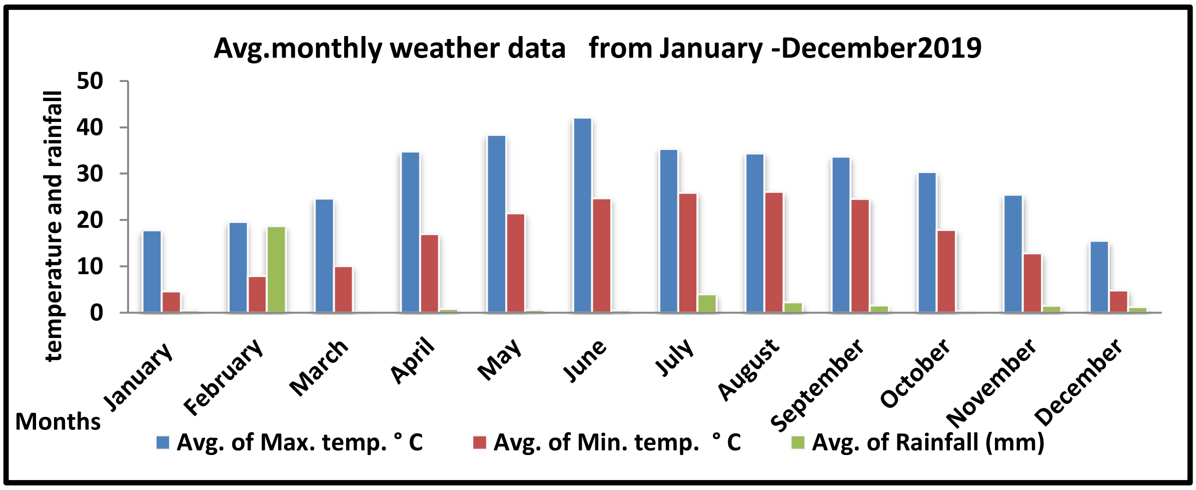


Fig. 3.2(b): Standard Meteorological monthly average weather data of 2019(www.accuweather.com)

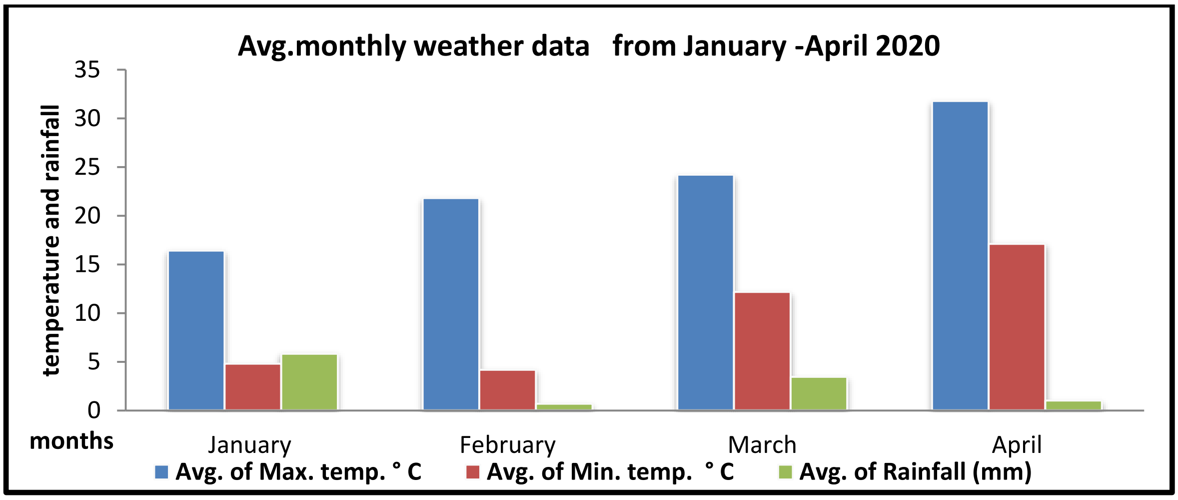


Fig. 3.2(c): Standard Meteorological monthly average weather data from January-April 2020

3.3 Soil Properties: The soils of the site where experiment was conducted are classified as coarse loamy mixed with hyperthermia family of Typic Haplustept (Sidhu et al., 1995). The soil was dug from the depth of 0-15cm and collected from different parts of experimental site and analyzed for physical, chemical and biological properties. The experimental site contains high amount of sand (77%) and considered as sandy loamy soil. The results showed that soil is slightly acidic in nature, non-saline with low organic carbon, nitrogen and potassium content and medium phosphorous content. The initial physico-chemical and biological properties of sol presented in table no. 3.3.1

Table 3.3.1: Initial basic characteristics of experimental soil

S.No.	**Soil characteristics**	**Values**
1.	Physical properties	
(a)	Texture –Sand, silt and clay (%)	77%,10.9% and 13.1%
(b)	Textural class	Sandy loam
(c)	Bulk Density(g/cm^3)	1.8
(d)	Particle density(g/cm^3)	2.2
2.	Chemical properties	
(a)	pH(1.2.5)	6.18
(b)	Electrical conductivity(dSm^{-1})	0.18
(c)	Organic carbon (%)	0.47
(d)	Available N (kgha^{-1})	147
(e)	Available P(kgha^{-1})	15.71
(f)	Available K(kgha^{-1})	172
3.	Biological properties	
(a)	Urease(mg urea/g soil/24 hours)	0.75
(b)	Dehydrogenase(µg TPF /24 h/g soil)	2.45
(c)	Nitrate reductase(NR-mg/g soil/hr)	0.13
(d)	Acid phosphatase (µg PNP/hr/g soil)	4.78
(e)	Alkaline phosphatase(mgNH4+/g soil/hr)	4.56

3.4 Cropping history of the experimental field: The cropping history of the experimental area from the previous years examined carefully. Rice-wheat cropping system has been adopted during Kharif –Rabi season. Rice crop was sown during Kharif and wheat crop was sown during Rabi in 2018-2019 and 2019-2020. This study was conducted to aware about the nature of crop sown in particular region where research experiment was carried out which may be beneficial in the interpretation and discussion of result.

Table 3.4.1: Cropping history of experimental field

	Two year cropping system(2018-2020)	
Kharif 2018	Rice crop	June – November 2018
Rabi 2018	Wheat crop	December-April 2019
Kharif 2019	Rice crop	June – November 2019
Rabi 2019	Wheat crop	December 2019 –April 2020

3.5 Experimental details: The experiment was conducted during Kharif and Rabi Season of 2018-2019 and 2019-2020.The experiment was laid out in randomized complete block design with three replications and nine treatments. The total number of plots were 27. The details of treatments, design, plot size etc. given below in table no. 3.5.1

Table 3.5.1 Experimental details of experiment

Design of experiment	**Randomized complete Block Design**
Number of treatments	9
Number of replications	3
Number of total plots	27
Plot size	5*4m=20m^2
Total experimental area	600 m^2
Cropping system	Rice-Wheat
Varieties	Rice- Pusa Basmati 1121 Wheat-PBW550
Spacing	Rice-20*15 cm Wheat-22*5-7 cm

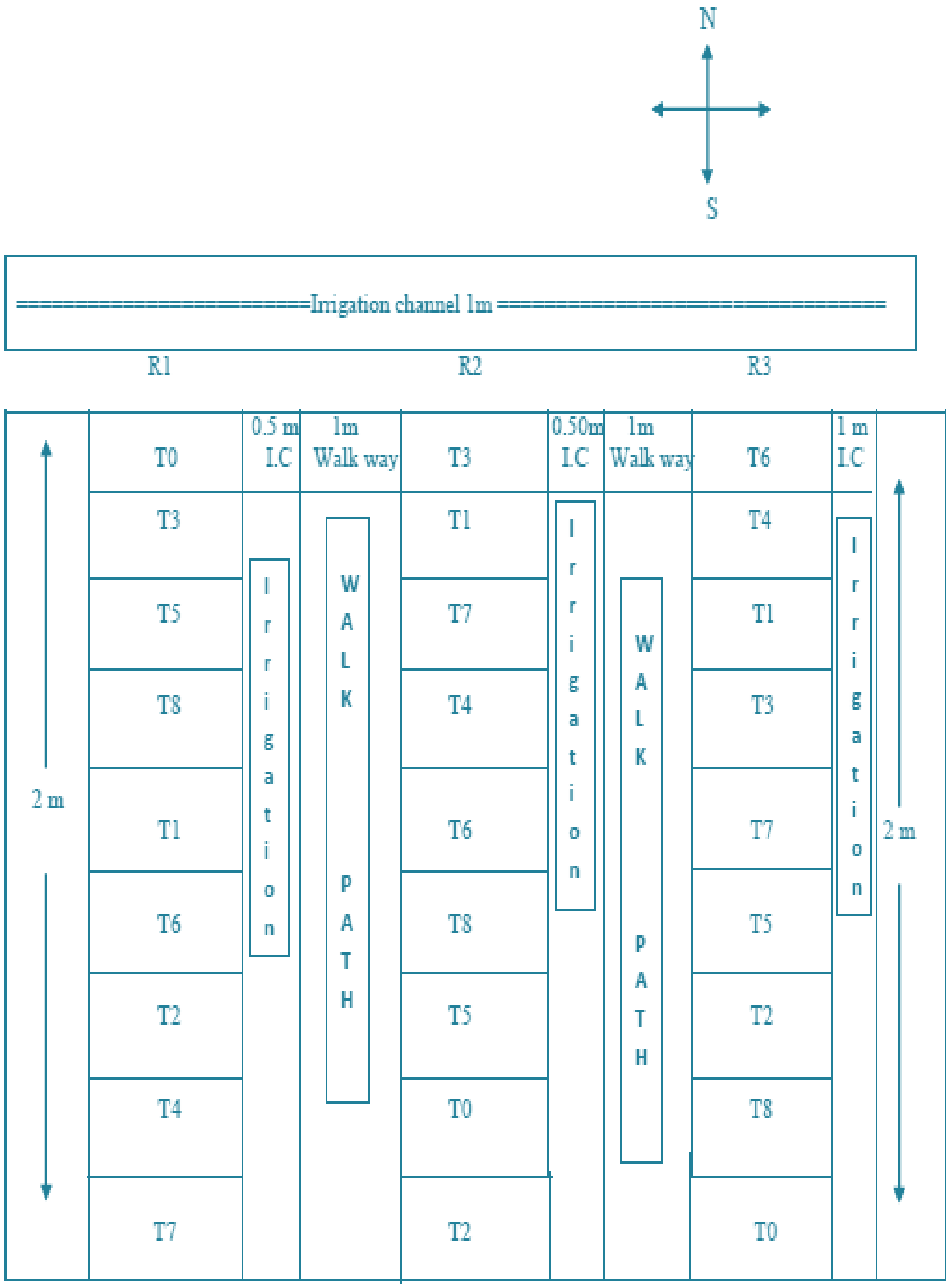
Table 3.5.2 Details of treatments

Treatment No.	**Treatment details**
T0	Control (no fertilizer)
T1	100%RDF
T2	50%RDF + Biochar
T3	50%RDF+25%FYM+Biochar
T4	50%RDF+50%FYM+Biochar
T5	50%RDF+ 25%Vermi-compost + Biochar
T6	50%RDF+ 50%Vermi compost+ Biochar
T7	50%RDF+ 25%poultry manure+ Biochar
T8	50%RDF+50% poultry manure+ Biochar

(**Recommended doses of fertilizer for rice** –Vermicompost-1tonne ha^{-1}, Poultrymanure-2tonne ha^{-1}, FYM-12.5tonne ha^{-1}, Rice straw Biochar-10tonnes ha^{-1},RDF (N: P_2O_5:K_2O)-42:30:30kg ha^{-1}).

Recommended doses of fertilizers for wheat: Vermi compost: 2.5 tonne ha^{-}1, Poultry manure: 6 tonnes ha^{-1}, FYM: 10 tonne ha^{-1}, Rice straw Biochar- 10 tonnes ha^{-1}, RDF (N: P_2O_5:K_2O)-120:60:60kg ha^{-1}).

Layout:



R1	0.5 m I.C	1m Walk way	R2	0.50m I.C	1m Walk way	R3	1 m I.C
T0			T3			T6	
T3			T1			T4	
T5			T7			T1	
T8			T4			T3	
T1			T6			T7	
T6			T8			T5	
T2			T5			T2	
T4			T0			T8	
T7			T2			T0	

3.6 Inputs for the experiments:

3.6.1 Seeds and variety description: The certified seeds of rice (Pusa basmati 1121) and Wheat seeds (PBW550) were obtained from the agriculture field of Lovely professional university, Phagwara. Pusa basmati 1121 is an early maturing variety and complete its life cycle in 145 days. The average height of the plant is 110-120cm. This photo insensitive and semi dwarf variety developed by IARI in 2003. PBW 550 variety released by Punjab Agriculture University, Ludhiana in 2007. This double dwarf variety having plant height 86 cm takes 146 days to mature. The grains are bold and amber in colour.

3.6.2 Organic manures: Well decomposed FYM, vermicompost and poultry manure were obtained from agriculture farm of LPU, Phagwara. The FYM, vermicompost and poultry manure were applied plot wise during land preparation and mixed thoroughly with soil.

3.6.3 Fertilizers: Urea, SSP, DAP and MOP used as source of nitrogen, phosphorous and potash for rice wheat crop. The treatment wise fertilizers quantity was applied uniformly in each plot. Recommended dose of phosphorous and potash were applied as basal dose where nitrogen applied in split forms i.e. half as a basal dose and remaining top dressed at critical stages.

Table 3.6.3 Characteristics of Manures ad fertilizers

S.No.	Fertilizers/manure	Nutrient content (%)
1.	FYM	$0.8\%N, 0.4\%P_2O_5, 0.74\ \%K_2O$
2.	Vermicompost	$3.0\%N, 1.0\%P_2O_5, 1.5\%\ K_2O$
3.	Poultry manure	$3.03\%N, 2.63\%P_2O_5, 1.4\ \%\ K_2O$
4.	Urea	46%N
5.	SSP	$16\%\ P_2O_5, 12\%S$
6.	DAP	$18\%N, 46\%\ P_2O_5$
7.	MOP	$60\%\ K_2O$

3.6.4 Biochar characterization and collection of Biochar: The Biochar used in the experiment was produced from rice straw. The rice straw Biochar was obtained from the Private organization of Phagwara. The characterization of Biochar presented in table 3.6.4

Table 3.6.4: Characteristics of Biochar

S.No.	**Characteristics**	**Values**
1.	pH	8.94
2.	EC	0.07dSm^{-1}
3.	Total Carbon	396$g^{-1}kg^{-1}$ Biochar
4	Total N	4.08 $g^{-1}kg^{-1}$ Biochar
.5.	Total phosphorous	738m $g^{-1}kg^{-1}$ Biochar
6.	Total potassium	8.35 $g^{-1}kg^{-1}$ Biochar
7.	Bulk density	0.117g cm^{-3}
8.	Particle density	0.2732g cm^{3}
9.	Solid space	39.9%
10	Porosity	60.07%
11.	Ash content	37.6%

3.7: Cultural operations: All the intercultural operations were done as per the package and practices of PAU, Ludhiana for the normal growth of crops. The plant protection measures were adopted on need basis. The details of cultural operations performed during two years of experiment were given below in table:

Table 3.7.1: **Crop calendar for the cultural operations performed in field in Rice crop during 2018 and 2019**

S.No.	**Particular operations**	**Rice**
1	Nursery bed preparation	15 days before sowing
2	Soaking of seeds	2 days before sowing
3.	Sowing of seeds	After 2 days of soaking
4	Main field preparation	20-25 days before tansplanting
5	Final land preparation-layout, Biochar incorporation, FYM, vermicompost and Poultry manure application	15 days before planting
6	Transplanting	25 days old seedlings
7	Basal fertilizer application	At time of transplanting
8	First split of urea	At tillering stage
9.	Irrigation	5-7 days interval
10.	Weeding	20-25 DAT, 40-45 DAT
11	Second split application of urea	At panicle initiaton
12	Harvesting	120DAT

Table3.7.2: Crop calendar for the cultural operations performed in field in wheat crop during 2018-19 and 2019-2020

S.No.	**Particular operations**	**Wheat 2018-19**
1	Pre sowing irrigation	10 days before land prepration
2	Ploughing, harrowing	4-5 days before sowing
3.	Layout preparation, Biochar incorporation, FYM, vermicompost and Poultry manure application	2 days before sowing
4	Sowing of seeds	10 days after land preparation
5	Basal fertilizer application	During day of sowing
6	First irrigation	21 DAS
7	First top dressing	30DAS
9.	Second Irrigation	20-25 days after first irrigation
10	Second split application of urea	Booting stage
12.	Weeding	20-25 DAS,40-45 DAS
13	Harvesting	120DAS
15.	Threshing	3-4 days after harvesting

3.7.2 **Establishment of crop and plant population**: The rice nursery first prepared 30-35 days prior to transplanting and 25-30 days old seedlings were transplanted in the main field by adopting 20*15 cm spacing. The wheat seeds were sown @120kg ha^{-1} by manual seed drill at 3-5 cm depth by adopting 22*5-7 cm spacing .

3.7.3 **Field preparation for rice and wheat**: For the rice seedlings transplanting the field was puddled by tractor drawn rotavator. The rotavator was drawn in standing water and muddy type condition formed. The field was levelled homogenously. The bunds were made around each sub plots to prevent the migration of water and fertilizers. The transplanting was done manually. After the harvesting of rice crop pre sowing irrigation given to the plots for the sowing of succeeding wheat crop. After 8-10 days field was ploughed and harrowed. The layout was prepared and manures added to the plots treatment wise.

3.7.4 **Weed and insect pest control**: The weeds in rice crop controlled by application of bispyribac sodium10 SC and in wheat weeds controlled by application of clodinafop. The insecticides were applied based on the incidence of insects.

3.7.5 **Harvesting and threshing**: Harvesting of rice was done in November month with sickle when the panicles fully dried and brownish in colour but plant somewhat green at 25 % moisture and threshed at 12-14% moisture. Harvesting of wheat was done in last of April when full plants turns golden brown in colour. Harvesting was done manually with sickle plot wise and threshing was done by beating the bundles on drum.

3.7.6 **Soil sampling after harvest**: The soil samples were collected from each plot from different depths after harvesting of both crops to analyse the properties of soil.

3.8 **Observations recorded during field and pot experiment**: The parameters recorded for Kharif and Rabi crops and soil samples at particular time period mentioned below:

3.8.1 Soil parameters:

S.No.	**Properties**	**Parameters**	**Stage of observation**
1.	Physical properties	Soil texture	Initial
		Bulk density(g m^{-3})	Initial and after harvest
		Porosity%	Initial and after harvest
		Particle density(gm^{-3})	Initial and after harvest
2.	Chemical properties	pH	Initial and after harvest
		EC(dSm^{-1})	Initial and after harvest
		Organic carbon (%)	Initial and after harvest
		Available N (Kg ha^{-1})	Initial and after harvest
		Available P (Kg ha^{-1})	Initial and after harvest
		Available K (Kg ha^{-1})	Initial and after harvest
		Labile carbon	Initial and after harvest
		Particulate organic carbon	Initial and after harvest
		Microbial biomass carbon	Initial and after harvest
3.	Biological properties(soil enzymes)	Urease	At initial and heading stage from surface and subsurface soil.
		Dehydrogenase	At initial and heading stage from surface and subsurface soil.
		Nitrate reductase	At initial and heading stage from surface and subsurface soil.
		Acid phosphatase	At initial and heading stage from surface and subsurface soil.
		Alkaline phosphatase	At initial and heading stage from surface and subsurface soil.

3.8.2 **Crop growth parameters**

S.No.	**Parameters**	**Growth attributes**	**Stage of observation**	
			Rice	Wheat
1.	Plant growth attributes and physiological factors	Plant height(cm)	20,40,60,80 DAT and at harvest	30,60,90 DAS and at harvest
		Tillers (m^{-2})	20,40,60,80 DAT	30,60,90 DAS
		Flag leaf length(cm)	40 and 80 DAT	60 and 75 DAS
		Fresh and dry weight of plant(g)	40 and 80 DAT	60 and 75 DAS
		Chlorophyll Index(SPAD)	40 and 80 DAT	60 and 75 DAS
		Leaf area index(cm)	40 and 80 DAT	60 and 75 DAS
		Crop growth rate(gday^{-1})	40 and 80 DAT	60 and 75 DAS
		Relative growth rate(g. g^{-1}day^{-1})	40 and 80 DAT	60 and 75 DAS
		Net assimilation rate(g(crop)m^{-1} (leaf)day^{-1}	40 and 80 DAT	60 and 75 DAS
2.	Yield attributes	Number of panicles in rice and number of spikelets in wheat	At panicle initiation	At spikelet initiation
		Panicle length and spikelet length(cm)	At maturity	At maturity
		Filled grains and unfilled grains per panicle spikelet^{-1}	Grain filling stage	Grain filling stage
		Test weight(g)	At maturity	At maturity
		Grain yield(kg ha^{-1})	At harvest	At harvest
		Straw yield (kg ha^{-1})	At harvest	At harvest
		Harvest index (%)	At harvest	At harvest
3.	Nutrient content and uptake by plant	Nitrogen uptake by grain and straw	After harvest	After harvest
		Phosphorous uptake by grain and straw	After harvest	After harvest
		Potassium uptake by grain and straw	After harvest	After harvest
		Nutrient use efficiency (%)	After harvest	After harvest

3.9 Procedure used for recording data and analysis of soil samples:

3.9.1 Plant growth parameters:

3.9.1.1 Plant height: The height of the highest tiller was recorded from 5 tagged plants from the base to the tip of the highest plant part by measuring tape. Average of 5 plants were taken to calculate mean plant height at 20,40,60,80 DAT and at harvest in rice and 30,60,90 DAS and at harvest in wheat.

3.9.1.2 Number of tillers (m^{-2}): Total shoot and the shoots containing panicles per square m were counted at different intervals in both crops and named as total tillers and productive tillers.

3.9.1.3 Fresh and dry weight of plant (g): Plants from selected one meter square area was cut close to the ground from each plot to measure fresh and dry weight of plant at different intervals in both crops. The fresh weight was taken from fresh samples after that samples placed in oven at 65 degree Celsius till constant weight achieved . After drying the samples were weighed for measuring dry weight.

3.9.1.4 Leaf area: The leaves were plucked and separated from the lamina. Leaf area was recorded at 40 DAT and 80 DAT in rice and 60 DAS, 75 DAS in wheat with the help of leaf area meter. The leaf area was also calculated with the help of formula given by Watson, D.J. (1947)

$$LA= \frac{Total\ leaf\ area(cm^2)}{Total\ land\ area(cm^2)}$$

3.9.1.5 Chlorophyll index Chlorophyll index was estimated from the greenness of leaves by SPAD meter (Soil plant analysis development meter). The fully expanded leaf selected for the estimation of chlorophyll content. Three times with the SPAD meter the value taken from a single leaf and then take average of these values as chlorophyll content (Arregui, 2006)

3.9.1.6 Crop growth rate (CGR, g day^{-1} m^{-1}): CGR may be defined as increase in dry weight of plant materials from a unit area per unit time. It can be calculated by formulae given by Watson (1952) .

$$CGR= \frac{W2-W1}{T2-T1}$$

Where W2 is the dry weight of plant at time T2, W1 is the dry weight of plant at time T1.

3.9.1.7 Relative growth rate (RGR, g g^{-1} day^{-1}): RGR term was coined by Williams in 1946. It can be defined as the total increase in dry weight of plant at two intervals. It can be expressed as unit dry weight per unit dry weight per unit time (g g^{-1} day^{-1}).

$$\text{RGR}= \frac{\text{logeW2}-\text{logeW1}}{\text{T2}-\text{T1}}$$

3.9.1.8 Net assimilation rate (NAR, G (crop) m-^{1} leaf day^{-1}): The dry matter recorded at different intervals used to calculate NAR.Formulae of NAR given by given by Watson (1952)

$$\text{NAR}= \frac{(\text{W2}-\text{W1})\ (\text{logeL2}-\text{logeL1})}{(\text{T2}-\text{T1})(\text{L2}-\text{L1})}$$

Where W2, W1= Dry weight (g) of plants at time T2, T1

L2, L1=leaf area index

3.9.2 Yield Attributes:

3.9.2.1 **Number of panicles and spikelets per plant**: Randomly one square meter selected and number of panicles in rice and number of spikelets in wheat per plant counted from each plot. The mean values of five plants taken as original value.

3.9.2.2 **Panicle length and spikelet length (cm):** Length of five panicles in rice and spikelets in wheat selected randomly from each plot from each replication were recorded with the help of measuring scale and average value was expressed as panicle and spikelet length.

3.9.2.3 **Number of grains per panicle and spikelet**: Five panicles and Five spikelets randomly selected from each treatment plot and the number of filled and unfilled grains per spike or panicle counted.

3.9.2.4 **Test weight (g):** One thousand grains from the produce of the net plots were counted and their weight was measured in grams.

3.9.2.5 **Grain yield and straw yield (kg ha^{-1}):** The harvested product of individual plot was tied in bundles and left in field for 3-4 days for drying and weight the product to get biological yield. Threshing was done manually and grain yield was recorded per plot. The straw yield was measured by subtracting the grain yield from biological yield. The yield of per plot was converted into kg ha^{-1}.

3.9.2.6 **Harvest index (%):** It is the ratio of economic yield to the biological yield. The formulae of harvest index were given by Donald (1962).

Harvest index= Economic yield/ Biological yield *100

3.9.3 **Soil sampling**: The soil samples were collected from surface and subsurface soil from each treatment replication wise and dried in shade, grinded in pestle mortar and passed through 2mm sieve and used for chemical analysis. For enzyme analysis, the fresh soil samples collected from 0-15 cm and 15-30 cm from each treatment .Soil sampling, storage analysis, pH, electrical conductivity, organic carbon, available N,P,K and soil enzymes were analysed by following methods discussed below:

3.9.3.1. Physical properties of soil:

3.9.3.1.1 Soil texture: The mechanical composition of experimental soil i.e. sand ,silt and clay percentage was determined by hydrometer method (Bouyoucos,1962). The textural triangle given by USDA used to find the texture of soil(Brady and Weil,2002).

3.9.3.1.2 Particle density: Firstly the weight of a dry clean pycnometer with a glass stopper was measured. 10g of oven dried soil was shifted to dry pycnometer, the stopper was removed and weight was noted down. After that . boiled and cool water was added up to two third of pycnometer and remained undisturbed for 10 minutes. The trapped air was removed by boiling water and shaken with glass rod . The pycnometer was filled with air free boiled water and cool water to brim and we put stopper tightly on it. The outside of pycnometer was dried by wipedit with dry cloth and weighed to 0.01 g. The weight of pycnometer filled with water was recorded and particle density calculated by following formulae (Danienison and Suthrel, 1986)

Particle density $\frac{= \quad (\mathrm{Wps} - \mathrm{Wp})}{(\mathrm{Wpw} + (\mathrm{Wps} - \mathrm{Wp})}$

Where Wp =Mass of empty dry pycnometer

Wps = Weight of pycnometer+ soil

Wpw =Weight of pycnometer+ water

3.9.3.1.3 Bulk density: Soil samples collected before and after the harvest of crop from 0-5 cm and 5-10 cm depth with auger. The soil samples were mixed and oven dried at 105 degree

C for 48 hours. Bulk density of soil was calculated from the formulae given by Blake and Hartage, 1986.

Bulk density (gm^{-3}) = $\frac{X-Y}{Y}$

Where X= Weight of core with oven dry soil, Y= Weight of core, V= volume of core

3.9.3.2 Chemical Properties:

3.9.3.2.1 Soil pH: soil pH was measured by the procedure given by Jackson, 1973. Soil pH was determined with pH meter. pH meter was calibrated by two buffer solutions with neutral pH 7 and pH9. The buffer solution was taken in two beakers. The electrodes inserted alternately in beakers and the pH adjusted. 10g of soil taken in a 100ml beaker and 25ml distilled water added to it. The soil was equilibrated with water for 30 minutes with occasional stirring. The electrode was inserted in suspension and the pH with pH meter was recorded.

3.9.3.2.2 Electrical conductivity: The electrical conductivity is the estimation of the dissolved salts in solution. The supernatant extract getting from the soil water suspension used for the estimation of pH was kept undisturbed overnight and utilized for the estimation of EC by EC meter (Jackson, 1973). The units of EC are dSm^{-1}.

3.9.3.3.3 Organic carbon: 2g of soil weighed and put in 500ml volumetric flask. 10ml of 1N potassium dichromate ($K_2Cr_2O_7$) was added and shake well. 20 ml conc. $H_2SO_4$was added and the flask shaken with mechanical shaker for 20 minutes. 20 ml distilled water added to the flask. After this 10 ml of orthophosphoric acid (H_3PO_4) and 7-8 drops of diphenylamine indicator was added. The burette was filled with 0.2N ferrous ammonium sulphate solution for titration. The solution was titrated till the violet colour changed to bright green colour. The volume of ferrous ammonium sulphate was note down. Organic carbon in soil calculated was by following formulae:

Organic carbon (%)= $\frac{(\text{Blank reading} - \text{final reading}) \times 0.003 \times 100}{2}$

3.9.3.3.4 Available soil N analysis: Available soil N was estimated by alkaline potassium permanganate method where organic matter in soil has been oxidized by hot alkaline potassium permanganate solution. During oxidation the evolved ammonia was distilled and trapped by boric acid and mix indicator. The NH_3 which was trapped measured by procedure

(Subbiah and Asija, 1956). 20g of soil shifted in a distillation flask. 20 ml water and 100 ml of 0.32% $KMnO_4$ solution was added. 20 ml of boric acid in 250ml volumetric flask was taken and 4-5 drops of mixed indicator added in that. The flask was put below the receiver tube. Tip of receiver tube was dipped into boric acid solution. 100 ml of 0.32% $KMnO_4$ and 100 ml of 2.5% NaOH was added to distillation flask which contained soil and connected the flask to distillation apparatus. The distillation flaskwas heated. Free ammonia which was released absorbed in boric acid solution. When distillation complete then the sample took out. The burette was filled with 0.02N H_2SO_4. Boric acid solution was titrated with conc.H_2SO_4 until pink colour appears. Initial and final reading was note down.

Formulae for calculation of available N:$\frac{\mathrm{Rx0.2x14x2.24x106\ (Kg\ ha}^{-1}}{\mathrm{W*100}}$

Where R is sample reading- blank reading, 0.002=Normality of H_2SO_4, 14= Atomic weight of N,2.24*10^6= weight of one hectare soil, W= weight of soil

3.9.3.3.5 Available Phosphorous in soil: Available soil phosphorous was analyzed with sodium bicarbonate ($NaHCO_3$) at 8.5 pH (Olsen's reagent) and the amount of phosphorous in the extract was analyzed by chlorostannous reduced phosphomolybdate blue colour method using spectrophotometer at 660nm (Olsen et al., 1954).The units are Kg ha^{-1}. 5 g of soil was put into 250ml volumetric flask and 1 spoon of Darco G-60(phosphorous free activated charcoal) added to it. 100 ml of 0.5M $NaHCO_3$ solution added into flask. The flask was shaken for 25-30 minutes on mechanical shaker. The suspension was filtered through the whatmann's no.1 filter paper. 5ml of filtrate was taken into 25 ml volumetric flask. 5ml of ammonium molybdate and somewhat the distilled water was added into the volumetric flask and shaken for some time. 1 ml of working $SnCl_2$added into 25 ml volumetric flask and volume made up to 25 ml with distilled water and shake well. The transmittance of blue colour solution was measured within 5-20 minutes of addition of $SnCl_2$ at 660nm in a spectrophotometer. Similarly blank was run without soil by following same procedure.

3.9.3.3.6. Available Potassium in soil: Available soil potassium was analyzed by using flame photometer (Jackson, 1973). IN ammonium acetate was used to analyze the available potassium in soil. 5g of soil was taken in 250ml volumetric flask and after that 25 ml ammonium acetate solution was added. The flask was shaken with hand for 20 minutes and on mechanical shaker for 5 minutes. The suspension was filtered through Whatmann's filter paper no.1. Reading was taken on flame photometer. .

3.9.3.3.7. Particulate organic carbon Particulate organic carbon was analyzed using method of Cambardella and Elliot 1992.10g of 2mm sieved air dried soil sample was shaken with 05% sodium hexametaphosphate in a shaker for 15 hours. Then soil suspension was passed through 0.053mm sieve by spraying water from the top of sieve. The solid portion which was remained on sieve termed as particulate organic matter. The solid portion was shifted to pre weighed plastic bottles by washing with spray of water. This solid portion comprised with organic matter and sand particles. The plastic bottles were placed inside the forced air oven at 50 degree C temperature for 3 days for drying and after drying weights of bottles recorded. The solid material in boat was grounded with pestle mortar to make it to a fine powder. The total organic content in particulate organic matter was analyzed by wet oxidation method (Walkley and black, 1934).

3.9.3.3.8 Permanganate oxidizable carbon (labile carbon):): Permanganate oxidizable carbon also known as active or labile carbon determined by the procedure of Blair *et al.* (1995) as modified by Weil et al. *(*2003). The amount of carbon in soil which is oxidizable by 333 mM $KMnO_4$ considered as labile carbon. 2g of soil was taken in a centrifuge tube and oxidized with 25ml of 333 $KMnO_4$ by shaking on mechanical shaker for 1 hour. The contents were centrifuged for 5 minutes at 4000 rpm and 1 ml of supernatant solution was diluted to 250 ml with double distilled water. The concentration of $KMnO_4$ was measured at 565nm wavelength by spectrophotometer. The change in concentration of $KMnO_4$ was used to estimate the amount of carbon oxidized.

$$\text{POXC (mg Kg}^{-1}\text{)} = \frac{(B-S) X\ 50\ X \text{ volume of } KMnO4\ X\ 1000\ X\ 9}{2\ X\ 1000\ X\text{weight of soil}}$$

Where B= Conc. (m M) of $KMnO_4$ in blank, S= Conc. (m M) of $KMnO_4$ in sample, 50/2= dilution factor, 9= mg C oxidized by 1mM $KMnO_4$.

3.9.3.3.9 Microbial biomass carbon: Soil microbial biomass carbon was determined according to Vance et al. *(*1987) involving extraction of organic carbon from fumigated and unfumigated soils with K_2SO_4. The fresh moist soil samples about 10g soils on oven dry basis were fumigated with ethanol free chloroform for 24 hours in a vacuum desiccator. After this soil samples evacuated and fumigated. The soil samples were extracted with 0.5 M K_2SO_4 (1:4 soil: solution ratio) by shaking on mechanical shaker for 30 minutes. The suspension of soil was filtered through whatmann's filter paper no. 42. In same manner, non-fumigated soil samples were extracted with 0.5 M K_2SO_4. The readily oxidizable carbon in extracts of fumigated and non-fumigated soil samples were measured by dichromate digestion method and expressed as oven dry weight basis (105^0 C for 24 hours). For expressing the microbial biomass carbon on oven dry weight basis of soil, the moisture content was analyzed by gravimetric method. The results were presented in terms of MBCµg^{-1} soil. Biomass carbon in soil can be calculated by formulae;

$$\text{MBC}= \frac{Fc}{k}$$

Where, Fc= difference between extractable carbon from fumigated and non -fumigated soil

K c = Efficiency factor, k=0.45

3.9.3.3.10 Microbial Quotient: Microbial quotient was determined as the ratio of microbial biomass carbon to the total soil organic carbon (Anderson and Domsch (1989). It is expressed as q_{mic} (µg biomass C µg total organic C^{-1} x10^2).

3.9.3.4 Soil biochemical Analysis:

3.9.3.4.1 Dehydrogenase activity: Enzyme dehydrogenase activity was measured by the procedure given by (Tatabati, 1982).Dehydrogenase enzyme activity was determined by using modified 2, 3, 5 triphenyl tetrazolium chloride reduction technique (Casida, 1977). 5g of soil was taken in test tube. 1.5ml of distilled water added to test tube. The test tubes plugged with cotton and incubate for 24 hours at 30 ^{0} C. After 24 hours resulted slurry was shifted to whatmann's no.1 filter paper. The TPF triphenyl formazon was extracted with concentrated methanol in a 50ml. volumetric flask. The pink colour was obtained, the extinction of pink colour was read out with the help of spectrophotometer at 485nm.The methanol was used as control (without soil). Dehydrogenase activity was expressed as µg TPF g^{-1} dry soil 24h^{-1}..

Formulae:

$$\text{Dehydrogenase activity (µg TPF g}^{-1}\text{ dry soil 24h}^{-1}) = \frac{Cx50}{w}$$

Where C= corrected reading of µg TPF ml^{-1} from standard curve, 50= extractant volume (ml), W= dry weight of soil

3.9.3.4.2 Urease activity: The urease activity was assayed by urea reduction technique of Mc Garity and Myers (1967). 10g of fresh soil was put in a 100ml volumetric flask. 1ml toluene, 10 ml of buffer solution having pH 7 and 5 ml of 10% freshly prepared urea solution added in volumetric flask contained soil. After thoroughly mixing, the flask placed in incubator for 3 hours at 37 degree Celsius in dark. For the control, instead of 10% urea solution 5ml of distilled water added. After 3 hours the samples take out from incubator and volume raised up to 100ml with distilled water and mix thoroughly and suspension shifted to whatmann's filter paper no.5. Due to urease activity ammonia released which was recorded by indolephenol blue method. In 25ml volumetric flask 0.5 ml of filtrate was taken. Then 2 ml of phenolate solution {mixture of 20 ml of stock A 962.5g phenol crystals dissolved in a minimum volume of methanol and make volume up to 100ml with ethyl alcohol after adding 18.5 ml acetone) and 20 ml of stock B(27g of NaOH dissolved in 100ml distilled water and kept in freezer} was added. After that 1.5ml of sodium hypochlorite solution was added. The volume of flask was made 25ml with distilled water and light blue colour obtained and reading was read out 630nm with spectrophotometer. The urease activity was measures by following formulae::

Urease activity (mg NH_4^+-N g^{-1} dry soil $3h^{-1}$) $= \frac{Cx25x100}{w}$

Where C= corrected reading of mg NH_4^+-N ml^{-1} from standard curve, 25= extractant volume (ml), 100= Total solution volume, W= dry weight of soil

3.9.3.4.3 Acid phosphatase and alkaline phosphatase activity: The total activity of acid and alkaline phosphatase in soil was analyzed by the procedure given by Tatabai and Bremner, (1969) .p-nitro phenyl phosphate tetra hydrate (pH6.5) solution was used for the acid phosphatase and same p-nitro phenyl phosphate tetra hydrate (pH11) was used for the assay of alkaline phosphatase.1g of soil sample was taken in 100 ml conical flask. 0.25ml toluene, 1ml of p-nitro phenyl phosphate and 4ml of modified universal buffer (pH6.5) for the acid phosphatase and pH11 for alkaline phosphatase was added. The flasks were shaking properly for few seconds and stopper the flask and place it in incubator at 37 degree C for 1 hour. After 1 hour the stopper removed and 1ml of 0.5ml $CaCl_2$ and 4ml of 0.5M NaOH added. After that flask was shaken for few seconds and the suspension was shifted to whatmann's No.12 filter paper. Yellow colour filtrate colour intensity was recorded through spectrophotometer at 430nm wavelength. For control, 1ml p-nitro phenyl phosphate was added after $CaCl_2$ and NaOH were added into mixture without soil just before filtration..

Acid/Alkaline phosphatase (µg p-NPP g^{-1}dry soil h^{-1}) $= \frac{Cx10}{w}$

Where C= corrected reading of µg p-NPP ml^{-1} from standard curve, 10= Solution volume (ml), W= dry weight of soil (g)

3.9.3.4.4 Nitrate reductase: Soil nitrate reductase activity was measured by use of sulfanilamide (diazotizing agent) and N-1-naptyhl-ethylenediamine (coupling reagent) which converts NO_2 into Azo compound of reddish purple colour which was measured colorimetrically (Keeney *et al*, 1982). 5g of soil was taken in 250ml volumetric flask. 2ml of absolute ethanol added in 2, 4-Dinitrophenol solution drop wise to completely cover the soil. The alcohol was evaporated using a stream of air for 2 hours. After that soil was treated with 10ml of 5mM $KNO_{3.}$Bottles was shaken for few seconds to mi contents and held in dark for 24 hours. After 24 hours take out samples and removed the stopper and add 40ml of 2.5 M KCl added. Again plugged the stopper and shake horizontally in a reciprocating shaker for 330 minutes. The suspension was filtered through whatmann's filter paper no. 42. Transfer 1ml of filtrate into 50ml volumetric flask. After this add 1ml of sulphanilamide acid with pH 1.73. After10 minutes add 1ml of N-[1-napthyl) ethylene diamine hydrochloride pH 1.7. 1ml of buffer solution of acetic acid pH2.5 was added. Volume raised to 25ml with distilled water. The samples remained undisturbed for 15 minutes and take reading on spectrophotometer at 540nm wavelength. The resulted solution was of reddish brown in colour.

3.9.4 Nutrient concentration and uptake by plant: The plant samples (grain and straw) were collected, cleaned and dried under shade and in oven at 65 degree c till constant weight achieved and grinded. The processed plant samples were used for plant analysis. The processed plant samples should be checked by micro-Kjeldahl's method to find nitrogen content. Wet digestion (di-acid) method was used for the preparation of aliquot to analyze P and K uptake content in plant samples. Vando-molybdate yellow colour method was used for the analysis of phosphorous by using spectrophotometer and flame photometer for the potassium as discussed by Jackson(1973).

3.9.4.1 Estimation of total nitrogen content in plant samples0.5-1 g (grain/straw) plant material weighed and transfer into 250ml digestion tube. 20ml sulphur-salicylic acid mixture added into digestion tube and the tube was rotated to wash any sample sticked to neck of tube and wait for 2 hours and not disturb the sample. 2.5g sodium thio sulphate was added through a long stemmed funnel to the tube containing content and shakes for some time and allowed to stand for one night. 4g catalyst mixture and 3-4 granules of pumice mixed properly and kept tubes on the block digester pre heated to 400^0C. A small glass funnel in mouth of tubes was kept to ensure proper digestion of mixture and inhibit loss of H_2SO_4 and continue with digestion until mixture clears. The tubes were removed from block digester and allowed them to cool for 20 minutes. The tube contents were shaken thoroughly; kept the tubes back on block digester and digest for 2 hours. No particulate material remained in tube after digestion. After the digestion was finished the digest was allowed to cool at room temperature and distilled water added to made volume 250ml.Each batch of samples for digestion contained at least one reagent blank and one standard plant samples. The digest titrated by 0.1 N H_2SO_4 up to the appearance of purple colour.

3.9.4.2 Estimation of total phosphorous and potassium content in plant samples: : 0.5-1 g of dry plant material weighed and shifted to digestion tube. 10 ml Di-acid (HNO_3+$HClO_4$) mixture was added in digestion tube. The sample was digested at 150^0C in KEL plus digestion block till the content becomes colorless. The material which was digested shifted to 100 ml volumetric flask and made the volume up to the mark by addition by distilled water. The digested material used for the estimation of P and K uptake. Vando-molybdate phosphoric acid yellow colour method (Jackson, 1973) was used for the estimation of phosphorous. 10 ml of digested content taken in a 50 ml volumetric flask and 10 ml of Vando-molybdate yellow colour reagent was added. The volume was made up to 50 ml with distilled water. The colour intensity was read out with spectrophotometer. The potassium content was estimated by flame photometer [Chapman and Pratt (1961)].Each samples contained one blank (no plant/grain) and one standard plant sample.

3.9.4.3 Nutrient uptake efficiency: The nutrient (N, P, K) uptake by grain and straw was calculated as per the formulae:

Nutrient uptake Efficiency (%)=

$$\frac{\text{Nutrient uptake from treated plot- Nutrient uptake from control plot}}{\text{Total fertilizer applied}} \times 100$$

Nt= Amount of nutrient taken from test treatment plot kgha^{-1}, No= Amount of nutrient taken from control plot kgha^{-1}, N= Amount of nutrient added kgha^{-1}.

3.10 **Experiment II- Pot experiment:** This study was conducted to ‘Probe the impact of Biochar combined fertilizers on soil nutrient status in relation to growth and yield of

Rice-Wheat cropping system' in sequence in pot for two consecutive years 2018-2019 and 2019-2020. Rice crop was cultivated in Kharif season and wheat crop was cultivated in Rabi season by following the recommended package and practices of PAU, Ludhiana. The soil was collected from agricultural farm of LPU, Phagwara. The characteristics of soil were determined before planting which were same as filed soil characteristics. The treatments were 9 in number and replicated thrice in completely randomized block design. Total 27 plastic pots used, having dimension of 16 cm upper and 14 cm lower diameter and 17 cm height. Total volume of pot was 2754cm^3. The pots were filled with 2 kg of grinded and sieved soil. Water was added to take the soil to its field capacity. Biochar, FYM, vermicompost, poultry manure were added to soil at the starting of experiment with rice crop during July, 2019. Full dose of phosphorus and potassium were added as basal dose to both the crops but nitrogen was supplied through urea in 3 equal splits as basal, at tillering and at panicle initiation stages in rice and at the time of sowing, at CRI and at heading stage in wheat crop. The test varieties for rice crop and wheat were Pusa basmati 1121 and PBW550.Rice nursery in both the years was raised during second week of June and 25-30 days old seedlings were transplanted during second week of July The number of plants were maintained per pot were 4.Irrigation was given as and when required to maintain optimum moisture in soil. Rice crop was harvested during second week of November. The wheat crop was sown in third week of November during both years by digging the soil of pot with khurpa. After establishment of crop thinning was done and 5 plants per pot maintained. Wheat crop was harvested end of April during both years. The main aim of the pot study was to estimate the leaching amount to calculate the uptake and nutrient use efficiency. So, for this aim, the bottom holes of each pot covered by gauze to reduce loss of particulate matter but allow leaching of soil solution. The leachates were collected by covering the bottom of pots with sealable plastic polythene bags. The leachate collected in polythene bags were shifted to plastic tubes and stored at 4 ^{0} C. Leachate samples were collected in rice 5 DAT ,9 DAT and after top dressing at panicle initiation stage. In wheat crop leachate samples were collected 5DAS, 25 DAS and after top dressing at heading stage. The NH4$^+$- N and NO_3^- -N losses in form of leaching calculated by multiplying N concentration by volume of leachate (Agegnehu *et al.*2014). The Nitrogen content in NH4$^+$- N and NO_3^- -N was estimated by the procedure followed by Bremner and Keeney, 1965. All the parameters related to soil, plant and nutrient uptake were recorded at same time when recorded in field by the same procedure discussed under section 3.9.

3.11 **Economic analysis:** Economics plays a vital role in the recommendation and adoption of any practice by the farmers. Therefore it is necessary to work out the economics of different treatments for observing the maximum net profit per hectare.

3.11.1 Cost of cultivation: For the various treatments ,the total input cost calculated on the basis of recent market prices of fertilizers, manures, Biochar, seeds, irrigation, labour wages and harvesting and any other charges related to crop production.

3.11.2 Gross returns: It means the total money earned by selling the product in the market. The gross returns calculated on the basis of current price of the product prevailed in market at the time of harvesting.

3.11.3 Net returns: The net returns were computed by subtracting cost of cultivation from gross returns.

3.11.4 Benefit: Cost ratio: It was calculated treatment wise. The net returns per hectare of every treatment was divided by cost of cultivation for respective treatment.

3.12 Statistical analysis: The recorded data was tabulated treatment wise under three replications. The differences between the mean values were estimated by one way ANOVA (analysis of variance) with the SPSS 22 version software. To find out the most efficient treatment Duncan's multiple range test (DMRT) a mean separation technique was applied with probability $p< 0.05$. Fisher's LSD test as post hoc test was used to test the significance of the variation components. The significant difference among the means were calculated on the basis of LSD (least significant difference) at 5% level of significance.

DEMONSTARTION

Plate1: prepration of field for rice transplanting

Plate 2: Seedlings of rice

Plate3: Transplanting of rice

Plate 4: Basal Fertilizer application after transplanting

Plate5: Rice crop at tillering stage

Plate6: Rice crop at full vegetative stage

Plate8: Rice crop at dough stage

Plate8: Harvesting of rice crop

Plate 9: Pre sowing irrigation after harvesting of rice crop

Plate 10: land preparation for sowing of wheat crop

Plate 11: Demarcation of plots by bunds

Plate 12: Line sowing of wheat by manual seed drill

Plate 13: Germination of wheat

Plate 14: Emergence of wheat

Plate 15: irrigation to wheat field

Plate 16: Application of urea at CRI stage

Plate 17: Tillering stage of wheat

Plate 18: Top dressing of urea in wheat

Plate 19 and 20 : Comparison of control with other treatments

Plate21: Wheat crop at booting stage

Plate 22: Wheat crop at heading

TOPIC-

Probing the impact of biochar combined fertilizers on soil nutrient status in relation to growth and yield of rice - wheat cropping system.

CROP NAME – WHEAT

VARIETY – PBW550

PROGRAM NAME – Ph.D. Agronomy

STUDENT NAME- Anita Jaswal (Reg. no.41700110)

MENTOR NAME – Dr. Chandra Mohan Mehta

Plate 23: Display board

Plate 24

Plate 25

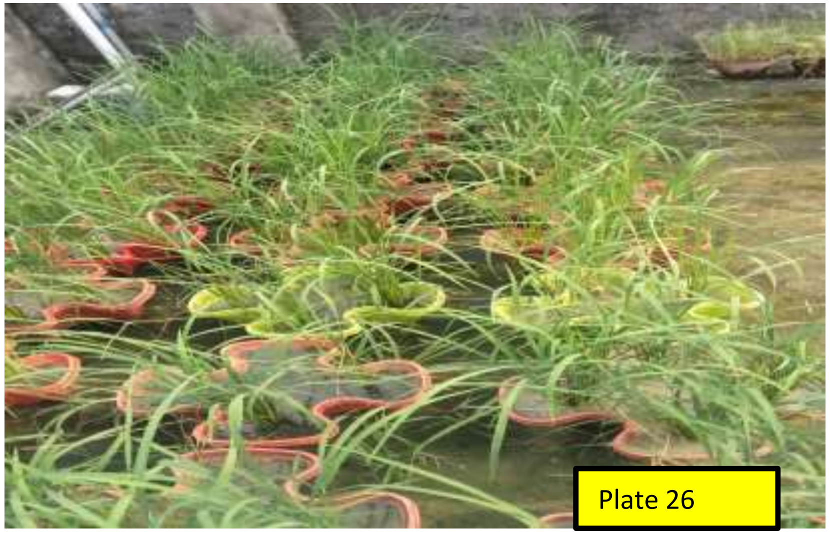


Plate 26

Plate 27

Pot experiment of rice crop

Plate 28

Plate 29

Plate 30

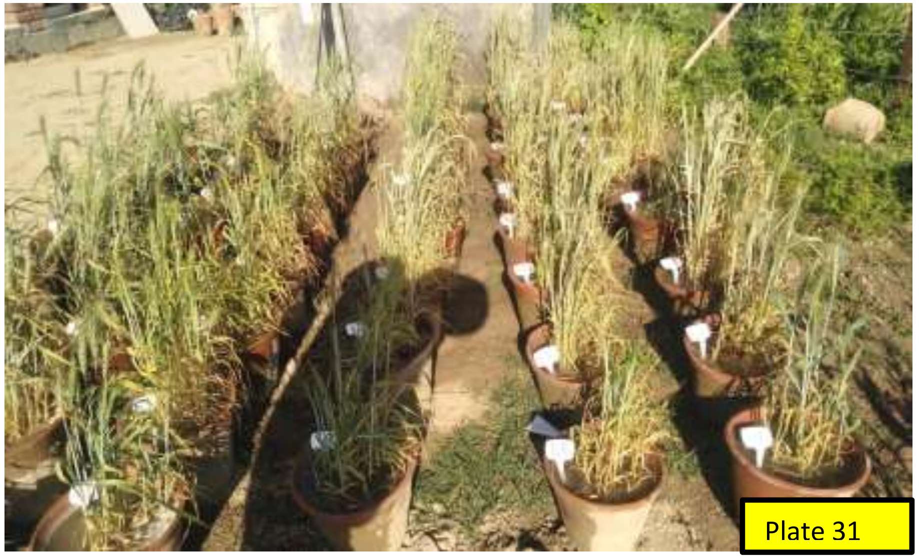


Plate 31

Pot experiment of wheat crop

Plate 32: Testing organic carbon in soil

Plate 33: Volumetric analysis

Plate 34: Volumetric analysis of available N

Plate 35: labile carbon testing

Plate 36: Resultant pink colour of dehydrogenase enzyme

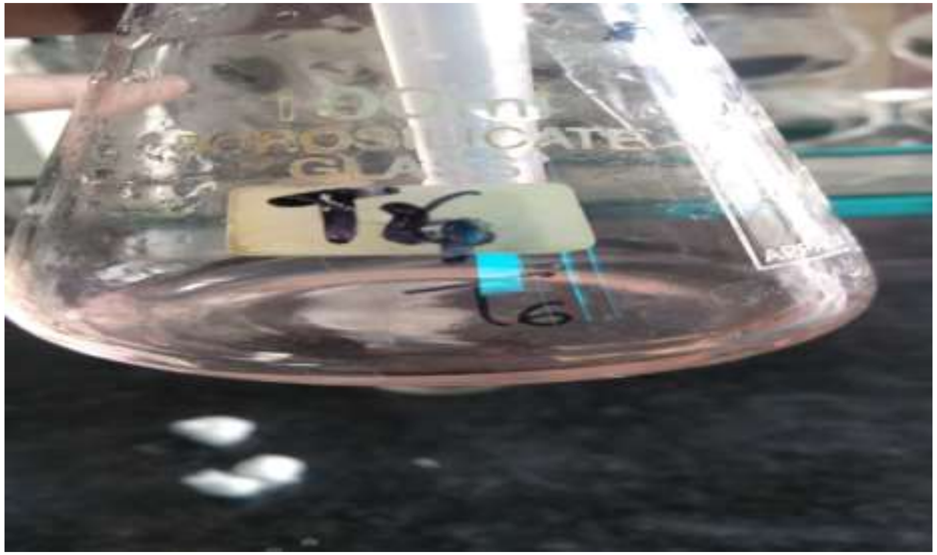


Plate 37: Yellow colour of sample of alkaline phosphatase

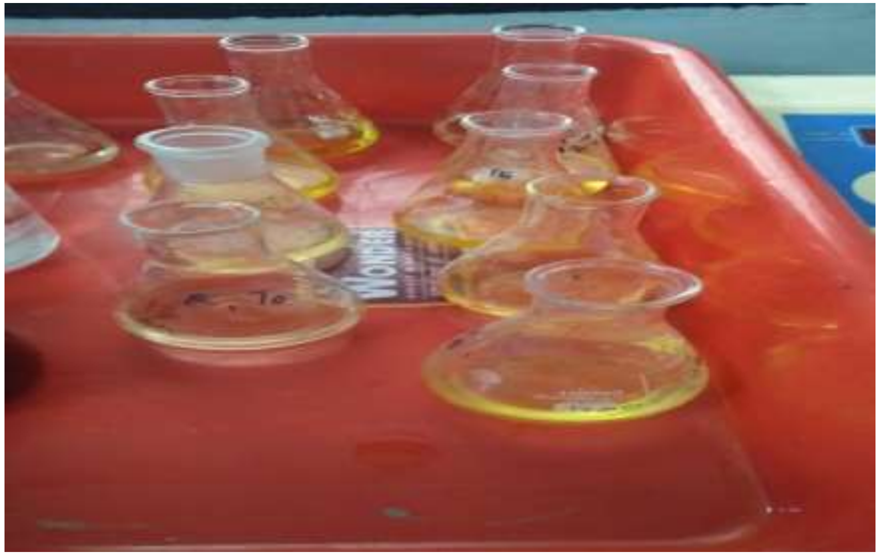


Plate 38: Nitrate reductase enzyme resultant product

Plate 39: Spectrophotometer reading

CHAPTER 4

RESULT AND DISCUSSION

The results of the investigation” Probing the impact of Biochar combined fertilizers on soil nutrient status in relation to growth and yield of rice- wheat cropping system” have been discussed in this chapter. The observations recorded on rice and wheat crop and soil properties in field and pot experiment during both years were statistically analysed. An attempt has been made to present and describe the findings of the study based on the supported mean data with standard error and critical difference at 5% level of probability with the help of Fig.s and tables. The significant experimental results got during the time of study with possible explanation to find out the correlation among various treatments has been discussed under this chapter. To sort out the information based on practical value and ease of understanding some illustrations has also been incorporated. The results of the study presented under following headings:

4.1 Impact of Biochar combined fertilizers on soil physico-chemical properties

4.2 Impact of Biochar combined fertilizers on soil carbon fractions

4.3 Impact of Biochar combined fertilizers on soil biological indicators

4.4Effect of Biochar application on growth and yield of crops

4.5 Effect of Biochar based amendments on nutrient uptake and nutrient use efficiency

4.6 Pot experiment: Effect of Biochar amendments on crop growth, yield and leaching in pot experiment

4.7 Economics

4.8 Discussion

4.1: Impact of Biochar combined fertilizers on soil physico-chemical properties: To observe the changes in soil properties after the addition of Biochar combined fertilizers to agricultural soils, the soil samples before and after the initiation of experiment was collected from every plot. The recorded observations were analysed and variation in soil properties were observed. The recorded observations discussed under following headings.

4.1.1 Bulk density and porosity (%): The mass of soil per unit volume including pore space is known as bulk density. Compactness and porosity of soil is indicated by bulk density. The combined application of Biochar with manures and fertilizers decreased the bulk density of soil. The results showed that the highest bulk density was recorded in control which remains same during first year and increased during second year. The bulk density was decreased in Biochar amended plots as compared to control and sole NPK fertilizers in 2018 and 2019 after harvesting of rice crop (table 4.1.1). Bulk density (gcm^{-3}) ranged from 1.55 to 1.88 gcm^{-3} after harvesting of rice crop during first year. During second year of Biochar application changes in soil bulk density was observed. The unamended (control) plot bulk density same as initial value during first year but slightly increased during second year of study. The bulk density was decreased with the application of rice straw Biochar. The minimum bulk density (1.55 g cm^{-3}) was recorded in T8 followed by T7 (1.60 g cm^{-3}) during 2018 and 1.45 gcm^{-3} and 150 gcm^{-3} during 2019. All the treatments were significantly different from each other. The maximum bulk density (1.88 and 1.85 gcm^{-3}) recorded in control during both years. The porosity (%) was also significantly different ($p>0.05$) among treatments. The change in porosity (%) was recorded after the application of Biochar to soil during both years of rice crop. The minimum porosity (27.4, 29.4%) recorded in control followed by T2(100% RDF) having 30.5% ,31.63% porosity during2018 and 2019.The maximum porosity (39.37,40.2%) respectively followed by T7 with 37.83 and 34.4% porosity.

In case of wheat crop all the treatments were significantly different from control. The reduction in bulk density was recorded in Biochar amended plots after harvesting of wheat crop. Bulk density ranged from 1.52-2.10 gcm^{-3} during 2018-19 and 1.4-1.9 gcm^{-3}dring 2019-2020.The highest bulk density (2.10 and 1.90 gcm^{-3}) recorded in T(control) during both years and lowest bulk density (1.55,1.4 gcm^{-3}) recorded in T4- 50% RDF+50% FYM+ Biochar followed by T6- 50% RDF+50% VC+ Biochar having 1.59,1.45 gcm^{-3} .The porosity values were significantly different from each other at $p>0.05$. The porosity % was increased after addition of Biochar as compared to control and 100% RDF. The porosity values ranged from26.87%- 36.57% and 29.1-38% during 2018-19 and 2019-2020.The maximum porosity (38.03% and 39.76%)was observed under T4- 50%RDF+50% FYM+ Biochar followed by T6- 50% RDF+50% VC+ Biochar(37.10 and 38.46%) . The lowest porosity (26.87% and

29.1%) recorded in T0 during both years. The data of bulk density and porosity (%) of rice and wheat crop after harvesting presented in Fig. 4.1.1(a) and 4.1.1(b)

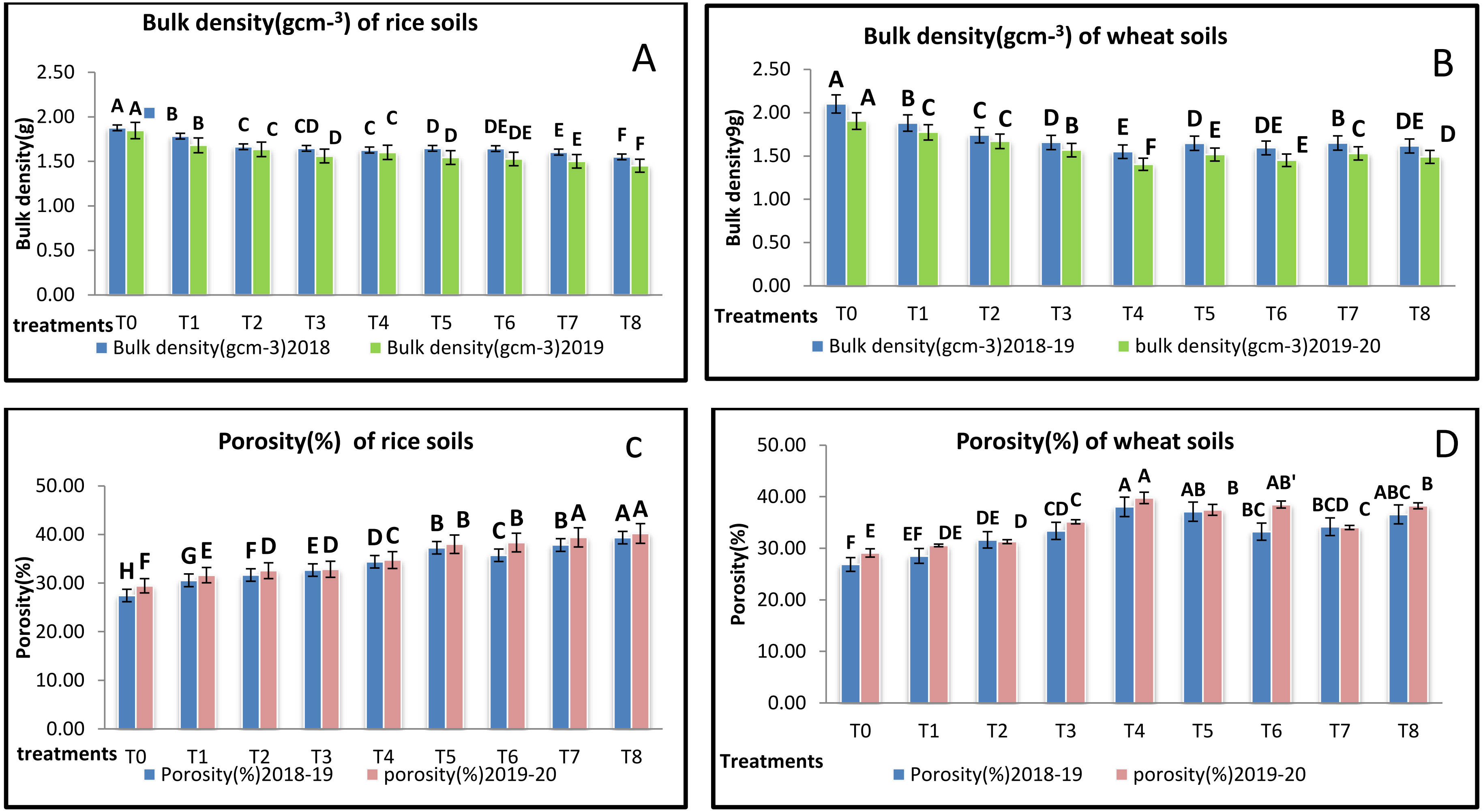


FIG.4.1.1 (A,B) representing bulk density(mean±S.E) of soil and Fig.4.1.1(C,D) representing porosity(%) of soil(mean±S.E) of soil after after biochar amendement in rice- wheat cropping system during 2018-19&2019-2020. Values with similar alphabet are not significantly different according to DMRT at (p<0.05).

Table 4.1.1(a) Effect of biochar based amendements on soil bulk density(gcm^{-3}) and porosity (%) after harvesting of rice crop growing season during 2018&2019

Treatments	**2018**		**2019**	
	Bulk density**(gcm^{-3})**	Porosity (%)	Bulk density**(gcm^{-3})**	Porosity
T0- Control (no fertilizer)	1.88 ±0.026A	27.43 ±0.42H	1.85±0.035A	29.43 ±0.33F
T1-100%RDF	1.78 ±0.028B	30.57 ±0.49G	1.68±0.028B	31.63±0.37E
T2- 50%RDF + Biochar	1.66 ±0.024C	31.67 ±0.34F	1.63±0.018C	32.57±0.33D
T3-50%RDF+25%FYM+Biochar	1.65 ±0.018CD	32.67 ±0.34E	1.56 ±0.014D	32.83±0.21D
T4-50%RDF+50%FYM+Biochar	1.63 ±0.082C	34.37±0.26D	1.60 ±0.025C	34.73 ±0.39C
T5-50%RDF+ 25%Vermi-compost + Biochar	1.65 ±0.015D	37.27 ±0.25B	1.54 ±0.018D	38.00±0.16B
T6-50%RDF+ 50%Vermi compost+ Biochar	1.64 ±0.019DE	35.73 ±0.52C	1.53 ±0.025DE	38.33 ±0.62B
T7-50%RDF+ 25%poultry manure+ Biochar	1.60 ±0.026E	37.83 ±0.17B	1.50 ±0.018E	39.40±0.28A
T8-50%RDF+50% poultry manure+ Biochar	1.55 ±0.028F	39.37 ±0.26A	1.45 ±0.025F	40.20 ±0.54A

Table 4.1.1(b) Effect of biochar based amendements on soil bulk density(gcm^{-3}) and porosity (%) after harvesting of wheat crop growing season during 2018-2019 & 2019-2020

Treatments	**2018**		**2019**	
	Bulk density**(gcm^{-3})**	Porosity (%)	Bulk density**(gcm^{-3})**	Porosity%
T0- Control (no fertilizer)	2.10±0.08A	26.87±0.42F	1.90±0.018A	29.100±0.787F
T1-100%RDF	1.88±0.02B	28.50±0.86EF	1.77±0.025C	30.533±0.249DE
T2- 50%RDF + Biochar	1.74±0.02C	31.63±0.12DE	1.67±0.018C	31.300±0.374D
T3-50%RDF+25%FYM+Biochar	1.66±0.02D	33.37±0.79CD	1.57±0.014B	35.133±0.411C
T4-50%RDF+50%FYM+Biochar	1.55±0.03E	38.03±0.45A	1.40±0.016F	39.767±1.109A
T5-50%RDF+ 25%Vermi-compost + Biochar	1.65±0.01D	37.10±0.22AB	1.52±0.018E	37.433±1.053B
T6-50%RDF+ 50%Vermi compost+ Biochar	1.59±0.01DE	33.20±0.30BC	1.45±0.022E	38.467±0.685AB
T7-50%RDF+ 25%poultry manure+ Biochar	1.65±0.02B	34.17±0.31BCD	1.53±0.024C	34.033±0.419C
T8-50%RDF+50% poultry manure+ Biochar	1.62±0.01DE	36.57±0.49ABC	1.49±0.013D	38.233 ±0.591B

4.1.2: pH: Soil pH is considered as an important soil health indicator. Variations in pH of soil after addition of Biochar were statistically different among treatments during both years. During rice crop 2018-19 pH ranged from6.18 to 7.8 where highest (7.8) pH recorded in T8 and lowest (6.18) recorded in control (table 4.1.2a). In following wheat season of 2018-19, T4 showed highest pH (7.84) and T0 recorded lowest pH (6.19). T4 was followed by T6 having pH 7.78. All the treatments showed superiority over control in case of soil pH and statistically different from each other. In the next year (2019) rice crop the maximum pH value(7.73) was observed in T8-50%RDF+50% PM+ Biochar which was at par with T7 having pH value (7.70) but significantly more than other treatments and lowest (6.25) in control after the harvesting of rice crop. In following wheat season T4 recorded highest pH value of 7.88 which was at par with T6 having pH 7.79 and significantly better as compared to other treatments.T0 (control) recorded minimum pH (6.22) after harvest of what crop of 2019-20(Table 4.1.2b). The data of pH of rice and wheat crop was presented in Fig. 4.1.2(a) and 4.1.2(b).

4.1.3 Soil EC: EC value of soil significantly varied among treatments in rice crop of 2018. EC value ranged from 0.215 to 0.296 dS m^{-1}. The maximum value (0.29dSm^{-1}) observed in T4 which was significantly more than T7 (0.262dSm^{-1}). The lowest value (0.215 dSm-1) was recorded in T0-control (table 4.1.13(a).. In following wheat season EC significantly varied among treatments .All treatments showed variation in soil EC value as compared to control. Maximum EC value (2.78 dSm^{-1}) was recorded in T8 which was at par with T4 (2.77 dSm^{-1}) and T6 (2.75 dSm^{-1}.T8,T6 and T4 treatments were non-significant among themselves but significantly different from all other treatments. The minimum EC during 2019 -2020 after harvest of rice crop EC value ranged from 0.220 to 0.292 dS$m^{-1.}$Maximum EC value recorded with T4(0.292 dSm^{-1}) which was statistically significant from all other treatments. The minimum EC was recorded in T0 (0.220dSm^{-1}) which was at par with T1 and T2 having EC value 0.222 and 0.224 dSm^{-1}. T0, T1, T2 treatments are non-significant among themselves. In next wheat season significant variations among treatments recorded where T4 recorded maximum EC value (0.282dS$m^{-1)}$ which was at par with T8 and T6 having (0.280 and 0.279 dSm^{-1}). Lowest EC recorded in T0 (0.227) (Table 4.1.3(b).

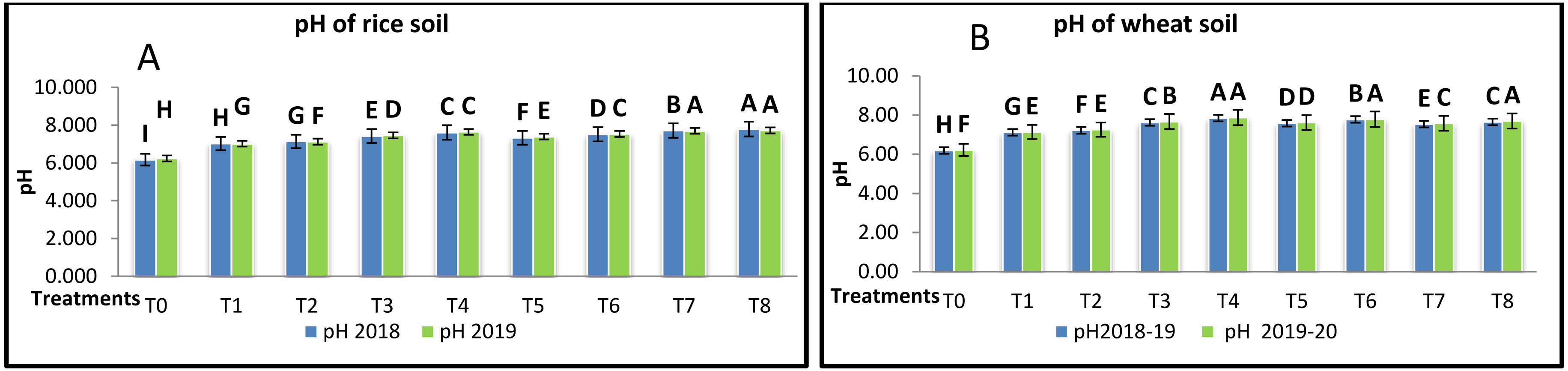
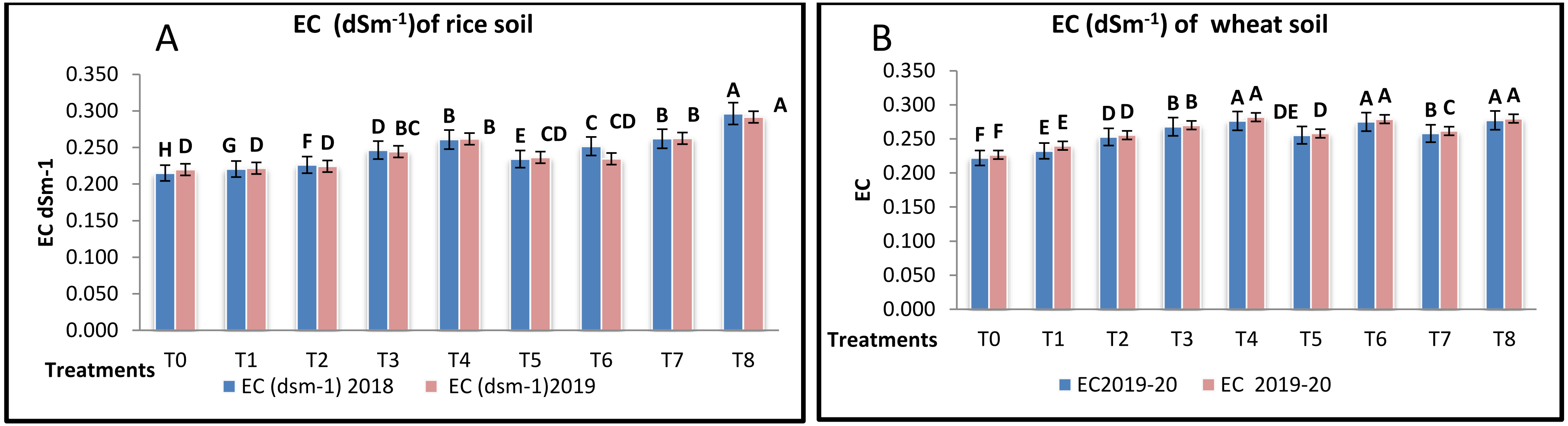


FIG 4.1.2(A,B) representing effect of biochar combined fertilizers on pH (mean±S.E)of soil after harvesting of rice –wheat crop during 2018-2019 &2019-2020.



.Fig 4.1.3(A,B) representing the impact of biochar based amendments on EC(dSm^{-1}) of soil after harvesting of rice- wheat crop of 2018-19&2019-2020. Different letters above the error bars indicate treatments are significantly different according to DMRT($p< 0.05$)

Table 4.1.2 (a) Effect of biochar combined fertilizers on pH and EC (mean ± S.E) of soil after harvesting of rice crop during 2018-2019.

Treatments	**2018**		**2019**	
	pH	ECdSm^{-1}	pH	EC dSm^{-1}
T0- Control (no fertilizer)	6.18±0.026I	0.215±0.001H	6.25±0.032H	0.220±0.001D
T1-100%RDF	7.03±0.024H	0.221±0.002G	7.02±0.024G	0.222±0.001D
T2- 50%RDF + Biochar	7.14±0.016G	0.226±0.001F	7.13±0.018F	0.224±0.001D
T3-50%RDF+25%FYM+Biochar	7.43±0.028E	0.246±0.001D	7.46±0.017D	0.244±0.002BC
T4-50%RDF+50%FYM+Biochar	7.62±0.014C	0.261±0.001B	7.65±0.015C	0.262±0.001B
T5-50%RDF+ 25%Vermi-compost + Biochar	7.33±0.032F	0.234±0.002E	7.40±0.014E	0.236±0.001CD
T6-50%RDF+ 50%Vermi compost+ Biochar	7.52±0.023D	0.25±0.002C	7.54±0.024C	0.235±0.025CD
T7-50%RDF+ 25%poultry manure+ Biochar	7.72±0.028B	0.262±0.004B	7.70±0.018A	0.263±0.007B
T8-50%RDF+50% poultry manure+ Biochar	7.80±0.025A	0.296±0.001A	7.73±0.014A	0.292±0.001A

Table 4.1.2 (b) Effect of biochar combined fertilizers on pH and EC (mean ± S.E) of soil after harvesting of wheat crop during 2018-2019&2019-2020.

Treatments	**2018-2019**		**2019 -2020**	
	pH	ECdSm^{-1}	pH	EC dSm^{-1}
T0- Control (no fertilizer)	6.19 ±0.01H	0.222 ±0.002F	6.22 ±0.01F	0.227 ±0.002F
T1-100%RDF	7.12 ±0.03G	0.232 ±0.002E	7.13 ±0.01E	0.234 ±0.002E
T2- 50%RDF + Biochar	7.22 ±0.01F	0.253 ±0.001D	7.26 ±0.02E	0.256 ±0.002D
T3-50%RDF+25%FYM+Biochar	7.62 ±0.01C	0.268 ±0.002B	7.67 ±0.01B	0.270 ±0.002B
T4-50%RDF+50%FYM+Biochar	7.84 ±0.02A	0.276 ±0.001A	7.88 ±0.02A	0.282 ±0.002A
T5-50%RDF+ 25%Vermi-compost + Biochar	7.58 ±0.02D	0.255 ±0.002DEF	7.62 ±0.02D	0.258 ±0.002D
T6-50%RDF+ 50%Vermi compost+ Biochar	7.78 ±0.02B	0.275 ±0.001A	7.79 ±0.01A	0.279 ±0.001A
T7-50%RDF+ 25%poultry manure+ Biochar	7.53 ±0.02E	0.258 ±0.002B	7.58 ±0.02DC	0.262 ±0.001C
T8-50%RDF+50% poultry manure+ Biochar	7.65 ±0.02C	0.277 ±0.002A	7.70 ±0.02A	0.280 ±0.001A

4.1.4 Available N: Soil available nutrient status also varied with Biochar application. Soil available N was maximum (562.6 Kg ha^{-1}) in T8 and lowest in T0 control (276 kgha^{-1}) after harvest of rice crop of 2018-2019(Table 4.1.14(a). All the treatments showed significantly more available N as compared to control. The available N was in the order T8>T7>T6>T4>T5>T3>T2>T1>T0.The Biochar amended plots recorded higher available N as compared to T0 (control) and T1 (100% RDF). In consecutive wheat crop all the treatments were statistically significantly different from all other treatments. The maximum available N (563.8 kgha^{-1}) recorded in T4 which was at par with T6 (562.5kg ha^{-1}) and followed by T8 (560 kg ha-1). The minimum available N was recorded (284.7 kgha-1) in control. In next year (2019-2020) the soil available N was ranged from 281.3 to560.5 kgha^{-1}. Highest available N was recorded by T8 (560.5 kgha^{-1}) followed by T7 (556 kg ha^{-1}) and T0(control) recorded lowest(281.3 kgha$^{-1)}$ value of soil available N during this period. The Biochar amended plots gave more available N as compared to control and 100 % RDF In following wheat crop all treatments were significantly different from each other. The maximum available N recorded in T8 (566.3 kg ha^{-1}) which was at par with T6 (564.6 kgha^{-1}) and followed by T8(563 kg ha^{-1}). All treatments except control recorded highest available N in soil after wheat crop harvesting of 2019-20. The lowest soil N was recorded with control. The available N was in the order T4>T6>T8>T7>T5>T3>T2>T1>T0.The data of rice and wheat available N depicted in Fig. 4.1.4a) and 4.1.4(b).

4.1.5 Available Phosphorous: Significant differences in changes of available P were found among treatments during 2018-2019.. After the harvesting of rice (2018-19) highest available P was found in soils of T8 plot (24.93 kg ha-^{1}) followed by T7 (24.03 kgha^{-1}) and minimum available P (6.39 kgha^{-1}) was recorded in control. In consecutive wheat soil available P was recorded significantly higher in all treatments except control. Highest available P recorded in T$(27.23 kgha^{-1}) followed by T6 (26.67 kg ha^{-1}). All the treatments were significantly different from each other. Lowest available P was recorded in control (7.15 kgha-^{1}).In the next year (2019-2020) highest available P recorded in T8 (25.13 kgha^{-1}) followed by T7-(23.7 kgha^{-1}). The lowest P was recorded in control (6.65 kg ha^{-1}).The order of highest available P was T8>T7>T6>T4>T5>T3>T2>T1>T0 (Table 4.1.5(a). In following wheat crop the same trend was found as previous year. Highest available P recorded in T4(28.52 kg ha^{-1}) followed by T6 (27.6 kgha^{-1}). The trend followed in available P in wheat T4>T6>T8>T3>T5>T3>T7>T2 >T1>T0. The minimum (7.64 kgha^{-1}) available P recorded in control. All the treatments were significantly different from each other as presented in Table 4.1.5(b) Fig 4.1.5(a) and 4.1.5(b).

4.1.6 Available Potassium: Available K in soil was significantly different from each other during both years (Table 4.1.6(a) and 4.1.6(b), Fig. 4.1.6(a) and 4.1.6(b). After harvesting rice in 2018, the highest available K (365 kg ha^{-1}) was found in T8 (50% RDF+50% PM+ Biochar). The second highest available K was found was found in T7 (50% RDF+25% PM+ Biochar).the lowest available K was recorded in T (control)-244.7 kg ha^{-1} followed by T1 (100% RDF) – 309kgha^{-1}.The other treatments were statistically comparable with control. After succeeding wheat crop, highest available K was recorded in T4 (386.23 kg ha^{-1}) followed by T6 (377.9 kg ha^{-1}). The lowest available K (238.3 kgha$^{-1)}$ was recorded in T0 followed by T1 (100% RDF) having 312.9 kg ha^{-1}. All the treatments were significantly comparable to control. In the next year again T8 (360.7 kg ha^{-1}) recorded highest available K. The second highest available K was found in T7 (350.1 kg ha^{-1}) followed by T4(344.3 kg ha^{-1}). The lowest potassium was recorded in T0 (40.2 kgha^{-1}) followed by T1 (305 kg ha-^{1}).The order of maximum available K was T8>T7>T4>T6>T3>T5>T2>T1>T0. After the consecutive wheat crop control recorded lowest available K (240.4 Kgha^{-1}) and maximum available K (387 kg ha^{-1}) recorded in T4 followed by T6. All other treatments gave more available K as compared to control. The order of highest available K in soil after wheat harvest was - T4>T6>T8>T3>T5>T3>T7>T2 >T1>T0.

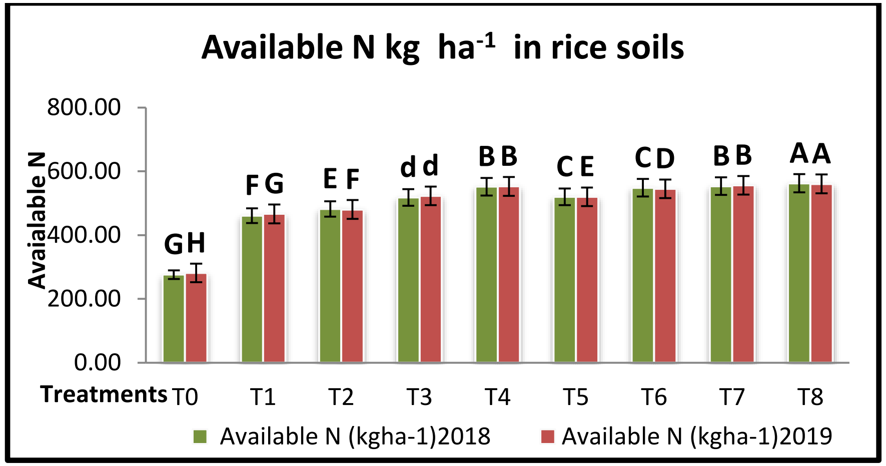


Fig.4.1.4 (a)

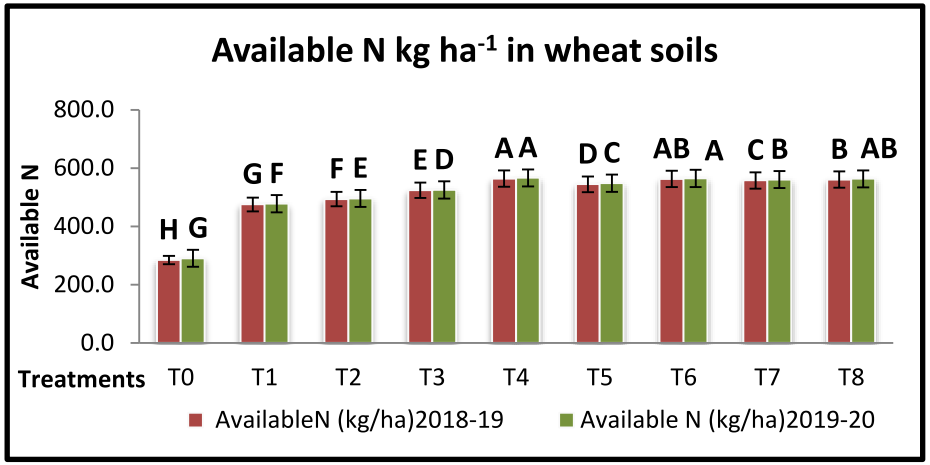


Fig 4.1.4(b)

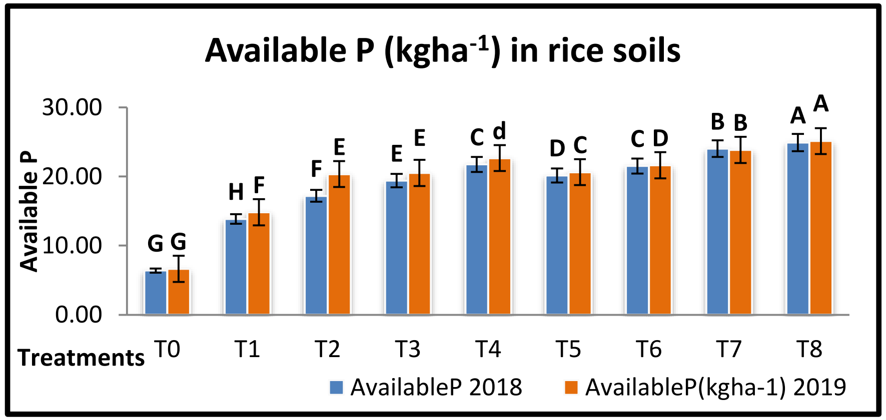


Fig 4.1.5(a)

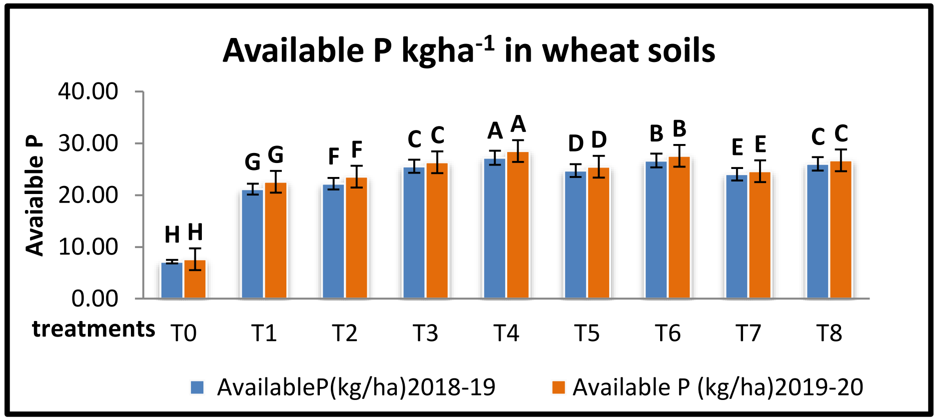


Fig. 4.1.5(b)

Fig 4.1.4,4.1.5 (a,b) depicting soil available Nitrogen and Phosphorouos(Kgha^{-1}) after the application of biochar combined fertilizers after the harvesting of rice- wheat crop during 2018-2019& 2019-2020. Common letters indicate that means are not significantly different according to DMRT($p<0.05$).

Fig. 4.1.6(a)

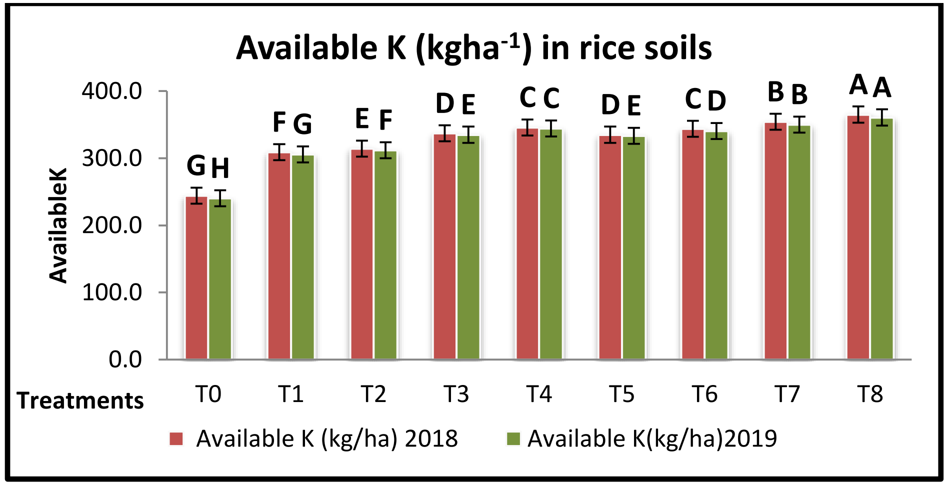


Fig 4.1.6(b)

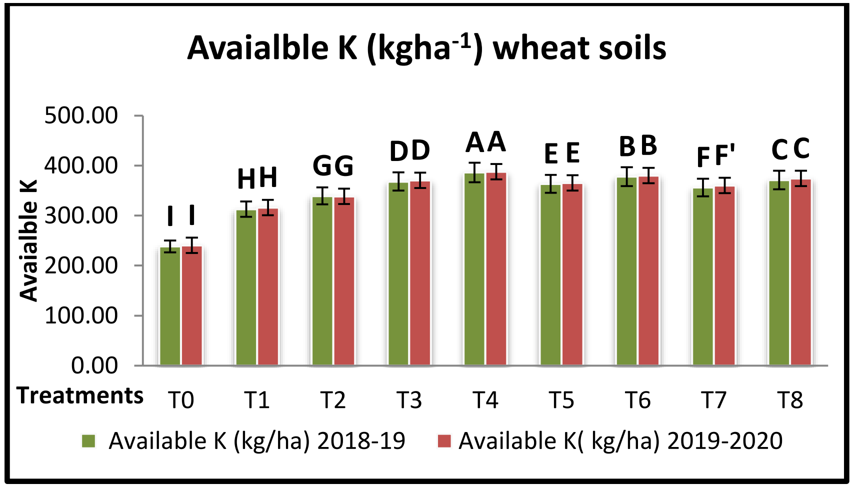


FIG. 4.1.6 (a,b) depicting soil available potassium (Kgha^{-1}) after the application of biochar combined fertilizers after the harvesting of rice-wheat crop during 2018-2019& 2019-2020. Different letters indicate that means are significantly different according to DMRT($p<0.05$).

Table 4.1.4(a) Effect of biochar based amendemnts on soil available N,P and K(kg ha^{-1}) (mean± S.E) after harvesting of two seasons of rice crop 2018-19

Treatments	**2018**			**2019**		
	Available N kgha^{-1}	Available P kgha^{-1}	Available K kgha^{-1}	Available N kgha^{-1}	Available P kgha^{-1}	Available K kgha^{-1}
T0- Control (no fertilizer)	276.00±1.63G	6.39±0.06G	244.77±2.68G	281.37±1.29H	6.65±0.17G	240.23±0.86H
T1-100%RDF	461.23±0.86F	13.87±0.25H	309.00±0.82F	466.43±1.14G	14.84±0.26F	305.67±1.23G
T2- 50%RDF + Biochar	482.28±0.88E	17.20±0.29F	314.33±0.98E	480.23±0.71F	20.36±0.18E	311.93±1.27F
T3-50%RDF+25%FYM+Biochar	518.00±1.63D	19.40±0.37E	337.03±0.74D	522.77±1.93D	20.52±0.14E	335.00±1.36E
T4-50%RDF+50%FYM+Biochar	551.97±1.59B	21.77±0.21C	345.90±1.28C	552.77±1.11B	22.67±0.07D	344.30±0.70C
T5-50%RDF+ 25%Vermi-compost + Biochar	519.97±1.49C	20.17±0.29D	335.00±1.31D	520.17±0.87E	20.63±0.04C	333.43±0.76E
T6-50%RDF+ 50%Vermi compost+ Biochar	548.53±1.70C	21.53±0.25C	343.73±1.32C	544.83±2.37D	21.63±0.10D	340.57±0.82D
T7-50%RDF+ 25%poultry manure+ Biochar	553.37±0.95B	24.03±0.40B	354.20±1.66B	556.17±1.55B	23.87±0.21B	350.13±1.17B
T8-50%RDF+50% poultry manure+ Biochar	562.60±1.28A	24.93±0.69A	365.07 ±0.74A	560.53±1.11A	25.13±0.05A	360.70 ±1.16A

Table 4.1.4(b) Effect of biochar based amendemnts on soil available N,P and K(kg ha^{-1}) (mean± S.E) after harvesting of wheat crop during 2018-2019 and 2019-2020.

Treatments	**2018**			**2019**		
	Available N kgha^{-1}	Available P kgha^{-1}	Available kgha^{-1}	Available N kgha^{-1}	Available P kgha^{-1}	Available K kgha^{-1}
T0- Control (no fertilizer)	284.7±1.93H	7.15 ±0.03H	238.33 ±0.68I	290.67 ±1.25G	7.64 ±0.24H	240.40 ±1.18I
T1-100%RDF	475.3±1.25G	21.17 ±0.29G	312.90 ±0.99H	477.67±2.05F	22.55 ±0.10G	316.37 ±1.68H
T2- 50%RDF + Biochar	493.60 ±1.10F	22.23 ±0.25F	339.43±0.70G	496.00 ±1.63E	23.56±0.28F	338.73 ±1.03G
T3-50%RDF+25%FYM+Biochar	523.80 ±1.07E	25.57 ±0.21C	368.20 ±0.82D	525.00±2.16D	26.34 ±0.15C	370.77 ±1.29D
T4-50%RDF+50%FYM+Biochar	563.80 ±1.19A	27.23 ±0.29A	386.23 ±0.82A	566.33±1.25A	28.52 ±0.32A	387.80 ±1.36A
T5-50%RDF+ 25%Vermicompost + Biochar	544.37 ±0.70D	24.77 ±0.37D	363.37 ±0.98E	548.0 ±1.63C	25.48 ±0.27D	365.27 ±1.72E
T6-50%RDF+ 50%Vermi compost+ Biochar	562.57±1.27AB	26.67±0.34B	377.90 ±1.20B	564.67±1.25A	27.60 ±0.18B	380.37 ±1.52B
T7-50%RDF+ 25%poultry manure+ Biochar	557.80 ±0.49C	24.03 ±0.17E	356.13 ±0.82F	560.67 ±1.25B	24.61 ±0.19E	360.17 ±1.42F
T8-50%RDF+50% poultry manure+ Biochar	560.40 ±0.59A	26.03 ±0.12C	371.40 ±1.07C	563.00±0.82AB	26.69 ±0.21C	374.23 ±1.59C

4.2 Impact of Biochar combined fertilizers on soil carbon fractions:

4.2.1: Organic carbon (%) : Soil organic carbon (%) in soil under different treatments after the harvest of each crop has been presented in table 4.2.1(a) and 4.2.1(b) . In 2018., after the harvesting of rice , Organic carbon(OC%) was found highest in T8(1.2%) and second highest OC(%) was found in T7 (1.06%). The lowest (0.58%) was found in T0 (control). All the treatments were significantly different among themselves. In following wheat crop OC % was increased in Biochar applied plots as compared to control and 100% RDF. The highest soil OC% content found in T4 (1.45%) followed by T6 (1.32%).and lowest OC% (0.60) was found in T0 control followed by T1 (100% RDF) having 0.79% OC. In 2019, after harvesting of rice crop, OC% was found highest in T8 (1.16%). This treatment was immediately followed by T7(1.05%) and T4(1.04%) respectively. The minimum OC% was recorded in control T0(0.59%) followed by T1(100% RDF). The order of maximum OC % was T8>T7>T4>T6>T5>T3>T7>T2 >T1>T0. After succeeding wheat crop OC % was found more in Biochar amended plots as compared to unamended plots. The SOC% ranged from 0.62-1.52%. Different treatments significantly differ from each other during both years. T4 (50%RDF+ 50% FYM+ Biochar) recorded maximum (1.52%) OC and T0 (control) recorded lowest (0.62%) OC in soil after harvest of wheat crop. SOC % in soil after second wheat crop among different treatments was in order : T4>T6>T8>T3>T5>T7>T2>T1>T0. All treatments were significantly better in OC % as compared to control. The data of OC presented in Fig. 4.2.1(a) and 4.2.1(b).

4.2.2 Labile carbon/ permanganate oxidizable C (POXC): POXC considered as active carbon fraction of soil organic matter. POXC was statistically significantly different among treatments during both years. In 2018, after harvesting of rice the labile C ranged from 93.5 to 342 mg kg-1.The highest POXC was recorded in T8(342 mg) which was immediately followed by T7 (326.3 mg). All the treatments except control showed increase in POXC content and all were significantly different from each other. The lowest POXC (93.5 mg) was recorded in control followed by T1 (165.3 mg). The data presented in table 4.1.1(a) and Fig. 4.2.2(a). After succeeding wheat crop, POXC ranged from 95.4 to 363 mg. T4 recorded highest (363mg kg-1) POXC followed by T6 (353.5). T0 recorded lowest POXC content (95.4 mg) . All the treatments were superior in POXC as compared to control. POXC content slightly increased during second year after rice wheat cropping system in 2018. T8 recorded highest (345.17mg) POXC content. The second highest POXC content found in T7 (327.17 mg) which was followed by T4 (319.6 mg). The lowest (96.13 mg) POXC was found in unamended plot T0. The maximum POXC order after the harvest of rice crop during both years was- T8>T7>T4>T6>T5>T3>>T2 >T1>T0. In following wheat crop of 2019-2020 T0(control) recorded lowest POXC (98.06 mg) followed by T1 (100% RDF)-171.2 mg. T4 recorded significantly more POXC (366.3 mg) than all other treatments . All the treatments were statistically comparable to control in POXC. The trend of POXC content in soil after wheat crop harvesting was: T4>T6>T8>T3>T5>T7>T2 >T1>T0.The data of POXC was presented with the help of Fig.s 4.2.2(a) and 4.2.2(b).

4.2.3 Particulate Organic carbon (POC): Particulate organic carbon derived from plant materials. POC ranged from 4.53- 1.01 g after harvest of rice crop and 5.53 to 12.28 g after harvest of wheat crop during 2018-2019. (Table 4.2 and Fig 4.2.3a and 4.2.3b). T8-50 % RDF+50% PM+ Biochar) recorded highest POC (12.01g) which was at par with T7 (10.64 g) and followed by T4 and T6 having POC content 10.16 g and 9.22 respectively. Least POC content recorded with control (4.53 g) which was followed by T1 (6.91 g). All the treatments which received Biochar application along with inorganic fertilizers and organic manure recorded stsistically more POC as compared to control. POC content in soil after rice was in orderT8>T7>T6>T4> T> T3> T2> T1>T0. After consecutive wheat crop T4 stood highest in POC (12.28g) and second highest (11.54g) POC recorded with T6. All other treatments were significantly different among themselves. Least POC was recorded with T0 (5.53 g) followed by T1 (100% RDF)-6.42g. However during second crop cycle of 2019-2020 both T8 and T7 treatments recorded maximum POC (11.11 and 10.84 g) which was statistically non-significant among them. T8 and T7 followed by T6 with 10.24 g POC. The least POC (5.20g) recorded with T0 (control). All the plots which were treated with Biochar had more POC content as compared to unamended plots. After succeeding wheat cropT4 had highest (11.44g) POC content. It was statistically significantly different from all other treatments. The order of POC after harvest of wheat crop during both years was:T4> T6> T8> T3> T5>T7> T2> T1> T0 .The lowest POC content was recorded with control (unamended plot).

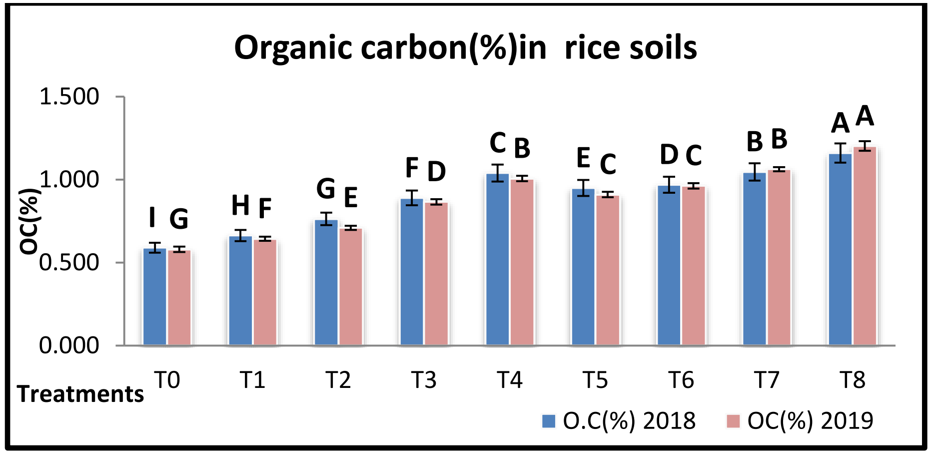


Fig.4.2.1(a)

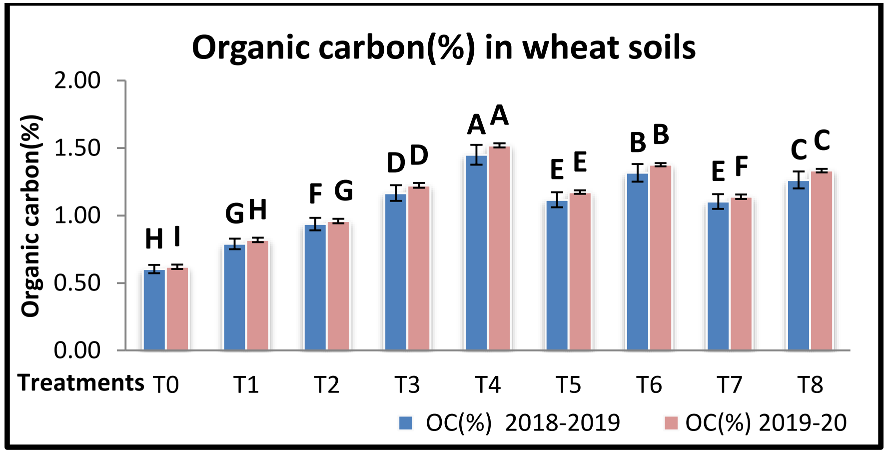


Fig 4.2.1(b)

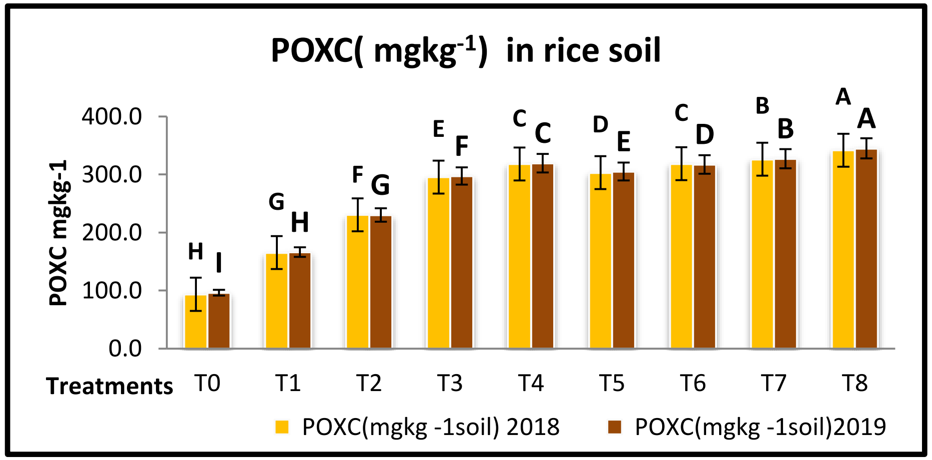


Fig. 4.2.2(b)

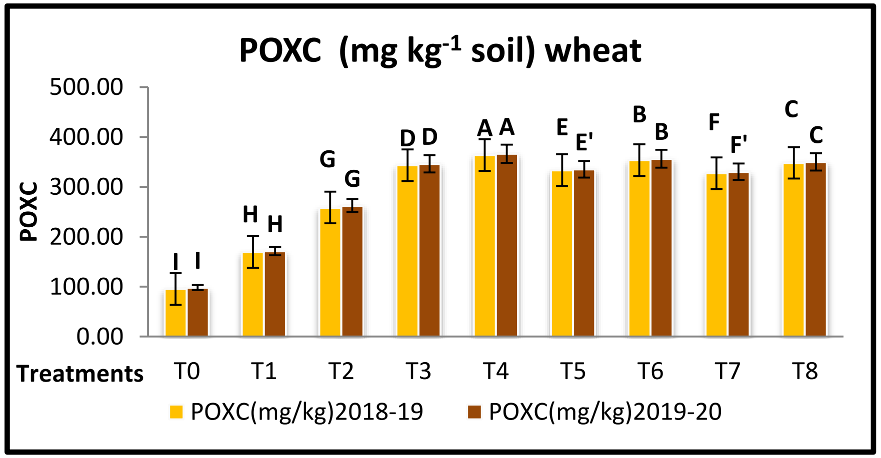


Fig.4.2.2(b)

Fig 4.2.1,4.2.2 (a,b) Representing the effect of biochar based amendments on organic carbon(%) and POXC(mg kg^{-1}soil) in soil after harvesting of rice –wheat crop during 2018-2019 and 2019-2020.Different symbols indicate that treatments are significantly different from each other according to DMRT ($p<0.05$).

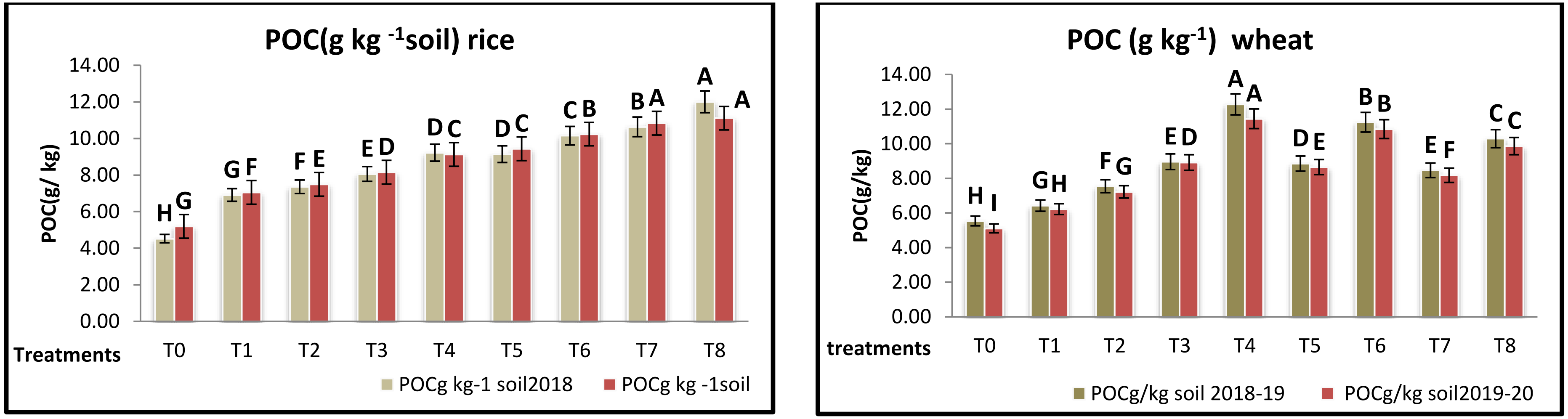


Fig 4.2.3(a) **Fig4.2.3(b)**

Fig ,4.2.3 (a,b) Representing the effect of biochar based amendments on Particulate organic carbon and (g kg^{-1}soil) in soil after harvesting of rice –wheat crop during 2018-2019 and 2019-2020.Same symbols indicate that treatments are non significant from each other according to DMRT ($p<0.05$).

Table 4.2.1(a) Impact of biochar combined manures and fertilizers on OC(%), POXC (mgkg^{-1}) and POC (gkg^{-1}) (mean±S.E) after harvesting of rice crop during 2018-2019.

Treatments	2018			2019		
	OC (%)	POXC	POC	OC (%)	POXC	POC
T0- Control (no fertilizer)	0.58±0.02I	93.50±0.82H	4.53±0.40H	0.59±0.02G	96.13±0.82I	5.20±0.16G
T1-100%RDF	0.64±0.02H	165.30±0.94G	6.91±0.08G	0.66±0.01F	166.10±0.28H	7.05 ±0.05F
T2- 50%RDF + Biochar	0.71±0.01G	230.50±1.63F	7.36±0.03F	0.76±0.01E	230.10 ±0.90G	7.50 ±0.24E
T3-50%RDF+25%FYM+Biochar	0.87 ±0.01F	295.57±.61E	8.06±0.05E	0.89±0.02D	297.27 ±0.71F	8.16 ±0.03D
T4-50%RDF+50%FYM+Biochar	1.01±0.01C	318.17±1.25C	9.22±0.02D	1.04 ±0.02B	319.60±0.70C	9.13±0.03C
T5-50%RDF+ 25%Vermi-compost + Biochar	0.91±0.01E	303.27±0.87D	9.15±0.02D	0.95 ±0.02C	305.13 ±0.90E	9.44±0.49C
T6-50%RDF+ 50%Vermi compost+ Biochar	0.96±0.01D	318.67±0.62C	10.16±0.02C	0.97±0.02C	317.43 ±0.86D	10.24±0.04B
T7-50%RDF+ 25%poultry manure+ Biochar	1.06±0.01B	326.33±1.68B	10.64±0.08B	1.05 ±0.01B	327.30 ±0.94B	10.84 ±0.04A
T8-50%RDF+50% poultry manure+ Biochar	1.20±0.01A	342.03±1.40A	12.01±0.08A	1.16 ±0.03A	345.17 ±0.86A	11.11 ±0.03A

Table 4.2.1(b) Impact of biochar combined manures and fertilizers on OC(%), POXC ($mgkg^{-1}$) and POC (gkg^{-1}) (mean±S.E) after harvesting of wheat crop during 2018-2019.

	2018			2019		
Treatments	OC (%)	POXC	POC	OC (%)	POXC	POC
T0- Control (no fertilizer)	0.60 ±0.02H	95.40±0.70I	5.53±0.08H	0.62 ±0.02I	98.06 ±0.47I	5.11±0.03I
T1-100%RDF	0.79 ±0.02G	169.37±0.74 H	6.42±0.08G	0.82±0.02H	171.20 ±0.82H	6.22 ±0.07H
T2- 50%RDF + Biochar	0.94 ±0.01F	258.4±0.87G	7.54±0.02F	0.96±0.02G	262.17±0.90G	7.22 ±0.02G
T3-50%RDF+25%FYM+Biochar	1.17±0.02D	343.30±0.94 D	8.96±0.02E	1.22 ±0.02D	346.27 ±0.87D	8.91 ±0.01D
T4-50%RDF+50%FYM+Biochar	1.45 ±0.02A	363.93±0.68 A	12.28±0.02A	1.52 ±0.02A	366.33 ±0.82A	11.44 ±0.29A
T5-50%RDF+ 25%Vermi-compost + Biochar	1.12 ±0.01E	333.37±0.85 E	8.85±0.02D	1.17±0.01E	335.10±0.90E	8.65 ±0.17E
T6-50%RDF+ 50%Vermi compost+ Biochar	1.32 ±0.01B	353.57±0.58 B	11.24±0.03B	1.38±0.01B	356.27 ±1.80B	10.85 ±0.02B
T7-50%RDF+ 25%poultry manure+ Biochar	1.10 ±0.01E	327.40±0.83F	8.47±0.03E	1.14±0.02F	330.23 ±0.92F	8.18±0.02F
T8-50%RDF+50% poultry manure+ Biochar	1.26 ±0.01C	348.00±1.40 C	10.29 ±0.25C	1.33±0.01C	349.83±1.24C	9.86 ±0.01C

4.2.4 Microbial biomass carbon (MBC): Microbial biomass carbon is the symbol of the response of microbial biomass to changes in soil management. All treatments except control significantly increased the microbial biomass carbon after rice crop during 2018-2019(Table 4.2.4(a) and Fig 4.2(a). T8- 50 % RDF+ 50% PM+ Biochar recorded highest(135.7µgg^{-1} soil) MBC in soil at this interval. MBC due to different treatments follow order: T8 (135.7)> T7 (130.3)>T4(122.3)>T6(118.7)>T5(115.5)>T3(111.4)>T2(88.5)>T1(81.7)>T0(56.8).Remaining all treatments was significantly different from each other. MBC in soil after consecutive wheat crop was highest with T4 (175.2) being significantly more than all other treatments. The Biochar treated plots showed more MBC as compared to treated plots T and T1. The highest MBC (175.2) observed in T4 immediately followed by T6 (168.97µgg-^{1} soil).The lowest MBC recorded in T0(56.57µgg-^{1} soil) followed by T1 with MBC(121.9 7µgg-1 soil). In the following year 2019-2020, higher MBC in soil after rice crop was recorded with T8 (133.3 7µgg^{-1} soil) which was followed by T7 (126.5 7µgg^{-1} soil). All the treatments showed superiority in case of MBC over control. Least MBC recorded in T0(52.6). Similarly MBC after harvest of wheat crop of 2019-2020 was highest with T4(176.47µgg-1 soil, while T0 recorded lowest (52.57µgg^{-1} soil) MBC content in soil. It is clear that application of Biochar with inorganic fertilizers and manures increased MBC content in soil after two crops cycle. The difference was significant with Biochar amended plots and unamended plots. The order of MBC in soil after wheat harvest during 2019-20 was T4(176.4)>T6(164.2)> T8(155.3)> T3(151.2)> T5(149.3)>T7(144.1)>T2(139.3)>T1(130.4)>T0(52.5) . The data of Wheat MBC content presented in Fig 4.2.4(b) and table 4.2.4(b).

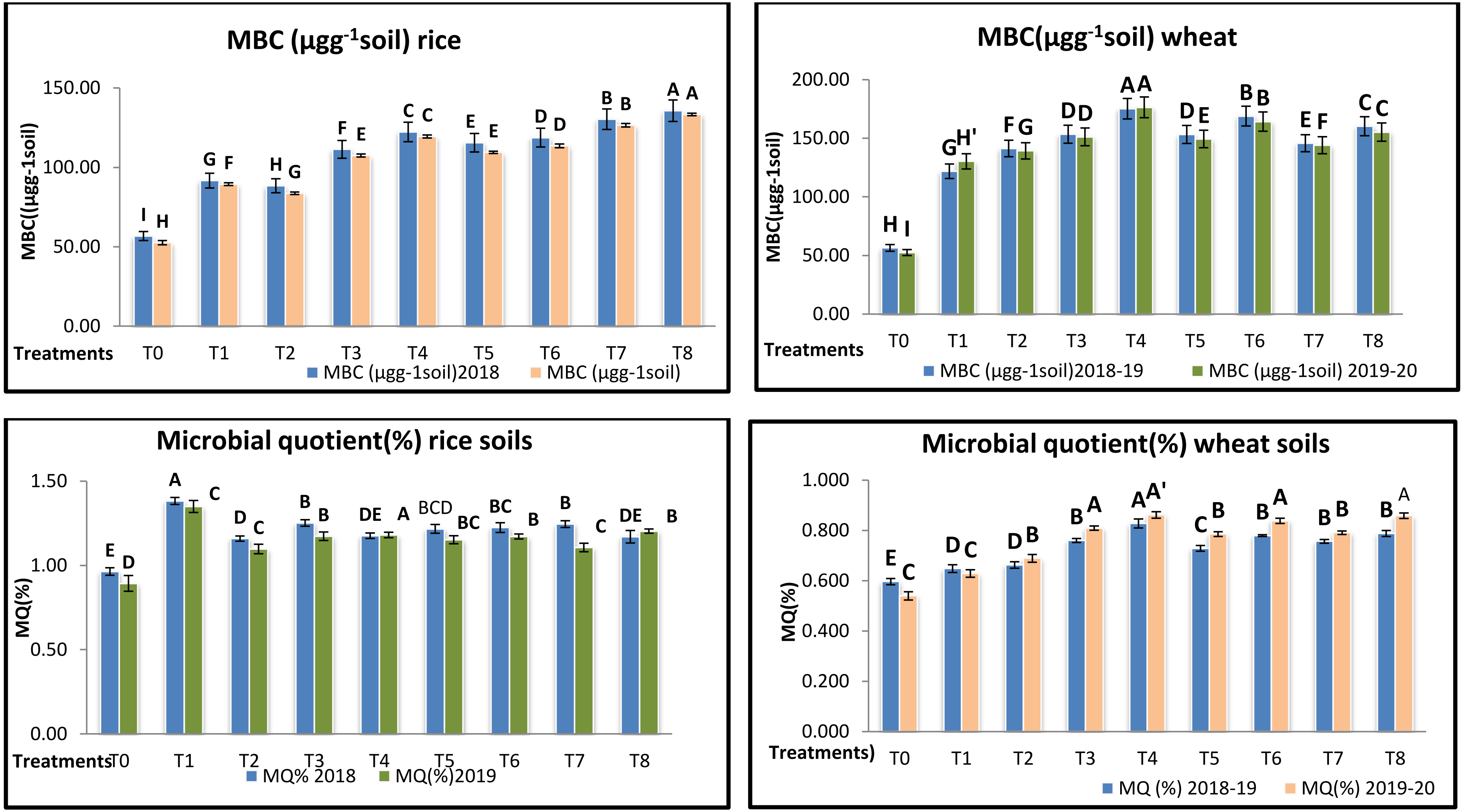
4.2.5 Microbial Quotient (%)(q $_{mic}$): Microbial quotient(%) significantly different among treatments during both years. q $_{mic}$ (%) ranged from 0.96- 1.38% after rice crop and 0.60 – 0.83% after wheat crop during 2018-2019(Table 4.2.4(a), 4.2.4(b) and Fig 4.2.5(a) and 4.2.5(b). The maximum q $_{mic}$ after 2018-2019 rice crop recorded with T1 (1.38%),T3, T7(1.25%) followed by T6 (1.22%).All treatments were significantly superior over control in case of q $_{mic}$. The lowest q $_{mic}$ recorded with control (0.96%). In following wheat crop trend was changed giving maximum q $_{mic}$ with T4 (0.83%) and lowest (0.60)with T0(control). All treatments of Biochar combined fertilizers comparable to control. T7, T6, T8 and T3 treatments were at par with each other and statistically non-significant. But these treatments significantly superior from T5, T2, T1 and T0. The minimum q $_{mic}$ recorded in control (0.60) followed by T1 (0.65%) and T2 (0.66%). In the next year 201-2020 T1 recorded highest (1.35%) q $_{mic}$ which was immediately followed by T8 (1.20%) The other treatments were at par among themselves but superior than control. The lowest q_{mic} recorded in control (0.89%). The trend of q mic was after harvest of rice crop was: T1>T8>T4>T6>T3>T5>T7>T2>T0. T4 recorded maximum (0.86%) q_{mic} which was at par with T8, T6, T5 and T3 having qmic0.85, 0.83, 0.809, 0.791, and 0.786 % respectively. All these treatments were non - significant among themselves but superior to T0, T1 and T2. The least q_{mic} recorded in T0 (0.54%) followed by T1(0.629%) . The Biochar amended plots in case of both seasons of wheat showed significant variation as compared to control. The data and the variation during both years presented in form of table and graphs along with standard error.

Table 4.2.4(a) Effect of biochar on Microbial Biomass Carbon and Microbial Quotient(mean±S.E) in soil at rice crop harvest during 2018-2019.

Treatments	**2018**		**2019**	
	MBC	q_{mic}	MBC	q_{mic}
T0- Control (no fertilizer)	56.8±0.5I	0.96 ±0.02E	52.6 ±1.3H	0.89 ±0.05D
T1-100%RDF	91.7±0.5G	1.38 ±0.02A	89.5 ±0.9F	1.35 ±0.04C
T2- 50%RDF + Biochar	88.5±1.0H	1.16 ±0.02D	83.8 ±0.8G	1.10 ±0.03C
T3- 50%RDF+25%FYM+Biochar	111.4±0.9F	1.25 ±0.02B	107.5 ±1.0E	1.17 ±0.02B
T4- 50%RDF+50%FYM+Biochar	122.3 ±0.5C	1.18 ±0.02DE	119.5±0.9C	1.18 ±0.02A
T5-50%RDF+ 25%Vermi-compost + Biochar	115.5±0.9E	1.2±0.03BCD	109.5 ±0.7E	1.15±0.02BC
T6-50%RDF+ 50%Vermi compost+ Biochar	118.7±1.2D	1.22 ±0.03BC	113.6 ±1.2D	1.17 ±0.01B
T7-50%RDF+ 25%poultry manure+ Biochar	130.3±0.7B	1.25 ±0.02A	126.5 ±1.1B	1.11 ±0.02C
T8-50%RDF+50% poultry manure+ Biochar	135.7 ±1.0A	1.17 ±0.04DE	133.3 ±0.7A	1.20 ±0.01B

Table 4.2.4(b) Effect of biochar on Microbial Biomass Carbon and Microbial Quotient(mean±S.E) in soil at wheat crop harvest during 2018-2019& 2019-2020.

Treatments	**2018**		**2019**	
	MBC	q_{mic}	MBC	q_{mic}
T0- Control (no fertilizer)	56.5 ±0.7H	0.60a ±0.01E	52.5±0.9I	0.540±0.016C
T1-100%RDF	121.9 ±0.5G	0.65b ±0.0D	130.4 ±0.6H	0.629±0.015C
T2- 50%RDF + Biochar	141.3 ±0.9F	0.66b ±0.01D	139.3±0.8G	0.689±0.016B
T350%RDF+25%FYM+Biochar	153.4 ±0.8D	0.76d ±0.01B	151.2 ±0.9D	0.809±0.008A
T450%RDF+50%FYM+Biochar	175.2 ±0.9A	0.83e ±0.02A	176.4 ±0.7A	0.862±0.013A
T5-50%RDF+ 25%Vermi-compost + Biochar	153.2 ±0.8D	0.73c ±0.01C	149.3 ±1.0E	0.786±0.010B
T6-50%RDF+ 50%Vermi compost+ Biochar	168.9 ±0.9B	0.78d ±0.00B	164.2 ±0.6B	0.838±0.011A
T7-50%RDF+ 25%poultry manure+ Biochar	145.8 ±0.4E	0.76d ±0.01B	144.1 ±0.9F	0.791±0.007A
T8-50%RDF+50% poultry manure+ Biochar	160.3 ±0.8C	0.79d ±0.01B	155.3 ±0.6C	0.859±0.011A



4.2.4(a)

4.2.4(b

4.2.5(a)

4.2.5(b)

Fig. 4.2.4(A,B) and 4.2.5(a,b) depicted microbial biomass carbon (µgg^{-1}soil) and microbial quotient(%) in soil at crop harvest during 2018-2019 and2019-2020. Common letters indicate that the treatments are non significant among themselves according to DMRT($p<0.05$).

4.3 Impact of Biochar based amendments on soil biological indicators:

4.3.1: Urease enzyme: The urease enzyme activities in soil influenced by Biochar combined fertilizers presented in table 4.3.1(a) ,4.3.1(b) and Fig. 4.3.1(a),4.3.1(b) . Highest urease enzyme activities after rice and wheat were observed in surface soil (0-15 cm) while it was lowest in sub surface soil and decreased continuously with the soil depth. In all the treatments, urease enzymes recorded highest activity at heading stage. Significantly highest urease activity (9.46 and 5.83 mg urea g^{-1} soil 24 h^{-1}) in 0-15 cm and 15-30 cm in rice crop was recorded with the application of 50%RDF+50%PM+Biochar (T8) which was statistically at par with 8.70 mg urea g^{-1} soil 24 $h^{-1}$and 4.82 mg urea released g^{-1} soil 24 h^{-1} by the application of 50%RDF+25%PM+Biochar. The second highest urease activity (7.43, 3.89 mg urea released g^{-1} soil 24 $h^{-1}$was recorded with the application of 50%RDF+50%VC+Biochar at surface and subsurface soil. The lowest urease activity(2.59 mg and 1.75mg urea released g^{-1} soil 24 h^{-1}) recorded with T0(control).All the other treatments were statistically significantly different from each other in both seasons of rice crop. Urease activity in soil slightly increased after the following wheat season. The urease activity in wheat crop ranged from 2.22 mg to 8.65 mg urea released g^{-1} soil 24 h^{-1}. The highest urease enzyme activities in wheat crop (8.65, 6.73 mg urea released g^{-1} soil 24 h^{-1}) recorded by the application of 50%RDF+50%FYM+Biochar at 0-15 cm and 15-30 cm depth which was followed by T6 and T8 having 7.26 and 7.16 mg urea released g^{-1} soil 24 h^{-1}at 0-15 cm depth and 4.80 and 4.22 mg urea released g^{-1} soil 24 h^{-1}at 15-30 cm depth. The lowest urease enzymatic (2.26, 0.86 mg urea released g^{-1} soil 24h^{-1}) recorded with control. All the treatments amended with Biochar combined fertilizers were superior in urease activities compared to control and T1 .The order of urease activity in wheat was T4>T6>T8>T3>T5>T7>T2>T1>T0.

4.3.2 Dehydrogenase: The soil dehydrogenase enzymatic activity is one of the vital soil characteristic to indicate the soil quality. The activity of dehydrogenase decided the availability of nitrogen and microbial population. In view of this study, the soil dehydrogenase activities recorded at heading stage in rice –wheat crop from surface and subsurface soil. The use of Biochar combined fertilizers influenced the dehydrogenase enzymatic activities in soil during both years. The highest dehydrogenase activity of 14.2 and 10.47 mg TPF produced g^{-1} soil day^{-1} recorded from surface and subsurface rice soils by the application of 50% RDF+50% PM+Biochar-T8 followed by the application of

50%RDF+25% PM+Biochar-T7 having 12.89 and 9.52 mg TPF produced g^{-1} soil day^{-1}at surface (0-15 cm) and 15-30 cm. All the treatments were significantly different from each other. All the Biochar amended plots showed more dehydrogenase activity as compared to control. The lowest enzymatic activities (6.67, 2.85 mg TPF produced g^{-1} soil day^{-1}) recorded with control in case of rice crop (Fig 4.3.2(a). In the following wheat crop the integrated use of Biochar with 50% RDF +50%FYM showed maximum and significantly higher DHA values 27.5,23 mg TPF produced g^{-1} soil day^{-1} at surface and subsurface soil . Slightly higher dehydrogenase was recorded in wheat soils after the harvest of rice crop. Upper surface (0-15 cm) soil has higher values of DHA in wheat crop. The second highest (25, 20 mg TPF produced g^{-1} soil day^{-1}) activities if dehydrogenase recorded in T6. All the other treatments were significantly different among themselves. The lowest dehydrogenase activity of 4.7, 2.5 mg TPF produced g^{-1} soil day^{-1} were recorded with control from upper and lower surfaces of soil. The highest DHA enzyme activity in soil was T4> T6> T8> T3> T5> T7> T2> T3> T1>T0.The data presented in table and Fig. 4.3.2(b).

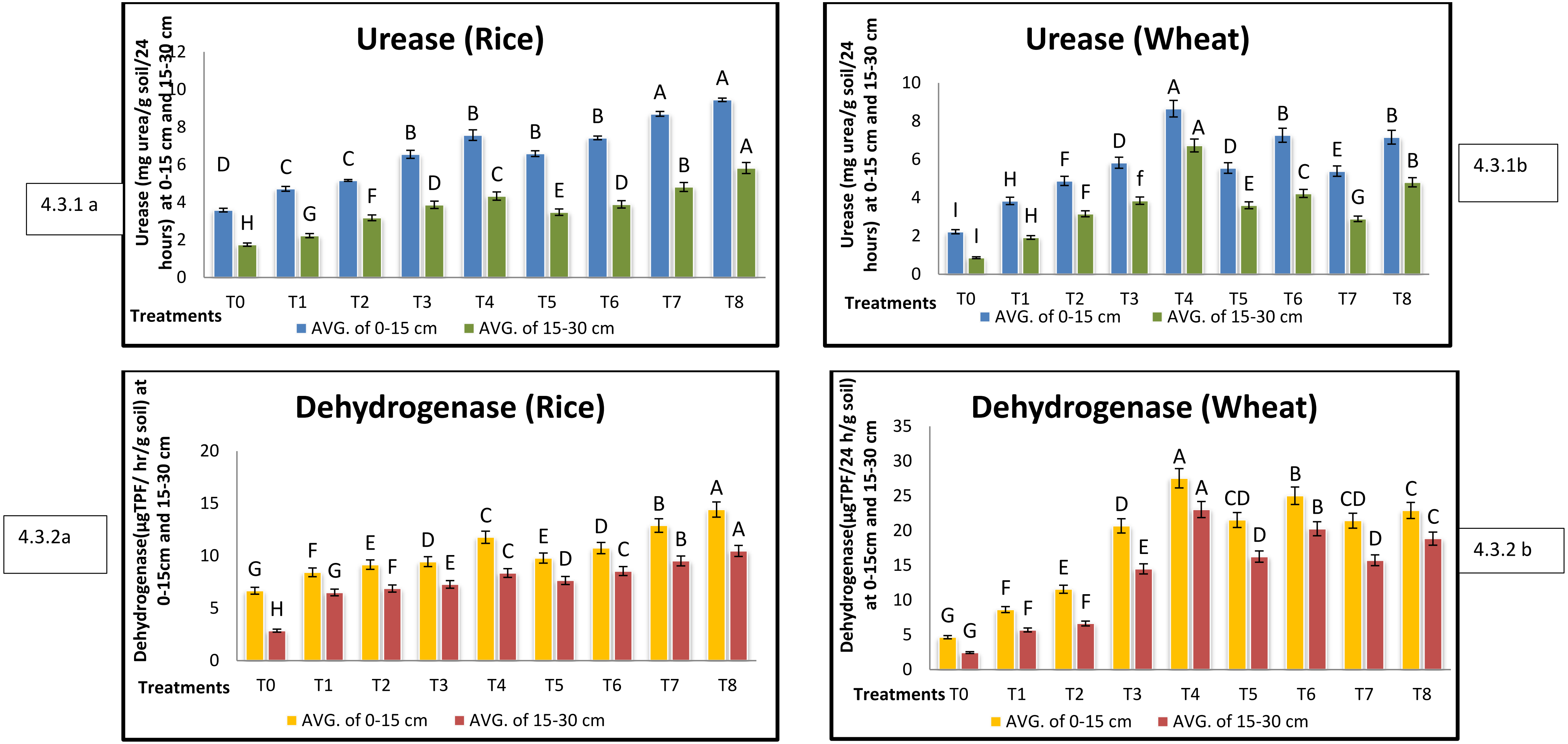


Fig. 43.1(a,b)& 4.3.2(a,b) : Impact of biochar based amendments on urease(mg urea g^{-1} soil 24h^{-1}) and dehydrogenase (µgTPF/ hr/g soil) at different depths in rice- wheat cropping system during 2018-2019& 2019-2020.Different letters represent treatments are significant from each other.

Table 4.3.1(a) Impact of biochar based amendments on Urease and dehydrogenase(mean± S.E) at different depths in rice crop at heading stage.

Treatments	Urease (mg urea g^{-1} soil24 hours-^{1})		dehydrogenase(µg TPF24 h-^{1}g soil^{-1})	
	0-15cm	15-30cm	0-15cm	15-30cm
T0- Control (no fertilizer)	2.59 ±0.10D	1.75 ±0.06H	6.67 ±0.12G	2.85 ±0.07H
T1-100%RDF	4.72 ±0.13C	2.22 ±0.09G	8.43 ±0.15F	6.50 ±0.04G
T2- 50%RDF + Biochar	5.16 ±0.05C	3.17 ±0.11F	9.16 ±0.14E	6.88 ±0.05F
T3-50%RDF+25%FYM+Biochar	6.55 ±0.21B	3.87 ±0.07D	9.44 ±0.07D	7.27 ±0.05E
T4-50%RDF+50%FYM+Biochar	7.57 ±0.29B	4.33 ±0.06C	11.77 ±0.16C	8.37 ±0.12C
T5-50%RDF+ 25%Vermi-compost + Biochar	6.59 ±0.15B	3.47 ±0.11E	9.79 ±0.04E	7.65 ±0.14D
T6-50%RDF+ 50%Vermi compost+ Biochar	7.43 ±0.10B	3.89 ±0.04D	10.74 ±0.14D	8.54 ±0.08C
T7-50%RDF+ 25%poultry manure+ Biochar	8.70 ±0.13A	4.82 ±0.03B	12.89 ±0.29B	9.52 ±0.09B
T8-50%RDF+50% poultry manure+ Biochar	9.46 ±0.09A	5.83 ±0.07A	14.42 ±0.06A	10.47 ±0.12A

Table 4.3.1(b) Impact of biochar based amendments on Urease and dehydrogenase(mean± S.E) at different depths inwheat crop at heading stage.

Treatments	Urease (mg urea g^{-1} soil24 hours-^{1})		dehydrogenase(µg TPF24 h-^{1}g soil^{-1})	
	0-15cm	15-30cm	0-15cm	15-30cm
T0- Control (no fertilizer)	2.22±0.086I	0.86 ±0.07I	4.7 ±0.12G	2.5 ±0.09G
T1-100%RDF	3.83 ±0.098H	1.92 ±0.03H	8.6 ±0.31F	5.7 ±0.08F
T2- 50%RDF + Biochar	4.88 ±0.026F	3.16 ±0.03F	11.6 ±0.25E	6.6 ±0.12F
T3-50%RDF+25%FYM+Biochar	5.83 ±0.046D	3.85 ±0.03F	20.7 ±0.44D	14.5 ±0.34E
T4-50%RDF+50%FYM+Biochar	8.65 ±0.064A	6.73 ±0.06A	27.5 ±1.02A	23.0 ±0.52A
T5-50%RDF+ 25%Vermi-compost + Biochar	5.55 ±0.074D	3.60 ±0.09E	21.5 ±1.05CD	16.3 ±0.75D
T6-50%RDF+ 50%Vermi compost+ Biochar	7.26 ±0.040B	4.22 ±0.04C	25.0 ±0.47B	20.3 ±0.71B
T7-50%RDF+ 25%poultry manure+ Biochar	5.38 ±0.069E	2.89 ±0.04G	21.4 ±0.74CD	15.7 ±0.42D
T8-50%RDF+50% poultry manure+ Biochar	7.16 ±0.050B	4.80 ±0.05B	22.9 ±0.94C	18.9 ±0.46C

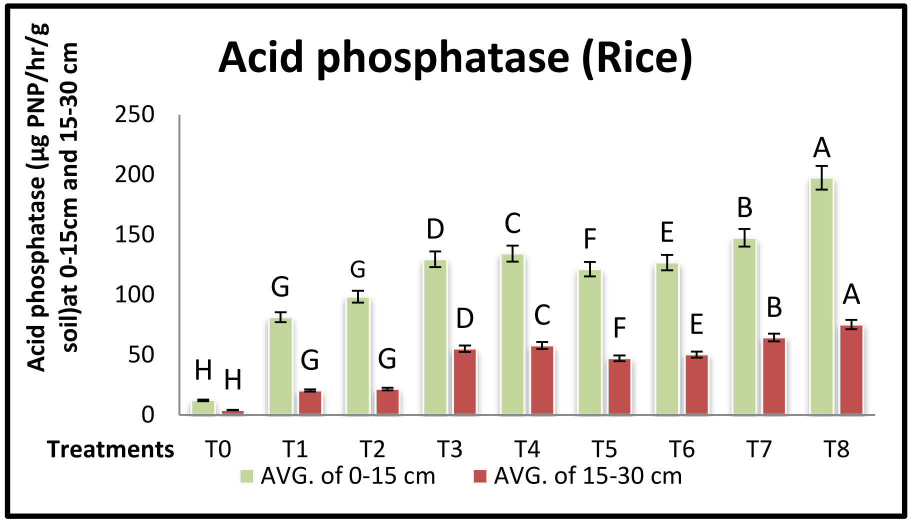
4.3.3 Acid phosphatase: Soil enzymatic activities enhanced with the Biochar application in all treated plots. The acid phosphatase activity in rice soils ranged from 12.21 to 197.33 µgPNPg^{-1} soil h^{-1} in upper surface4.12- 75.27 µgPNPg^{-1} soil h^{-1} in lower surface (Table 4.3.3, Fig 4.3.3(a)) All the treatments were statistically significant among themselves in acid phosphatase activity. Significantly high acid phosphatase activity of 197.33 and 75.27 µgPNPg^{-1} soil h^{-1} was recorded at heading stage from upper and lower surface rice soil in T8(50%RDF+50%PM+Biochar). The treatment T8 was followed by T7 (50%RDF+25%PM+Biochar) with147.47 and 64.39 µgPNPg^{-1} soil h^{-1} from upper and lower surface. The acid phosphatase activity of 12.21 and 4.12 µgPNPg^{-1} soil h^{-1} from surface and subsurface soil recorded with control (T0) which was lowest when compared to other treatments at both surfaces. The highest acid phosphatase activity in rice soil from both surfaceswasT8>T7>T4>T3>T6>T5>T2> T1>T0 µgPNPg^{-1} soil h$^{-1.}$ All the treatments were significantly superior over control. In the following wheat crop all the treatments recorded significantly more acid phosphatase activity than control. The acid phosphatase activity in wheat soils ranged from 17.4-152.3 µgPNPg^{-1} soil h^{-1}. Application of 50%RDF+50%FYM+biochar (T4) recorded highest (152.3 and 72.4 µgPNPg^{-1} soil h^{-1}) in wheat upper and lower surface soils. The second highest acid phosphatase activity recorded with T6-50%RDF+50%VC+biochar (147.3 and 63.8 µgPNPg^{-1} soil h^{-1}). Lowest acid phosphatase (17.4, 4.3 µgPNPg^{-1} soil h^{-1}) activity was recorded with control. All the treatments were significantly superior in acid phosphatase activity (Fig. 4.3.3(b)) .The order of acid phosphatase activity was T4>T6>T8>T3>T5>T7>T2>T1>T0.The acid phosphatase activity of both crops from both surfaces presented in table 4.3.3(b).

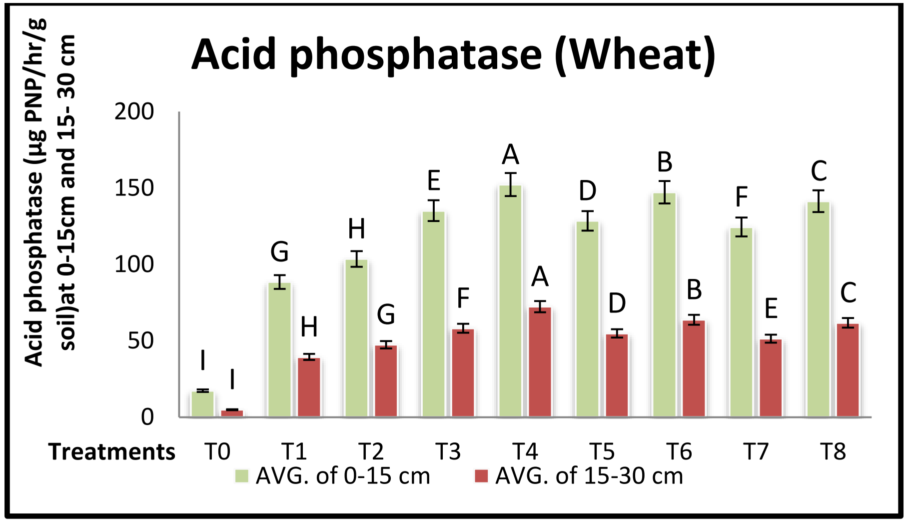
4.3.4 Alkaline phosphatase: Alkaline phosphatase activity in rice soils ranged from 25.17 to 181.3 µgPNPg^{-1} soil h^{-1} in surface soil (0-15 cm) and8.90 – 74.56 µgPNPg^{-1} soil h^{-1} in subsurface soil (15-30cm) at heading stage. (Table 4.3.3(a),Fig. 4.3.4 (a). All the treatments recorded significantly more alkaline phosphatase activity as compared to control. The alkaline phosphatase activity was highest when crop received 50% RDF+50% PM+ Biochar and activities were being181.33 and 74.56 µgPNPg^{-1} soil h^{-1} released during heading stage from surface and subsurface soil respectively. The treatment which received 50%RDF+25% PM+ Biochar recorded alkaline phosphatase activity of 174.37 and 71.56 µgPNPg^{-1} soil h^{-1} from 0-15cm and 15-30 cm. The lowest alkaline phosphatase of 25.17 and 8.90 µgPNPg^{-1} soil h^{-1} recorded with T0 (control). Alkaline phosphatase activities were significantly enhanced by Biochar application. The treatment T6,T5,T4,T3,T2 and T1recorded

161.3,152.2,167.23,146.3,128.7 and 107.23 µgPNPg^{-1} soil h^{-1}in surface soil and 61.28,58.45,67.36,52.27,50.3 and 39.27 µgPNPg^{-1} soil h^{-1}respectively in subsurface (15-30 cm) soil.

In consecutive wheat crop at heading stage the alkaline phosphatase activity ranged from 20.9- 197.4 µgPNPg^{-1} soil h^{-1}in 0-15cm layer and 7.2-80.4 µgPNPg^{-1} soil h^{-1} in 15-30 cm layer. All the Biochar amended treatments in case of alkaline phosphatase were significantly more as compared to control. Application of 50%RDF+50% FYM+ Biochar recorded maximum activity of alkaline phosphatase (197.4 and 80.4 µgPNPg^{-1} soil h^{-1}) in surface as well as sub surface soil. T4 treatment was followed by T6 (50%RDF+50%VC+Biochar) having 174.5 and 76.2 µgPNPg^{-1} soil h^{-1}alkaline phosphatase activities. The control recorded lowest (20.9 and 7.2 µgPNPg^{-1} soil h^{-1}) alkaline phosphatase activity. The trend followed in wheat in alkaline phosphatase was depicted in Fig. 4.3.4(b) and table 4.3.3(b).

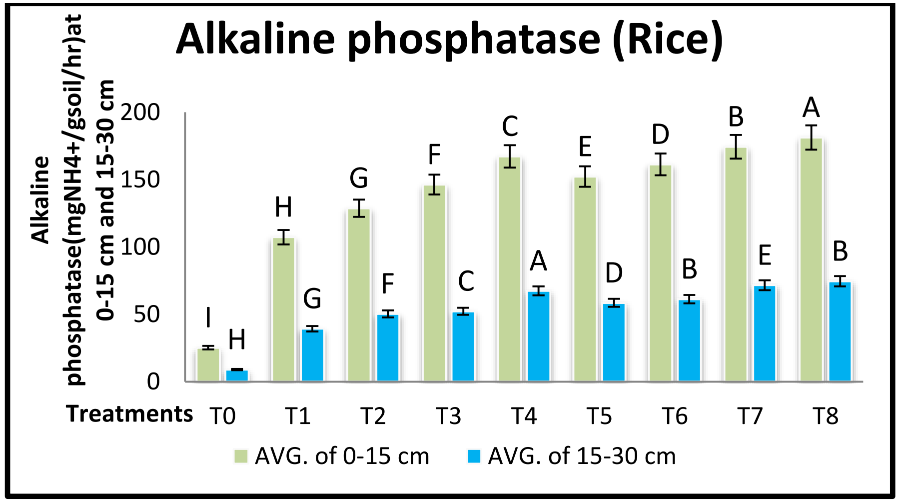
4.3.3a

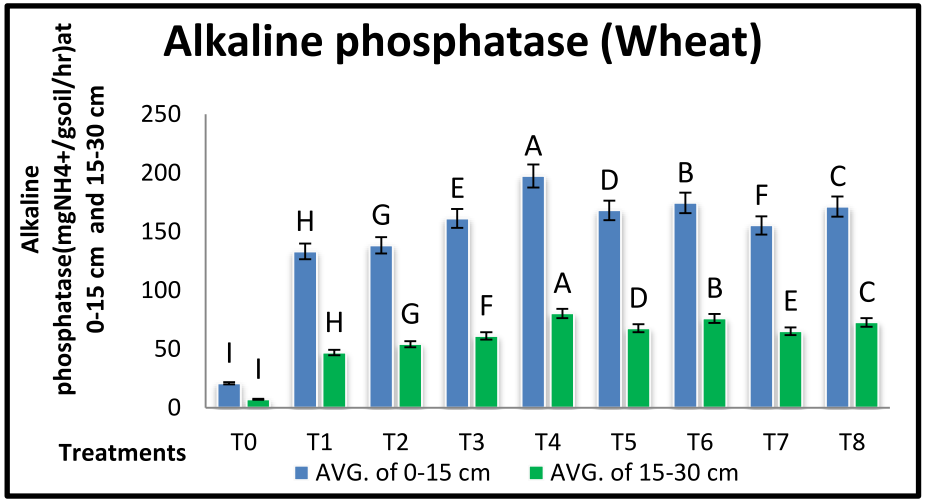




4.3.3.b

4.3.4.a

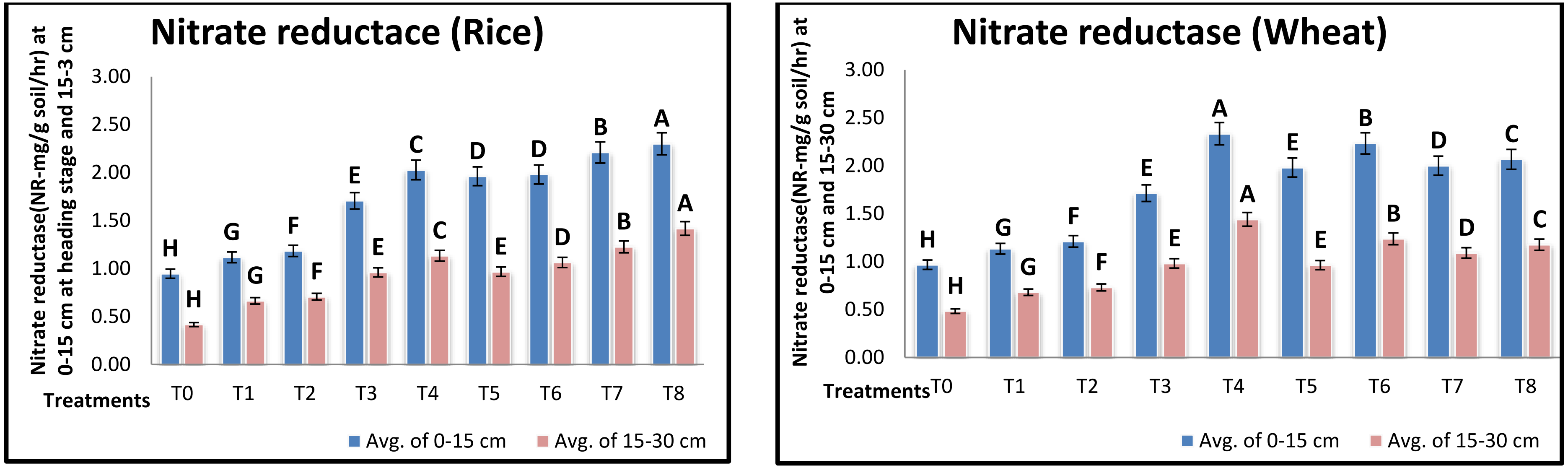




4.3.4b

Fig. 4.3.3, 4.3.4(a,b) indicating acid and alkaline phosphatase activities in rice wheat crop at heading stage from different depths during 2018-2019& 2019-2020. Different synbols above the standard bars indicate the treatments are statistically different from each other according to DMRt($p<0.05$)

4.3.5 Nitrate reductase: Nitrate reductase activity in soil varied significantly due to different treatments table 4.3.3.All the treatments of Biochar combined with fertilizers and manures registered significantly increase in nitrate reductase activity in soil. The effect of rice straw Biochar amendment at different depths on soil nitrate reductase activity presented in Fig. 4.3.35(a). Soil nitrate reductase showed similar trend in activity as earlier presented in urease, dehydrogenase, acid phosphatase and alkaline phosphatase. Nitrate reductase activity was significantly highest in T8 across the determined soil depth (0-15 cm) and 15-30 cm (2.3 and 1.42NR mg g^{-1} soil h^{-1}) respectively. This enzyme showed a declining trend with increasing soil depth. The lowest enzyme activities (0.95, 0.42 mg g^{-1} soil h^{-1}) were recorded with control. All the treatments were significantly more nitrate reductase activity as compared to control. The treatments T7,T6,T5,T4,T3,T2 ,T1 having nitrate reductase activity-2.21,1.98,1.96,2.03,.71,1.18,1.12 mg g^{-1} soil h^{-1}in 15-30 cm soil. In following wheat crop, the NR activity ranged from 0.97-2.33 mg g^{-1} soil h^{-1} in (0-15 cm) and 0.48 to 1.44 mg g^{-1} soil h^{-1} in 15-30 cm soil layer.NR activity in wheat soil at heading stage in 0-15 cm and 15-30 cm presented in table 4.3.3(b) and Fig. 4.3.5(b). The nitrate reductase highest activity recorded by application of 50% RDF+50% FYM+ Biochar (T4)-2.33 mg g^{-1} soil h^{-1}in 0-15 cm and 1.44 mg g^{-1} soil h^{-1}in 1-30 cm layer. The treatment T4 was followed by T6 having 2.23 and 1.24 mg g^{-1} soil h^{-1}NR activity. The other treatment T7, T8, T5, T3, T2 andT1 showed superiority in case of NR activity as compared to control. The lowest NR activity (0.97 and 0.48 mg g^{-1} soil h^{-1}) recorded with control which was followed by T1 with 1.13 and 0.68 mg g^{-1} soil h^{-1}. All the treatments were statistically significant among themselves. The order of NR activity in wheat was T4>T6>T8>T7>T5>T3>T2>T1>T0. The variation and data of nitrate reductase activity was presented in table 4.3.3(b) and Fig. 4.3.5(b).



4.3.5a

4.3.5b

Fig. 4.3.5(a,b) indicating nitrate reductase activities in rice- wheat crop at heading stage from different depths during 2018-2019& 2019-2020. Different symbols above the standard bars indicate the treatments are statistically different from each other according to DMRt($p<0.05$)

Table4.3.3(a) Impact of biochar based amendments on acid phosphatase, alkaline phosphatase activity and nitrate reductase activity at different depths from rice crop at heading stage during 2018-2019

	Acid phosphatase (µg PNPhr^{-1}g $^{-1}$soil)		Alkalinephosphatase(mgNH4^{+} g^{-1} soil hr^{-1})		Nitrate reductase(NR-mg g^{-1} soil hr^{-1})	
Treatments	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
T0- Control (no fertilizer)	12.21 ±0.09H	4.12±0.03H	25.17 ±0.90I	8.90 ±0.22H	0.95 ±0.01H	0.42±0.01H
T1-100%RDF	81.40 ±0.51G	20.38 ±0.59G	107.30 ±0.86H	39.27 ±0.85G	1.12 ±0.01G	0.66 ±0.01G
T2- 50%RDF + Biochar	98.40 ±0.82G	21.53 ±0.95G	128.77 ±1.43G	50.30±0.78F	1.18 ±0.01F	0.71 ±0.00F
T3-50%RDF+25%FYM+Biochar	129.56±0.50D	55.17 ±0.82D	146.30 ±0.90F	52.27±1.59C	1.71 ±0.01E	0.96 ±0.01E
T4-50%RDF+50%FYM+Biochar	134.23±0.82C	57.93 ±0.50C	167.23 ±0.70C	67.36±0.95A	2.03 ±0.02C	1.13 ±0.01C
T5-50%RDF+ 25%Vermi-compost + Biochar	121.33±0.74F	47.27 ±0.70F	152.20 ±0.59E	58.45 ±1.01D	1.96 ±0.02D	0.97 ±0.02E
T6-50%RDF+ 50%Vermi compost+ Biochar	126.90 ±1.15E	50.27 ±0.74E	161.30 ±0.86D	61.28 ±0.80B	1.98 ±0.01D	1.06 ±0.01D
T7-50%RDF+ 25%poultry manure+ Biochar	147.47 ±0.82B	64.39 ±0.86B	174.37 ±0.85B	71.56 ±0.74E	2.21 ±0.01B	1.23 ±0.01B
T8-50%RDF+50% poultry manure+ Biochar	197.33 ±0.50A	75.27 ±0.85A	181.33 ±0.94A	74.56 ±0.66B	2.30 ±0.01A	1.42 ±0.01A

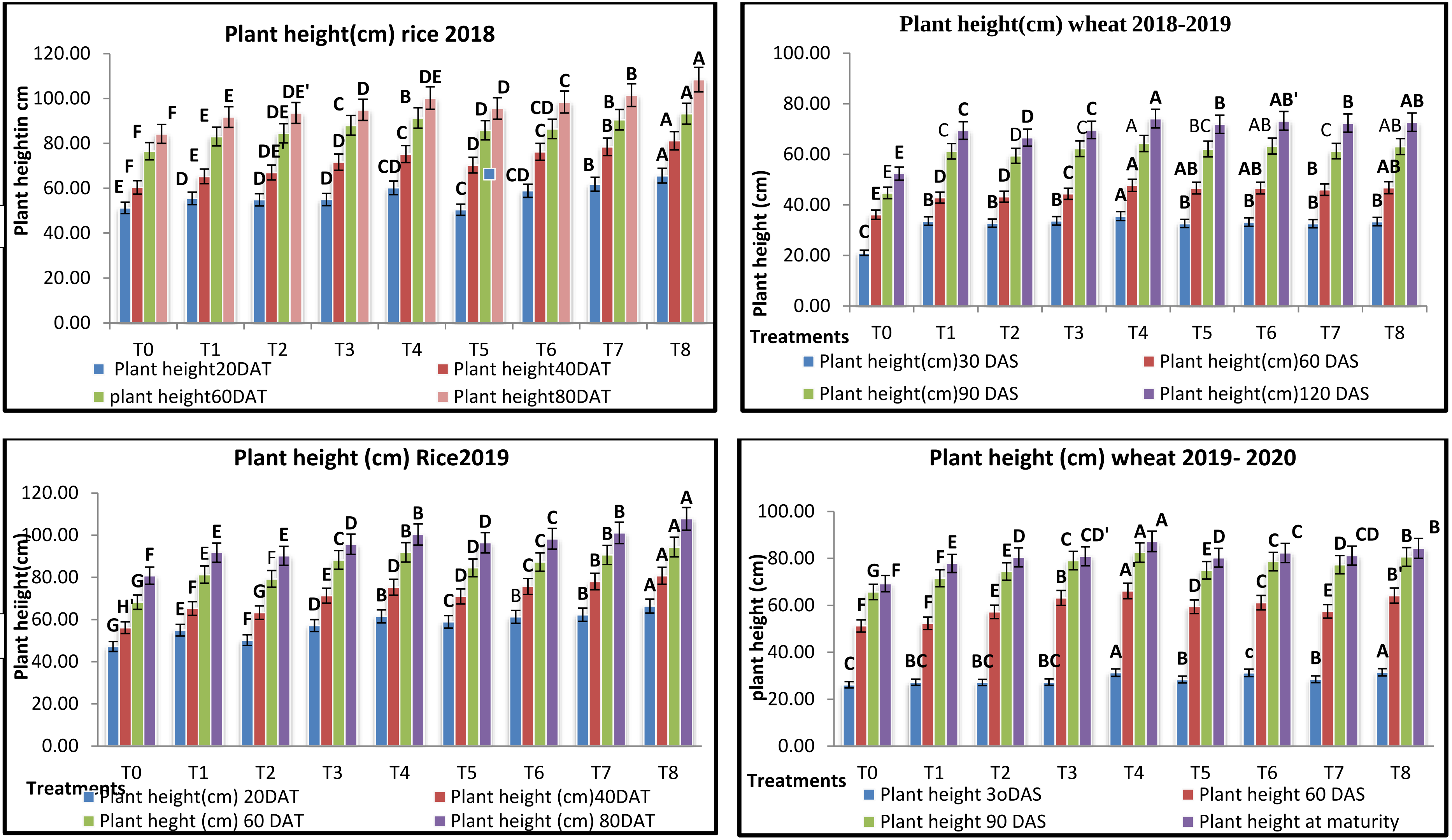
Table 4.3.3(b) Impact of biochar based amendments on acid phosphatase, alkaline phosphatase activity and nitrate reductase activity at different depths from wheat crop at heading stage during 2018-2019 & 2019-2020.

Treatments	Acid phosphatase (µg PNPhr^{-1}g $^{-1}$soil)		Alkalinephosphatase(mgNH4^{+}g^{-1} soil hr^{-1})		Nitrate reductase(NR-mg g $^{-1}$soil hr^{-1})	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
T0- Control (no fertilizer)	17.4±0.83I	4.9 ±0.04I	20.9 ±0.33I	7.2 ±0.08I	0.97 ±0.01H	0.48 ±0.04H
T1-100%RDF	88.5±0.86G	39.4±0.75H	133.2 ±0.86H	47.0±0.54H	1.13 ±0.01G	0.68 ±0.01G
T2- 50%RDF + Biochar	103.6±1.18H	47.5 ±0.71G	138.4 ±0.98G	54.2±0.83G	1.21 ±0.01F	0.73 ±0.01F
T3- 50%RDF+25%FYM+Biochar	135.2±0.82E	58.2 ±0.82F	161.3 ±0.86E	61.3 ±0.92F	1.71 ±0.02E	0.98 ±0.01E
T4- 50%RDF+50%FYM+Biochar	152.3 ±1.59A	72.4 ±0.85A	197.4 ±0.83A	80.4±0.86A	2.33 ±0.01A	1.44 ±0.01A
T5-50%RDF+ 25%Vermi-compost + Biochar	128.5 ±0.87D	54.9 ±0.45D	168.2 ±1.20D	67.8±1.13D	1.98 ±0.01E	0.96 ±0.02E
T6-50%RDF+ 50%Vermi compost+ Biochar	147.3 ±0.94B	63.8 ±0.52B	174.5 ±0.73B	76.2±0.30B	2.23 ±0.01B	1.24 ±0.01B
T7-50%RDF+ 25%poultry manure+ Biochar	124.5 ±0.76F	51.4 ±0.63E	155.3 ±0.84F	65.2±0.86E	2.00 ±0.01D	1.09 ±0.01D
T8-50%RDF+50% poultry manure+ Biochar	141.4 ±0.94C	61.7 ±0.40C	171.4 ±0.70C	72.7±1.06C	2.07 ±0.01C	1.18 ±0.02C

4.4.1 Plant height (cm): Plant height is an important parameter which can be used to study the effect of different treatments on crop growth. The data on periodic plant height of rice crop recorded at 20, 40, 60 and 80 DAT as presented in table 4.4.1 and Fig. 4.4.1(a) and 4.4.1(b) and the analysis of variance showed the mean over the different treatments also presented in Fig. and table. Rice plants attain their maximum plant height during early crop growth period and a slow rate of increase in plant height was registered during the period of study. In 2018-2019, all the treatments at 20, 40, 60 and 80DAT significantly increased plant height of rice over control. T8 (50%RDF+50%PM+Biochar) was recorded highest plant height (65.63, 81.2, 92.23, 108.43 cm) at 20, 40, 60 and 80 DAT (Days after transplanting). The second highest plant height recorded in T7 by application of (50%RDF+25%PM+Biochar)-61.79, 78.47, 90.53, 101.5 cm).All the other treatments were significant among themselves. The lowest plant height (51.3, 60.3, 76.55, 84.23 cm) recorded at 20, 40, 60 and 80DAT respectively. During consecutive wheat season the plant height recorded at 30, 60, 90 and 120 DAS (days after sowing). The plant height ranged from 52 cm to 74.13 cm at maturity time. The highest plant height (35.6, 47.7, 64.3, 74.13 cm) recorded by application of 50% RDF+50% FYM +Biochar(T4) which was immediately followed by T6 having plant height 32.67, 46.63, 62.10, 71.9 cm. All other treatments were statistically significant among themselves and superior over control at all intervals. The lowest plant height (2.03, 36.13, 44.73, 52.4 cm) recorded under T0 showed in table 4.4.1(b) and Fig. 4.4.1(c), 4.4.1(d) at 30, 60, 90 and 120 DAS. In 2019-20 rice plant height ranged from 80.8 to 107.7 cm. All the treatments were statistically significant from each other in case of plant height. T8 (50%RDF+50%PM+Biochar) recorded highest plant height 966.3, 80.77, 94.4 and 107.7 cm) at 20, 40, 60 and 80 DAT which was followed by T7 having (62.27, 78.03, 90.67 and 101.10 cm) plant height at all intervals. The data of plant height recorded at four intervals presented in table 4.4.1(a) T0 recorded the lowest plant height (47.23, 56.10, 68.2 and 80.8 cm). The order of maximum plant height during both years at both intervals was T8>T7>T4>T6>T5>T3>T2>T1>T0.In following wheat season all the treatments were significantly better than control in case of plant height at all intervals. The highest plant height(31.3,66.17,82.5,87.3 cm) was recorded with the application of (50%RDF+50%FYM+Biochar)T4which was immediately followed by T8(50%RDF+50%PM+Biochar) having plant height 31.47, 64.17 , 80.65,84.3 cm. Minimum plant height 26.17,51.23,65.73,69.27 cm recorded with control. The order of plant height in wheat was T4>T8>T6>T7>T5>T3>T2>T1>T0.The data presented in Fig. 4.4.1 (d).

4.4.1a,b

4.4.1 c,d



Plant height(cm) rice 2018

Plant height(cm) wheat 2018-2019

Plant height (cm) Rice2019

Plant height (cm) wheat 2019- 2020

Fig.4.4.1(a,b,c&d) depicted the plant height of rice and wheat during 2018-2019& 2019-2020 at different intervals.The similar letters above the standard bars indicate that treatments are non significant according to DMRT($p<0.05$).

Table 4.4.1(a) Effect of biochar combined fertilizers on plant height (cm)(mean± S.E) of rice at (20,40,60& 80 DAT) during 2018-2019.

Treatments	2018				2019			
	20DAT	40DAT	60DAT	80DAT	20DAT	40DAT	60DAT	80DAT
T0- Control (no fertilizer)	51.30± 0.78 E	60.33 ±0.74F	76.55 ±0.18 F	84.23 ±0.90F	47.23±0.82G	56.10 ± 0.62H	0.62 ± 0.86G	80.80 ± 0.45F
T1-100%RDF	55.47 ±0.09 D	65.27 ±0.86E	83.03 ±1.11E	91.73 ±0.16E	54.97±0.70E	65.23± 0.90F	0.90 ± 0.82 E	91.70 ± 0.99 E
T2- 50%RDF + Biochar	54.88 ± 0.79 D	67.00±1.31DE	84.50±0.83DE	93.53±0.17DE	50.20±0.8F	63.30 ±0.37G	0.37 ± 0.78 F	90.23 ± 0.78 E
T3-50%RDF+25%FYM+ Biochar	54.99 ± 0.62 D	71.63 ±0.62D	88.03 ±1.40C	94.93 ±0.47 D	57.17±0.7D	71.33 ± 0.98E	0.98 ± 0.86 C	95.67 ± 0.41 D
T4-50%RDF+50%FYM+ Biochar	60.20 ± 0.78 CD	75.27 ±0.77C	91.34 ±0.69B	100.17±1.56DE	61.53±0.69B	75.33 ± 0.56D	0.56 ± 0.88 B	100.37 ± 0.70 B
T5-50%RDF+ 25%Vermi-compost + Biochar	50.43 ± 0.94 C	70.30 ±0.86D	85.80 ±1.16 D	95.57±0.61 D	58.87±0.33C	70.90 ± 0.50D	0.50 ± 1.28D	96.43 ± 0.65 D
T6-50%RDF+ 50%Vermi compost+ Biochar	58.87 ±0.52CD	76.23 ±0.78C	86.43±0.59CD	98.43 ±0.98 C	61.23±0.18B	75.63 ± 0.48C	0.48 ± 0.82 C	98.27 ± 0.87C
T7-50%RDF+ 25%poultry manure+ Biochar	61.79 ± 0.64B	78.47 ±0.94B	90.53 ±0.74B	101.50±2.12B	62.27±0.56B	78.03 ± 0.46B	0.46 ± 0.41B	101.10 ±1.23B
T8-50%RDF+50% poultry manure+ Biochar	65.63 ± 0.54 A	81.20 ±0.49A	93.23 ±0.78A	108.43±0.76A	66.30±0.7A	80.77 ± 0.45A	0.45 ± 0.62 A	107.77 ± 0.62A

Table 4.4.1(b) Effect of biochar combined fertilizers on plant height (cm)(mean± S.E) of wheat at (30,60,90& 1200 DAS) during 2018-19,2019-20

Treatments	2018				2019			
	30DAS	60DAS	90DAS	120DAS	30DAS	60DAS	90DAS	120DAS
T0- Control (no fertilizer)	21.03±0.56C	36.13±0.68E	44.73±0.68E	52.40±0.98E	26.17±0.74C	51.23± 0.90F	65.73± 0.54G	69.27± 0.78F
T1-100%RDF	33.57±0.49B	42.87±0.25D	61.20±0.25C	69.43±0.53C	27.23±0.62BC	52.33± 0.57F	71.57± 0.57F	77.90± 1.20E
T2- 50%RDF + Biochar	32.77±0.68B	43.30± 0.59D	59.43±0.59D	66.60±0.37D	27.13±0.41BC	57.27± 0.86E	74.40± 0.78E	80.43± 0.79D
T3-50%RDF+25%FYM+Biochar	33.70±0.62B	44.43± 0.50C	62.23±0.50C	69.67±0.41C	27.30±0.70BC	63.17± 0.74B	79.10± 0.50C	80.90±0.86CD
T4-50%RDF+50%FYM+Biochar	35.60±0.54A	47.77±0.29A	64.33±0.29A	74.13±0.78A	31.30±0.54A	66.17± 0.82A	82.50± 0.54A	87.30± 0.62A
T5-50%RDF+ 25%Vermi-compost + Biochar	32.67±0.49B	46.63±0.41AB	62.10±0.41BC	71.90±0.51B	28.37±0.61B	59.40± 0.75D	74.93± 0.37E	80.30± 0.70D
T6-50%RDF+ 50%Vermi compost+ Biochar	33.23±0.29B	46.63±0.54AB	63.27±0.54AB	73.27±0.65AB	31.23±0.73C	61.17± 0.94C	78.67± 0.84C	82.33± 0.69C
T7-50%RDF+ 25%poultry manure+ Biochar	32.60± 0.54B	46.03± 0.70B	61.27±0.70C	72.37±0.87B	28.53±0.97B	57.40± 0.98E	77.33± 0.70D	81.20±0.73CD
T8-50%RDF+50% poultry manure+ Biochar	33.40± 0.51B	46.80±0.45AB	63.07±0.45AB	72.77±0.29AB	31.47±0.90A	64.17± 0.53B	80.63± 0.40B	84.30± 0.83B

4.4.2 Total tillers: Total tillers per plant are an important parameter for finding the effect of any treatment on growth and yield of a crop. The mean data of tillers were computed at 20, 40, 60DAT is presented in table 4.4.2(a) and Fig. 4.4.2(a). The highest number of tillers per plant produced by the application of 50%RDF+50%PM+Biochar- T8 (7.5, 12.3, 15.57). T8 treatment was followed by T7- 50%RDF+25%PM+Biochar having 7.31, 11.8, 14.77 tillers per plant at 20, 40 and 60 DAT. All the treatments showed significant effect on the number of tillers. The minimum number of tillers per plant recorded with control (T0) having 4.07, 7.87, 8.7 tillers at all intervals. In consecutive wheat crop, total tillers were significantly better as compared to control. All the Biochar amended plots increase the number of tillers m^{-2} (454) by the application of (50%RDF+50%FYM+Biochar) T4. The treatments T8, T7,T6, T5, T3 were at par with each other and showed non-significant difference among themselves. The lowest number of tillers m^{-2} was recorded with control (213). During the second year crop cycle different treatments were at par in total number of tillers in rice. In second year also the same trend followed in the number of tillers by T8 (8.3, 13, 15.3) followed by T7 and minimum recorded in control (4.3, 75, 8.8). The tiller number trend in rice at all intervals T8>T7>T6>T5>T4>T3>T2>T1>T0.In consecutive wheat crop the treatments were significantly different from each other. The maximum total tillers (457.3) recorded with T4 followed by T3 (450.3) and T7 (450). The order of maximum total tillers were T4>T3>T7>T8>T8>T5>T2>T1>T0.The data of total tillers m-^{2} in wheat presented in Fig. 4.4.2(c, d) and table 4.4.2(b).

4.4.3 Effective tillers: All the treatments except control produced significant effective tillers /plant. In 2018-2019 highest number of effective tillers were recorded with the application of (50%RDF+50%PM+Biochar) T8 which was at par with T7 (13.03). These treatments were followed by T6 (11.93). All the treatments were significantly better than control in case of effective tillers. The lowest effective tillers were recorded with T0 (control). In following wheat crop, the effective tillers m^{-2} recorded. All the Biochar amended plots resulted more number of effective tillers as compared to unamended plots. Maximum effective tillers m^{-2} (432) recorded by the application of (50%RDF+50%FYM+Biochar) T4 which was followed by the application of (50%RDF+50%PM+Biochar) T8 having 426 effective tillers. T8 treatment was at par with T7 (421) effective tillers m^{-2}.The minimum effective tillers m^{-2} (198.67) recorded in T0.In 2019-2020, effective tillers plant^{-1} in rice ranged from 5-7-14. All the treatments were superior to unamended plots. The maximum productive tillers (14) were resulted with the application of (50%RDF+50%PM+Biochar) T4, T7, T6, T5 resulted 12.6, 12.1,11.8 productive tillers , these treatments were at par with each other and statistically non- significant. The lowest productive tillers (5.7) were resulted with T0 (control). The data presented in table 4.4.2 and Fig. 4.4.2(a). The order of productive tillers in rice was T8>T7>T4>T6>T5>T3>T2>T1>T0. In following wheat crop different treatments differ significantly among themselves. The effective tillers ranged from 206-432. The highest tillers were obtained with T4 (432) which was followed by T7 and T8 having 426,425 tillers m-^{2} .All the treatments were significantly better than control. Control produced lowest effective tillers m-^{2}(206.33). The data of effective tillers m-^{2} was presented in table and Fig. 4.4.2(b).

4.4.2 a,b

4.4.2c,d

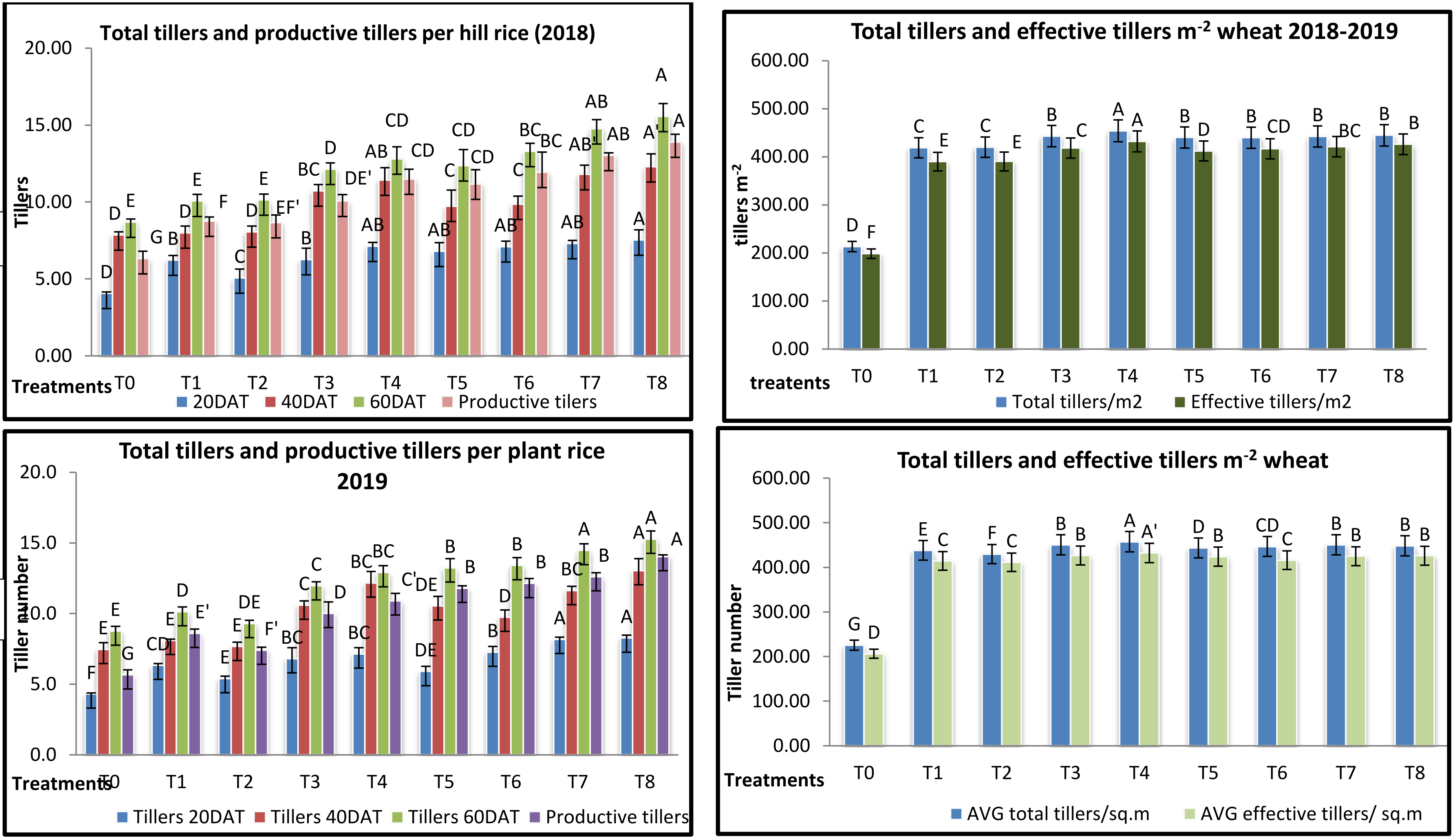


Fig. 4.4.2A&B ,C&D representing total and effective tillers in rice and wheat crop during 2018-2019&2019-2020 .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.4.2(a) Effect of different biochar based amendments on numbet of tillers and effective tillers (mean± S.E) of rice crop at different intervals during 2018-2019

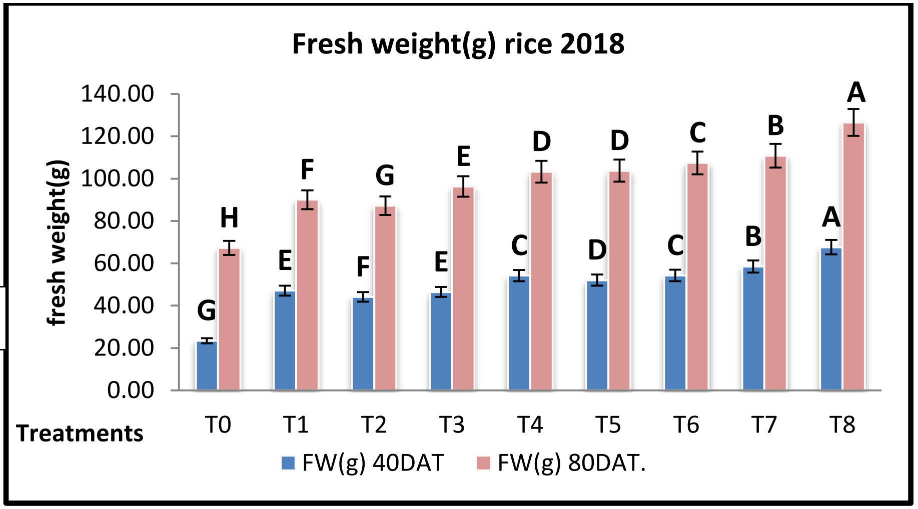
Treatments	2018				2019			
	20DAT	40DAT	60DAT	Productive tillers	20DAT	40DAT	60DAT	Productive tillers
T0- Control (no fertilizer)	4.07± 0.09D	7.87± 0.19D	8.70 ±0.77E	6.33 ±0.47G	4.3 ±0.08F	7.5 ±0.46E	8.8±0.33E	5.7 ±0.34G
T1-100%RDF	6.23± 0.29B	8.00 ±0.43D	10.07±0.6E	8.77 ±0.25F	6.3±0.12CD	8.1± 0.08E	10.1 ±0.34D	8.6 ±0.29E
T2- 50%RDF + Biochar	5.07± 0.57C	8.07 ±0.38D	10.13 ±0.57E	8.67 ±0.49EF	5.4 ±0.16E	7.7 ±0.31E	9.3 ±0.22DE	7.4 ±0.22F
T3-50%RDF+25%FYM+Biochar	6.27± 0.74B	10.73±0.41BC	12.13 ±0.52D	10.07±0.42DE	6.8 ±0.78BC	10.6±0.29C	12.0 ±0.29C	10.0 ±0.82D
T4-50%RDF+50%FYM+ Biochar	7.13± 0.25AB	11.43±0.79AB	12.80±0.93CD	11.50±0.64CD	7.1 ±0.45BC	12.2±0.82BC	12.9 ±0.50BC	10.9 ±0.54C
T5-50%RDF+ 25%Vermi-compost + Biochar	6.80± 0.57AB	9.73 ±1.05C	12.37±1.22CD	11.17±0.94CD	5.9 ±0.36DE	10.5±0.68DE	13.2 ±0.65B	11.8 ±0.18B
T6-50%RDF+ 50%Vermi compost+ Biochar	7.10± 0.36AB	9.87 ±0.52C	13.30±0.21BC	11.93±1.31BC	7.3 ±0.41B	9.7 ±0.52D	13.4 ±0.57B	12.1 ±0.34B
T7-50%RDF+ 25%poultry manure+ Biochar	7.31± 0.21AB	11.80±0.59AB	14.77±0.39AB	13.03±0.17AB	8.2 ±0.16A	11.6±0.29BC	14.5 ±0.46A	12.6 ±0.29B
T8-50%RDF+50% poultry manure+ Biochar	7.53± 0.66A	12.30 ±0.83A	15.57 ±0.70A	13.90 ±0.51A	8.3 ±0.21A	13.0 ±0.86A	15.3 ±0.57A	14.0 ±0.12A

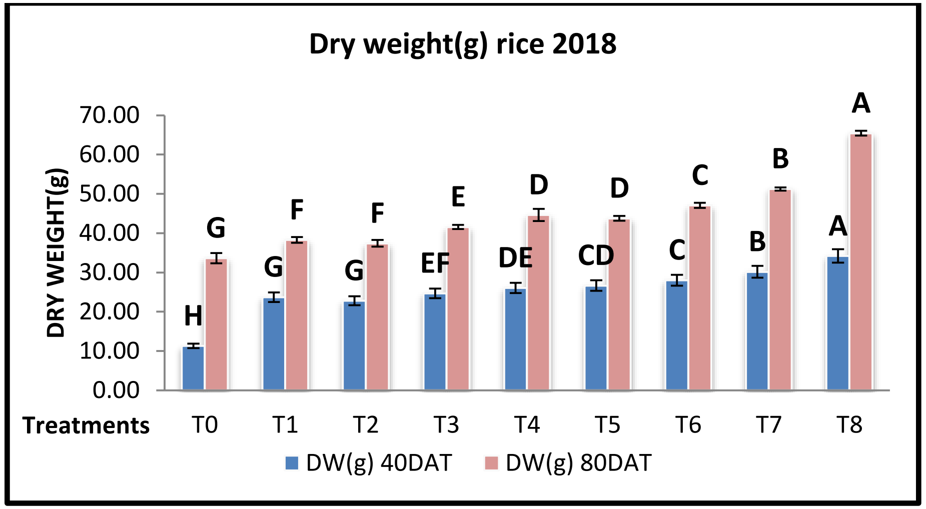
Table 4.4.2(b) Effect of different biochar based amendments total tillers and effective tillers (mean± S.E) of wheat crop during 2018-2019& 2019-2020.

Treatments	2018		2019	
	Total tillers m^{-2}	Effective tillers m^{-2}	Total tillers m^{-2}	Effective tillers m^{-2}
T0- Control (no fertilizer)	213.33±8.06D	198.67±2.49F	225.33±2.05G	206.33±2.05D
T1-100%RDF	418.67±8.06C	390.00±1.63E	438.00±1.63E	414.33±2.62C
T2- 50%RDF + Biochar	420.00±1.63C	390.33±3.30E	429.67±1.25F	411.33±3.30C
T3-50%RDF+25%FYM+Biochar	443.00±2.45B	418.00±1.63C	450.33±1.25B	426.67±2.05B
T4-50%RDF+50%FYM+Biochar	454.00±1.63A	432.00±1.63A	457.33±1.70A	432.33±2.87A
T5-50%RDF+ 25%Vermi-compost + Biochar	440.00±1.63B	412.00±1.63D	443.67±1.25D	424.00±2.16B
T6-50%RDF+ 50%Vermi compost+ Biochar	439.67±1.25B	416.67±4.03CD	446.67±2.05CD	416.00±1.63C
T7-50%RDF+ 25%poultry manure+ Biochar	442.33±1.25B	421.00±2.94BC	450.67±1.25B	425.00±1.63B
T8-50%RDF+50% poultry manure+ Biochar	444.67±2.05B	426.00±1.63B	448.33±1.70B	426.00±1.63B

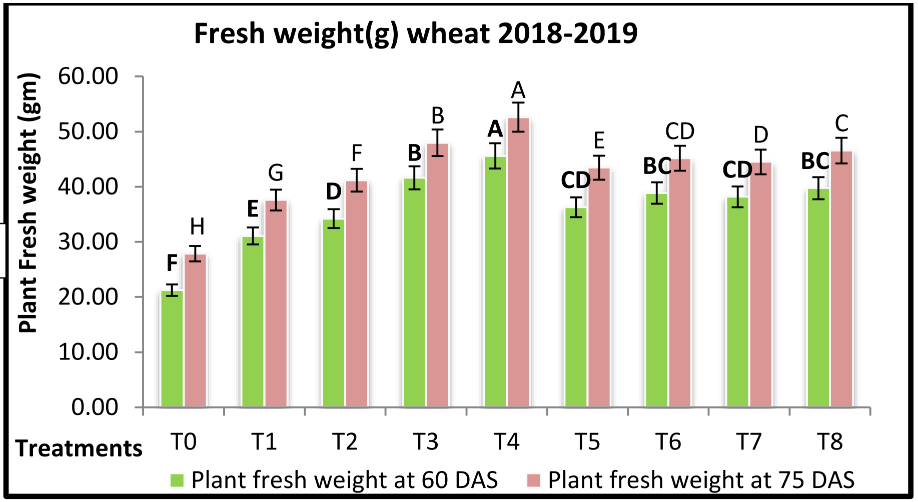
4.4.4 Fresh weight and dry weight of plants: Fresh weight and dry weight (g) were measured in rice and wheat crop. In rice fresh weight and dry weight (g) of plants was measured at 40 DAT and 80 DAT. These weights were measured to calculate the dry matter accumulation which indicates towards the photosynthesis left behind after respiration. So, it is a best indicator of growth of crop. In 2018-2019 rice crops all the treatments were significantly affected by the Biochar based amendments. The maximum fresh and dry weight (67.63, 34.17g) was obtained with the application of 50% RDF+50%PM+ Biochar (T8) at 40 DAT and 126.53 and 65.43g at 40 DAT. and 80 DAT. T8 was followed by T7 having fresh and dry weight at 40 and 80 DAT- 8.5,30.17gand 110.53,51.27g respectively. The lowest fresh weight (23.47, 67.30g) at 40 and 80 DAT were recorded in T0 and similarly dry weight 11.3, 33.63 g recorded in T0. All treatments were statistically significant. In following wheat crop the fresh weight and dry weight of crop recorded at 60 and 75 DAS. All the Biochar amended plots showed more fresh weight and dry weight. All the treatments were statistically significantly different from each other. The highest fresh weight and dry weight(45.5,822.4 g) of crop recorded with T4 at 60 DAS and 52.6 and 35.5 g at 75 DAS.T4 was immediately followed by T3 with(41.62,19.4 g) at 60 DAS and (47.97,29.1g) at 75 DAS. The data of fresh and dry weight of wheat at 60 DAS, 75 DAS presented in table 4.4.4(b), Fig. 4.4.4 (b). In 2019-2020 rice crop fresh weight of plant ranged from 26.23-69.93 g at 40 DAT and 71.57 to 138 g at 80 DAT. Dry weight of crop varied from 13.37-34.33 g at 40 DAT and 33.43- 64.43 g at 80 DAT. Maximum fresh weight and dry weight recorded at 40 DAT and 80 DAT with T8(69.93,34.3, and 138.37, 64.43 g)The minimum fresh weight and dry weight 26.23,13.37 and 71.57 and 33.43 g respectively at 40 and 80 DAT recorded with control. The data presented in table 4.4.4 (a) and Fig. 4.4.3(a). In following wheat crop as previous year maximum fresh weight and dry weight recorded with T4 (46.7, 22.6, 55.4, 35.3 g) and minimum with 21.47, 10.5, 26.37 and 14 g with control. The data presented in table 4.4.3(c) and Fig. 4.4.4(d). All the treatments were statistically significantly different from control.

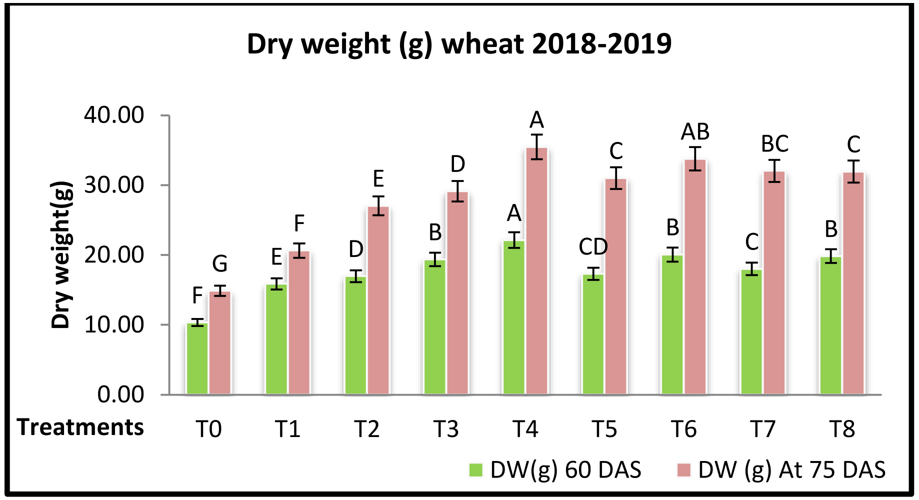
4.4.4a,b


Fresh weight(g) rice 2018
fresh weight(g)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Treatments
T0
T1
T2
T3
T4
T5
T6
T7
T8
G
H
E
F
F
G
E
E
C
D
D
D
C
C
B
B
A
A
FW(g) 40DAT
FW(g) 80DAT.

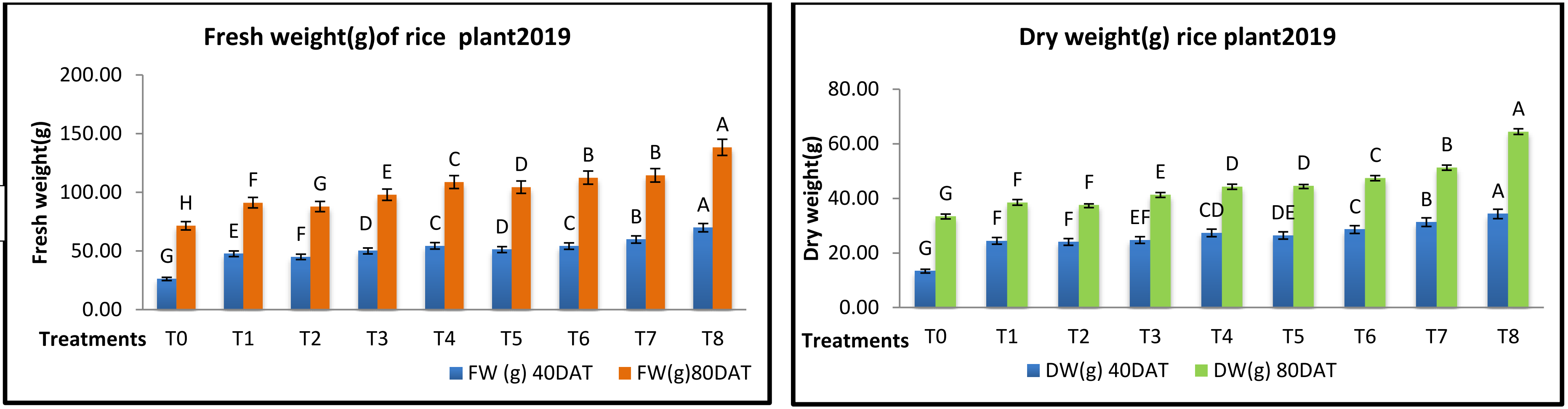

Dry weight(g) rice 2018
DRY WEIGHT(g)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Treatments
T0
T1
T2
T3
T4
T5
T6
T7
T8
H
G
G
F
G
F
EF
E
DE
D
CD
D
C
C
B
B
A
A
DW(g) 40DAT
DW(g) 80DAT

4.4.4c,d


Fresh weight(g) wheat 2018-2019
Plant Fresh weight (gm)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Treatments
T0
T1
T2
T3
T4
T5
T6
T7
T8
F
H
E
G
D
F
B
B
A
A
CD
E
BC
CD
CD
D
BC
C
Plant fresh weight at 60 DAS
Plant fresh weight at 75 DAS


Dry weight (g) wheat 2018-2019
Dry weight(g)
40.00
30.00
20.00
10.00
0.00
Treatments
T0
T1
T2
T3
T4
T5
T6
T7
T8
F
G
E
F
D
E
B
D
A
A
CD
C
B
AB
C
BC
B
C
DW(g) 60 DAS
DW (g) At 75 DAS

4.4.4f,g



4.4.4h,i

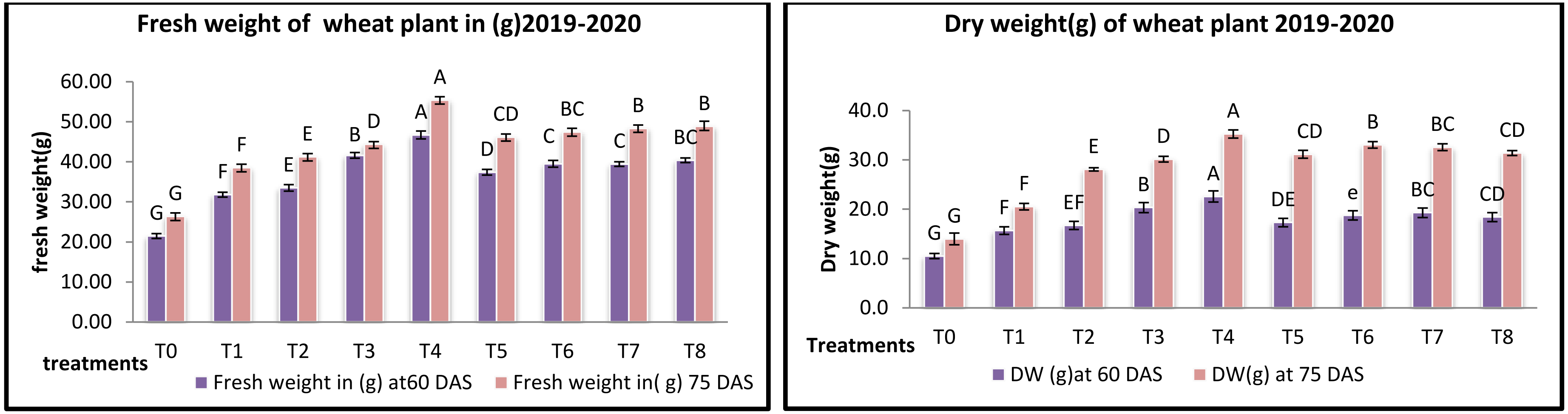


Fig.4.4.3 a,b ,f& grepresenting the fresh weight(g) at different intervals and Fig. 4.4.3 c,d,,h&I representing dry weight (g) of rice and wheat crop .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at p<0.05.

Table 4.4.4(a) Effect of different biochar combinations with manures and fertilizerson fresh and dry weight of plants at 40,80 DAT in rice during 2018-2019.

Treatments	2018				2019			
	Fresh weight(g) 40DAT	Dry weight(g) 40 DAT	Fresh weight(g) 80DAT	Dry weight(g) 80DAT	Fresh weight(g) 40DAT	Dry weight(g) 40 DAT	Fresh weight(g) 80DAT	Dry weight(g) 80DAT
T0- Control (no fertilizer)	23.47±1.29G	11.30±0.82H	67.30±0.78H	33.63±1.27G	26.23±1.31G	13.37±0.79G	71.57±0.65H	33.43±0.86G
T1-100%RDF	47.13±0.90E	23.70±1.10G	90.03±0.70F	38.27±0.70F	47.60±0.91E	24.43±0.74F	91.23±0.86F	38.50±1.10F
T2- 50%RDF + Biochar	44.13±0.78F	22.80±0.57G	87.27±0.82G	37.40±0.86F	44.97±0.40F	24.03±1.28F	87.89±1.25F	37.57±0.41F
T3-50%RDF+25%FYM+Biochar	46.47±0.54E	24.70±0.54EF	96.27±0.63E	41.57±0.54E	50.17±1.02D	24.70±0.54EF	98.00±0.41E	41.37±0.77E
T4-50%RDF+50%FYM+Biochar	54.20±0.71C	26.07±0.69DE	103.30±0.91D	44.63±1.56D	54.37±0.98C	27.33±0.82CD	108.77±1.08C	44.33±0.84D
T5-50%RDF+ 25%Vermi-compost + Biochar	52.07±0.63D	26.67±0.54CD	103.77±1.07D	43.77±0.60D	51.27±0.82D	26.43±0.90DE	104.47±1.93D	44.63±0.46D
T6-50%RDF+ 50%Vermi compost+ Biochar	54.23±0.26C	28.03±0.49C	107.43±0.15C	47.07±0.66C	54.23±0.26C	28.60±0.70C	112.47±1.76B	47.43±0.87C
T7-50%RDF+ 25%poultry manure+ Biochar	58.50±1.28B	30.17±0.86B	110.83±0.53B	51.27±0.41B	59.83±1.32B	31.27±0.98B	114.63±1.65B	51.33±0.86B
T8-50%RDF+50% poultry manure+ Biochar	67.63±1.20A	34.17±0.82A	126.53±1.20A	65.43±0.63A	69.93±1.16A	34.33±0.61A	138.37±1.76A	64.43±1.06A

Table 4.4.4(b) Effect of different biochar combinations with manures and fertilizerson fresh and dry weight of plants at 60,75 DAS in wheat crop during 2018-2019& 2019-2020

	2018				2019			
Treatments	Fresh weight(g) 60DAS	Dry weight(g) 60 DAS	Fresh weight(g) 75DAS	Dry weight(g) 75DAS	Fresh weight(g) 60DAS	Dry weight(g) 60 DAS	Fresh weight(g) 75 DAS	Dry weight(g) 75DAS
T0- Control (no fertilizer)	21.24±0.82F	10.3±0.7F	27.87±0.33H	14.9±0.6G	21.47±0.62G	10.5 ±0.7G	26.37 ±0.90G	14.0 ±1.2G
T1-100%RDF	31.08±0.76E	15.9±0.2E	37.60±0.43G	20.6±0.5F	31.80±0.59F	15.7±0.4F	38.53 ±0.90F	20.5 ±0.7F
T2- 50%RDF + Biochar	34.20±0.33D	17.0±0.2D	41.17±0.74F	27.0±0.4E	33.50±0.82E	16.7±0.4EF	41.23 ±0.86E	28.1 ±0.3E
T3-50%RDF+25%FYM+Biochar	41.62±0.55B	19.4±0.3B	47.97±0.48B	29.1±0.7D	41.60±0.73B	20.3±0.7B	44.37 ±0.66D	30.1 ±0.6D
T4-50%RDF+50%FYM+Biochar	45.58±0.70A	22.1±0.6A	52.60±0.36A	35.5±0.7A	46.70±1.00A	22.6 ±0.6A	55.40 ±0.86A	35.3 ±0.8A
T5-50%RDF+ 25%Vermi-compost + Biochar	36.27±0.41CD	17.3±0.4CD	43.47±0.53E	31.0±1.2C	37.40±0.70D	17.3 ±0.8DE	46.17 ±0.82CD	31.1 ±0.8CD
T6-50%RDF+ 50%Vermi compost+ Biochar	38.83±0.37BC	20.1±0.4B	45.13±0.78CD	33.8±1.6AB	39.50±0.86C	18.7±0.5E	47.43 ±0.95BC	33.0 ±0.7B
T7-50%RDF+ 25%poultry manure+ Biochar	38.17±0.21CD	18.0±0.4C	44.50±0.71D	32.0±0.3BC	39.43 ±0.57C	19.3 ±0.6BC	48.33 ±0.8B	32.6 ±0.7BC
T8-50%RDF+50% poultry manure+ Biochar	39.73±0.39CD	19.8±0.2B	46.57±0.39C	31.9±0.57C	40.37±0.58BC	18.4 ±0.6CD	48.83 ±1.29B	31.4 ±0.49CD

4.4.5 Chlorophyll index: Data of table 4.4.5(a) showed the effect of different treatments on the chlorophyll index(SPAD) of rice and wheat crop at various growth periods. The result revealed that the chlorophyll indexof rice and wheat increased significantly and consistently with the integrated use of Biochar at various crop growth stages during 2018-19. However, in 2018 at 40DAT T8 recorded highest chlorophyll index (48.4 SPAD) which was followed byT7 having 46.47 chlorophyll content. At 80 DAT, highest chlorophyll index 56.5 recorded by T8 which was followed by T7 having 53.37chlorophyll index. During both intervals minimum chlorophyll index 938.43, 40.27 SPAD) recorded with control. In 2019, rice season all the treatments were significantly different in chlorophyll indexamong themselves at both intervals. T8 recorded maximum (48.77, 51.23 SPAD) chlorophyll indexwhich was significantly superior to all other treatments. The minimum chlorophyll indexrecorded with T0 (38.17, 40.23) at 40 and 80 DAT. The data of chlorophyll indexpresented in Fig. 4.4.5(a, b). The order of chlorophyll indexin rice was T8>T7>T4>T6>T3>T5>T1>T2>T0. In wheat crop chlorophyll recorded at 60 and 75 DAS. All the treatments which were Biochar amended showed more chlorophyll indexas compared to unamended plots. In 2018-2019 and 2019-2020 wheat crop at 60 DAS, the application of 50% RDF+50%FYM+Biochar-T4 recorded highest chlorophyll index(43.3, 44.4) which was significantly better than all other treatments. At 75 DAS also T4 recorded highest chlorophyll index(46, 47.4). The treatment T4 was followed by T5, T6, T7 and T8 . These treatments were non- significant among themselves and at par with each other. The minimum chlorophyll indexat 60 DAS (32.53, 32.63) and at 75 DAS (34.5, 36.27) recorded in control-T0. All the data presented in table 4.4.5(b) and Fig. 4.4.5(d).The order of chlorophyll indexin wheat crop at both intervals during both years was- T4>T8>T7>T6>T5>T3>T2>T1>T0.

4.4.5a,b

4.4.5 c,d

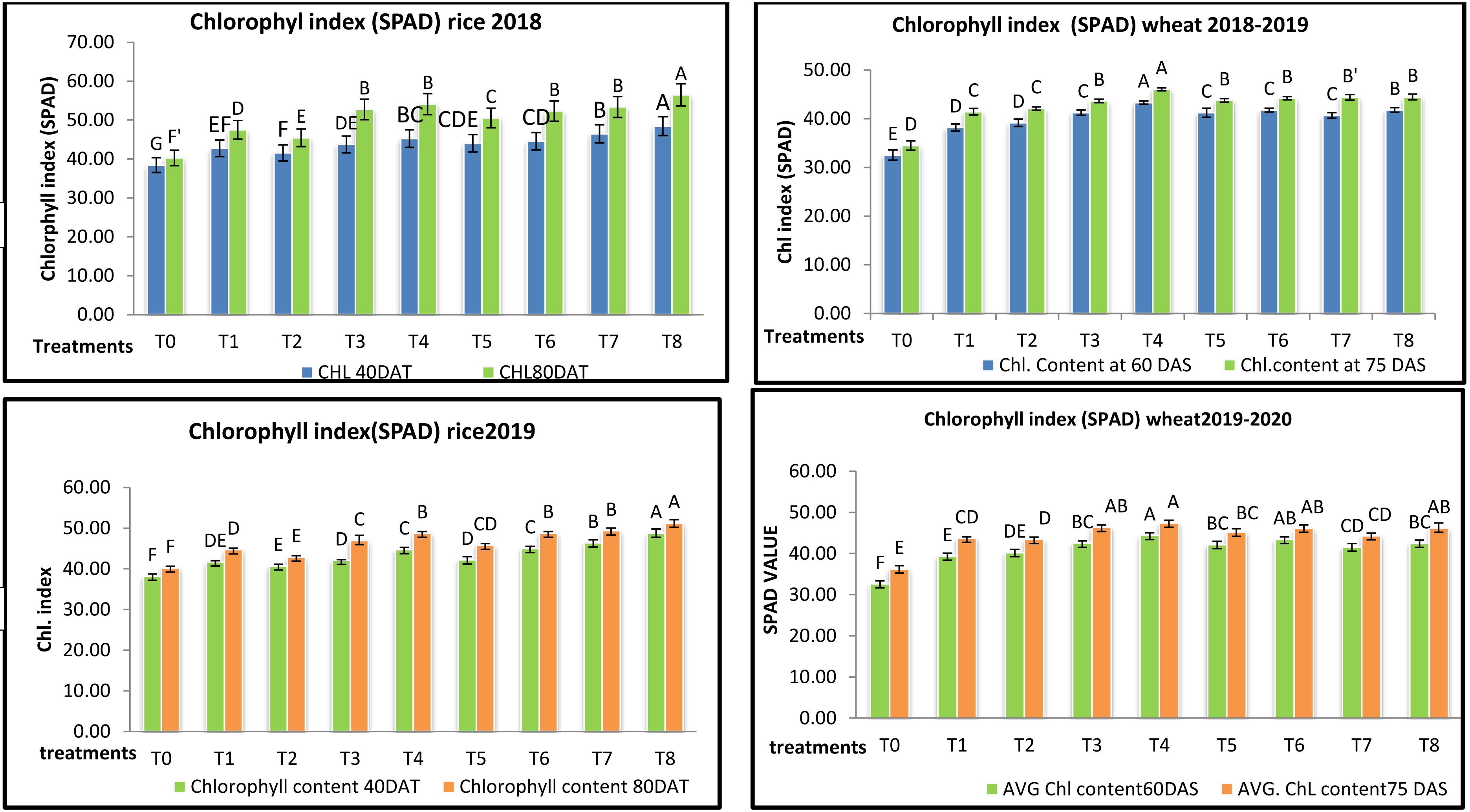


Fig. 4.4.5A&B,C&D representing the chlorophyll index(SPAD)at different intervals in rice and wheat crop during both years .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

4.4.6 Leaf area (cm^2): The leaf area determines the photosynthetic efficiency of crop. Data related to leaf area at various stages of crop growth were significantly affected by Biochar amended plots were presented in table 4.4.6(A) and depicted in Fig. 4.4.6(a). Similar to chlorophyll indexsignificantly highest leaf area was recorded by same treatments in wheat and rice crop. In rice crop during 2018 and 2019, leaf area was recorded at 40 DAT and 80DAT. During both years, in rice crop at 40 DAT maximum leaf area (66.27, 67.33 cm^2) was recorded with the application of 50% RDF+50% PM+Biochar-T8 and the same trend was followed at 80DAT with 77.97 and 78.23 cm^2 leaf area. T8 was followed by T7 with 65.8 cm^2 and 66.53 cm^2 leaf area at 40 DAT and 74.37, 73.57 cm^2 at 80 DAT. The minimum leaf area (57.5, 58.33, 65.13, 67.5 cm^2) at 40 and 80 DAT was recorded in T0 control. All the other treatments in case of leaf area in rice were significantly different from each other. The maximum leaf area order during both years at both intervals was: T8>T7>T6>T4 >T5>T3>T1>T2>T0.In following wheat crop during 2018-2019 and 2019-2020 leaf area recorded at 60 and 75 DAS. With regards to different Biochar based amendments significantly higher leaf area was recorded by T4 at all stages of crop however significantly lower leaf area was obtained by absolute control (T0). At 60 DAS during both years leaf area of wheat crop was (61.7, 60.27 cm^2) and at75 DAS (69.33, 71.53cm^2) were recorded by T4 which was followed by T6 with (58.3, 57.47 cm^2) LA at 60 DAS and 61.77, 68.27 cm2 at 75 DAS. The remaining treatments were significantly better than control and showed more leaf area. The data presented in table 4.4.6(b) and pertained in Fig. 4.4.6(b). The maximum leaf area order during both years at both intervals was T4>T6>T8>T3>T5>T7>T2>T1>T0.

4.4.6a,b

4.4.6c,d

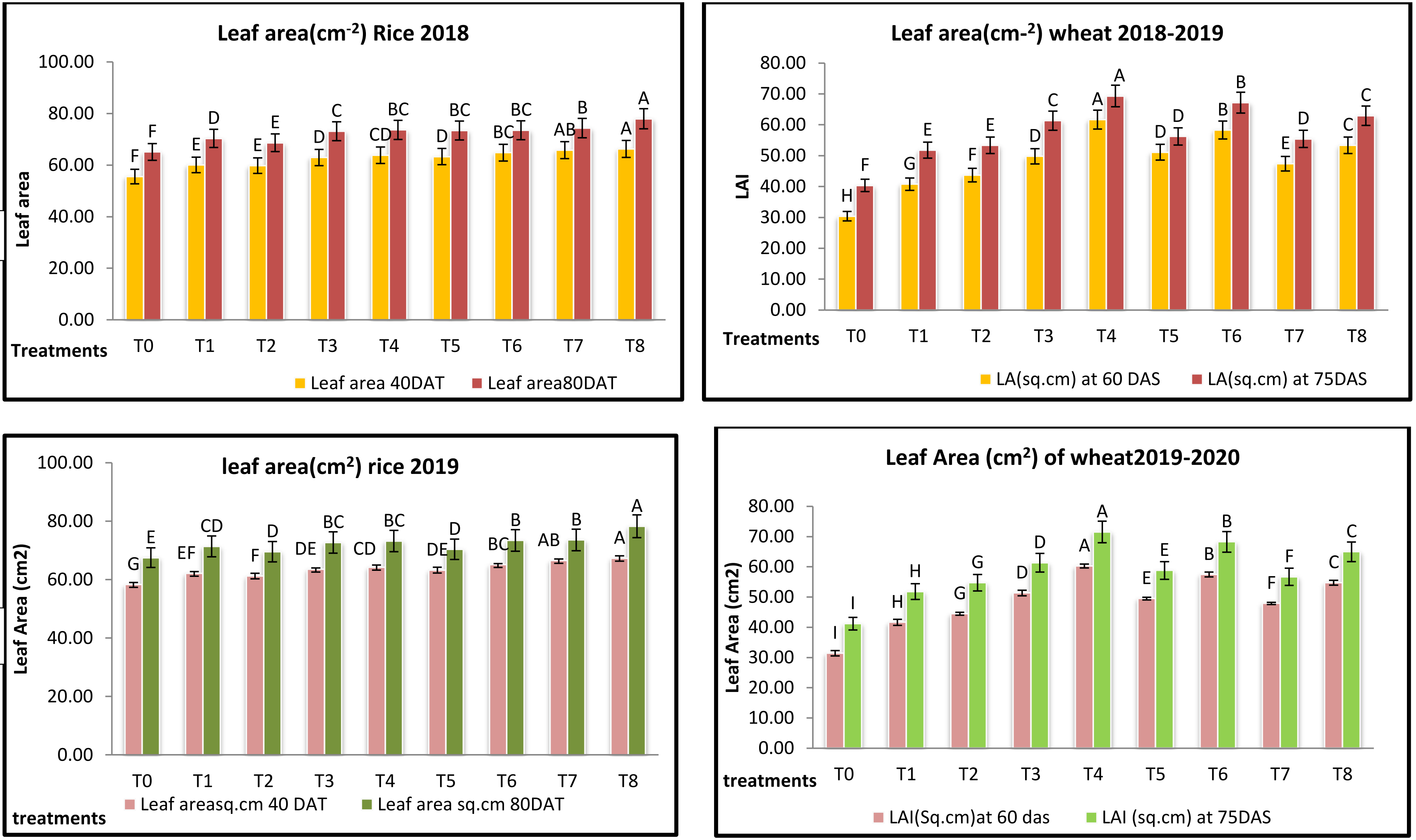


Fig. 4.4.6 A&B, C&D representing leaf area at different intervals in rice and wheat crop .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.4.6(a) Effect of biochar based amendments on chlorophyll index (SPAD) and leaf area(cm^2) of rice crop at 40,80 DAT during 2018-2019.

Treatments	2018				2019			
	Chlorophyll index (SPAD) 40DAT	Chlorophyll index (SPAD) 80DAT	Leaf area(cm^2) at 40 DAT	Leaf area(cm^2) at 80DAT	Chlorophyll index (SPAD) 40DAT	Chlorophyll index(SPAD) 80DAT	Leaf area(cm^2) at 40 DAT	Leaf area(cm^2) at 80DAT
T0- Control (no fertilizer)	38.43±0.87G	40.27±0.74F	55.57±1.21F	65.13±0.53F	38.17±0.54F	40.23±0.42F	58.33±0.66G	67.50±0.98E
T1-100%RDF	42.73±0.61EF	47.50±0.93D	60.07±0.42E	70.37±0.79D	41.70±0.29DE	44.70±0.37D	62.13±0.59EF	71.37±0.70CD
T2- 50%RDF + Biochar	41.57±1.02F	45.43±0.80E	59.80±0.37E	68.67±0.46E	40.70±0.45E	42.87±0.40E	61.23±0.94F	69.57±1.00D
T3-50%RDF+25%FYM+ Biochar	43.73±0.56cDE	52.73±1.15B	62.97±0.17D	73.13±0.26C	42.07±0.17D	46.93±1.29C	63.57±0.39DE	72.70±0.37BC
T4-50%RDF+50%FYM+ Biochar	45.27±0.98eBC	54.10±0.99B	63.87±0.17CD	73.67±0.34BC	44.73±0.54C	48.73±0.42B	64.23±0.71CD	73.20±0.73BC
T5-50%RDF+ 25%Vermi-compost + Biochar	44.05±0.18CDE	50.53±0.57C	63.30±0.54D	73.40±0.37BC	42.20±0.78D	45.77±0.45CD	63.27±0.98DE	70.37±0.79D
T6-50%RDF+ 50%Vermi compost+ Biochar	44.60±0.16CD	52.33±0.84B	64.83±0.17BC	73.53±0.47BC	45.00±0.51C	48.77±0.41B	65.13±0.39BC	73.40±0.59B
T7-50%RDF+ 25%poultry manure+ Biochar	46.47±0.31B	53.37±0.79B	65.80±0.22AB	74.37±0.66B	46.37±0.74B	49.33±0.69B	66.53±0.53AB	73.57±1.23B
T8-50%RDF+50% poultry manure+ Biochar	48.4±0.56A	56.50±0.08A	66.27±0.21A	77.97±0.45A	48.77±1.05A	51.23±0.86A	67.33±0.78A	78.23±0.79A

Table 4.4.6(a) Effect of biochar based amendments on chlorophyll index (SPAD) and leaf area(cm^2) of wheat crop at 60,75 DAS during 2018-2019& 2019-2020.

	2018				**2019**			
Treatments	Chlorophyll index (SPAD) 60DAS	Chlorophyll index (SPAD) 75DAS	Leaf area(cm^2) at 60 DAS	Leaf area(cm^2) at 75DAS	Chlorophyllindex (SPAD) 60DAS	Chlorophyll indexSPAD) 75DAS	Leaf area(cm^2) at 60 DAS	Leaf area(cm^2) at 75DAS
T0- Control (no fertilizer)	32.53 ±1.06E	34.50±0.94D	30.40±0.70H	40.37±0.70F	32.63±0.74F	36.27±0.79E	31.40±0.86I	41.20±0.82I
T1-100%RDF	38.20±0.73D	41.47±0.68C	40.77±0.56G	51.80±0.78E	39.37±0.69E	43.70±0.37CD	41.63±0.98H	51.80±1.28H
T2- 50%RDF + Biochar	39.17±0.78D	42.10±0.33C	43.70±0.59F	53.33±0.66E	40.23±0.74DE	43.43±0.56D	44.47±0.49G	54.73±0.33G
T3-50%RDF+25%FYM+ Biochar	41.27±0.56C	43.67±0.37B	49.80±0.24D	61.33±0.90C	42.50±0.57BC	46.37±0.54AB	51.33±0.96D	61.33±0.88D
T4-50%RDF+50%FYM+Biochar	43.33±0.33A	46.0±0.31A	61.70±0.45A	69.33±0.69A	44.40±0.65A	47.40±0.70A	60.27±0.62A	71.53±0.84A
T5-50%RDF+ 25%Vermi-compost + Biochar	41.23±0.94C	43.77±0.37B	51.10±0.70D	56.23±0.74D	42.17±0.82BC	45.20±0.82BC	49.50±0.45E	58.80±0.49E
T6-50%RDF+ 50%Vermi compost+ Biochar	41.80±0.37C	44.23±0.34B	58.30±0.29B	67.17±0.86B	43.43±0.62AB	46.13±0.82AB	57.47±0.82B	68.27±0.78B
T7-50%RDF+ 25%poultry manure+ Biochar	40.70±0.57C	44.40±0.57B	47.41±0.83E	55.43±0.58D	41.57±0.82CD	44.30±0.6CD	47.90±0.36F	56.70±0.37F
T8-50%RDF+50% poultry manure+ Biochar	41.80±0.45B	44.47±0.60B	53.40±0.91C	62.97±1.11C	42.47±0.78BC	46.17±1.25AB	54.73±0.77C	64.97±0.98C

4.4.7 Crop growth rate (CGR), Relative growth rate (RGR), Net assimilation Rate (NAR): Data pertaining to CGR at various stages of crop growth were significantly affected by Biochar based amendments presented in table 4.4.7(a) and depicted in Fig. 4.4.7(a). CGR increased significantly with Biochar based amendments as compared to control. The highest CGR (0.780, 0.753 gday^{-1}) recorded in rice during 2018 -2019 with the application of 50% RDF+50% PM+ Biochar in rice crop which was followed by T7 (50% RDF+25% PM+ Biochar) having 0.530, 0.502 g day^{-1}. The lowest CGR was obtained by control (0.36, 0.35 g). All the other treatments were significantly different from each other in case of CGR in rice crop. In following wheat crop, the CGR varied from 0.30- 0.94. The highest CGR (0.94) recorded with T7 which was at par with T6 (0.91),T5 (0.91),T4(0.89) and T8(0.81). All these treatments were non- significant among themselves. But these were significantly better than T3, T2, T1 and T0. In 2019, wheat highest CGR recorded (0.95) with T6 which was at par with T5 (0.92). During both years in 2018 and 2019, the minimum CGR (0.30 and 0.23) recorded with control.

RGR was significantly affected by the Biochar amendments. In 2018 and 2019 rice crop significantly highest RGR was obtained with T8 (0.0451 and 0.0450) which was followed by T7 (0.0424g). The minimum RGR (0.0378, 0.0377) was recorded with control during both years. In following wheat crop during 2018-2019 and 2019-2020, all the treatments were significantly different all other treatments. Significantly highest (0.102) RGR was recorded with T4 which was at par with T5, T6, T7 and T8.These treatments were non significantly different from the rest of treatments. There was slight variation recorded in RGR in wheat crop during both years. The minimum RGR was recorded with T0 (0.076 and 0.074) which was at par with T1 with 0.086 and 0.0857 RGR. The data of RGR was presented in table and Fig. Similarly NAR at various crop growth stages were significantly influenced by the Biochar based amendments. All the treatments were significantly different from all other treatments. In rice crop during 2018-2019 highest NAR was recorded in T8(0.126 and 0.134) which was followed by T7(0.115 and 0.134) The minimum NAR was recorded with control (0.065,0.070). The data of NAR in rice was presented in table 4.4.7(a) and depicted in Fig. 4.4.7(b). During 2018-19 and 2019-2020 wheat crop NAR showed variation in Biochar amended plots. Application of 50% RDF+50%FYM+Biochar recorded highest NAR(0.329) during 2018-2019 and (0.170) during 2019-2020.The minimum Nar was recorded with control with control T0(0.048,0.040) during both years . The data of wheat NAR presented in table 4.4.7 (b) and Fig 4.4.7(c, d).

4.4.7a.b

4.4.7 c,d

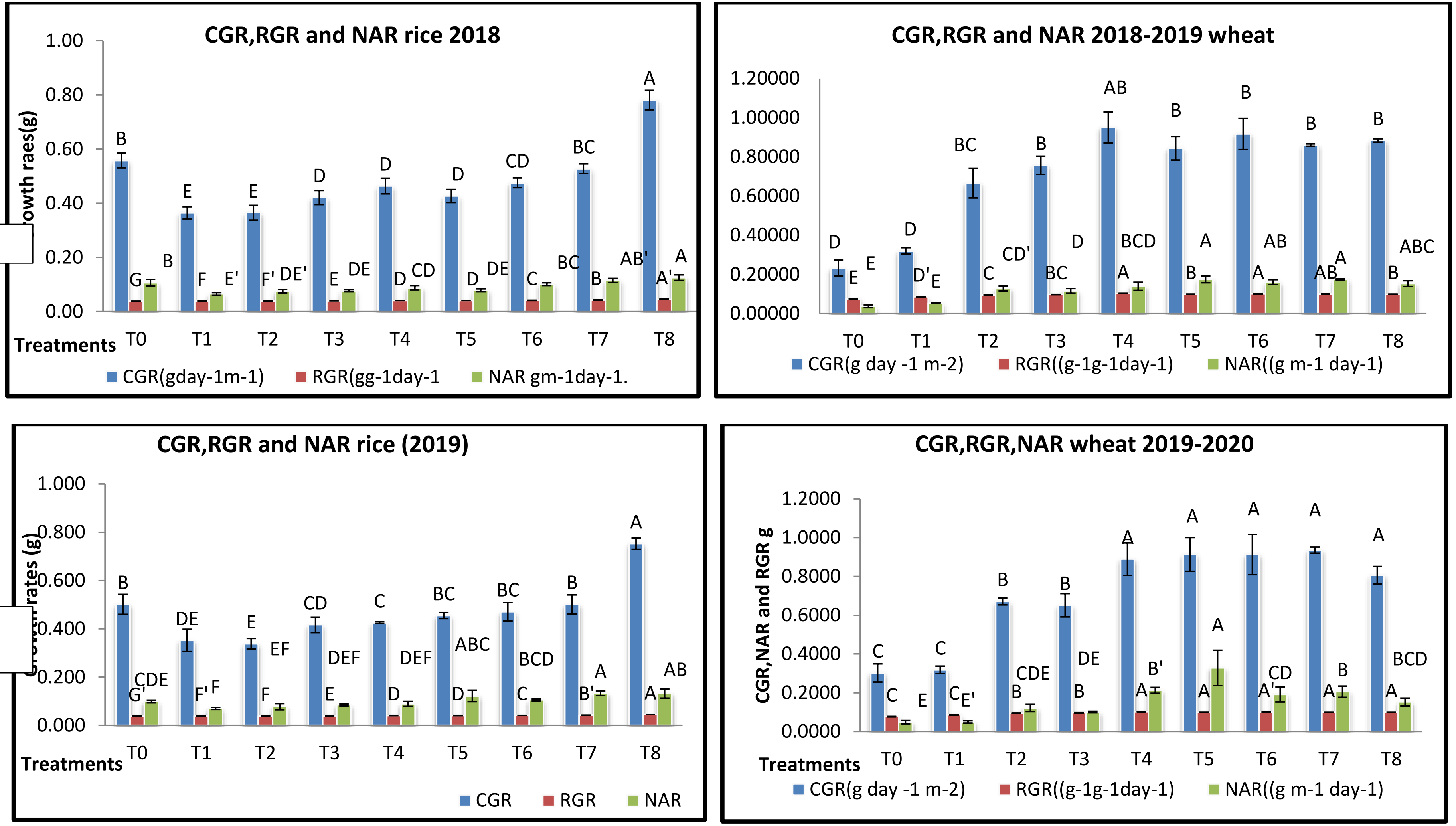


Fig. 4.4.7 a,b& c,d representing CGR, RGR, NAR of rice- wheat crop during 2018-2019,2019-2020. Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.4.7(a) Effect of biochar on CGR, RGR & NAR(mean ± S.E) of rice crop during both years of experimentation.

	2018			2019		
Treatments	CGR	RGR	NAR	CGR	RGR	NAR
T0- Control (no fertilizer)	0.56±0.03B	0.0378±0.0004G	0.107±0.01234B	0.502±0.041B	0.0377±0.0003G	0.099±0.0054CDE
T1-100%RDF	0.36±0.0E	0.0392±0.0002F	0.065±0.005165E	0.352±0.046DE	0.0392±0.0003F	0.070±0.0045F
T2- 50%RDF + Biochar	0.37±0.03E	0.0389±0.0003F	0.075±0.007265DE	0.338±0.022E	0.0390 ±0.0001F	0.077±0.0127EF
T3-50%RDF+25%FYM+Biochar	0.42±0.03D	0.0401±0.0001E	0.077±0.003462DE	0.417±0.033CD	0.0400±0.0002E	0.085±0.0046DEF
T4-50%RDF+50%FYM+Biochar	0.46±0.03D	0.0409±0.0004D	0.088±0.008607CD	0.425±0.004C	0.0408± 0.0002D	0.089±0.0110DEF
T5-50%RDF+ 25%Vermi-compost + Biochar	0.43±0.02D	0.0407±0.0002D	0.079±0.005464DE	0.455±0.012BC	0.0409± 0.0001D	0.122±0.0240ABC
T6-50%RDF+ 50%Vermi compost+ Biochar	0.48±0.02CD	0.0415±0.0002C	0.102±0.004867BC	0.471±0.039BC	0.0416± 0.0002C	0.106±0.0035BCD
T7-50%RDF+ 25%poultry manure+ Biochar	0.53±0.02BC	0.0424±0.0001B	0.115±0.007714AB	0.502±0.040B	0.0424± 0.0002B	0.134±0.0092A
T8-50%RDF+50% poultry manure+ Biochar	0.78±0.04A	0.0451±0.0001A	0.126±0.01036A	0.753±0.023A	0.0450± 0.0002A	0.133±0.0187AB

Table 4.4.7(b) Effect of biochar on CGR, RGR & NAR(mean ± S.E) ofwheat crop during both years of experimentation.

	2019			2018		
Treatments	CGR	RGR	NAR	CGR	RGR	NAR
T0- Control (no fertilizer)	0.3±0.05C	0.076±0.0012C	0.048±0.008E	0.23±0.04D	0.0740±0.0027E	0.038±0.007E
T1-100%RDF	0.32±0.02C	0.086±0.0008C	0.050±0.006E	0.32±0.02D	0.0857±0.0010D	0.054±0.002E
T2- 50%RDF + Biochar	0.67±0.02B	0.094±0.0005B	0.122±0.018CDE	0.76±0.08BC	0.0953±0.0004C	0.128±0.013CD
T3-50%RDF+25%FYM+Biochar	0.65±0.06B	0.096±0.0008B	0.100±0.004DE	0.65±0.05B	0.0973±0.0006BC	0.116±0.012D
T4-50%RDF+50%FYM+Biochar	0.89±0.08A	0.102±0.0006A	0.213±0.015B	0.85±0.08AB	0.1020±0.0007A	0.140±0.021BCD
T5-50%RDF+ 25%Vermi-compost + Biochar	0.91±0.09A	0.098±0.0012A	0.329±0.091A	0.92±0.06B	0.0984±0.0008B	0.17 5±0.016A
T6-50%RDF+ 50%Vermi compost+ Biochar	0.91±0.10A	0.101±0.0014A	0.191±0.038CD	0.95±0.08B	0.1001±0.0006A	0.161 ±0.012AB
T7-50%RDF+ 25%poultry manure+ Biochar	0.94±0.02A	0.099±0.0003A	0.206±0.029B	0.88±0.01B	0.0997±0.0006AB	0.175 ±0.003A
T8-50%RDF+50% poultry manure+ Biochar	0.81±0.04A	0.099±0.0005A	0.153±0.020BCD	0.86±0.01B	0.0986±0.0005B	0.154 ±0.015ABC

4.4.8 Panicle length/ spikelet length (cm): All the treatments resulted significantly higher panicle length over control in rice crop of 2018-2019 (Table-4.4.8 a,b). Highest panicle length was recorded with T8 (27.67) and lowest (20.13) for control. The treatment T8 was immediately followed by T4 (25.23) and T7 (25 cm). Remaining all other treatments was significantly superior to control. In the following wheat crop spike length is directly related to the number of spikelets and grains per spikelet and important indicator of grain yield. Length of spikelet is one of the important criteria for determining grain yield. The scrutiny of data presented in table () and Fig. T4 significantly increased spikelet length up to 11.47 cm which was followed by T3, T8 and T6 with 10.49, 10.40, 10.36 cm spikelet length. These treatments were non -significant among themselves but showed superiority over rest of the treatments. The minimum spikelet length recorded in control (7.14 cm). In the next year (2019-2020) panicle length varied from 19.93-27.43 cm. The highest panicle length recorded with T8 (27.43cm), and control showed lowest panicle length in rice crop. The order of panicle length in rice was T8>T4>T7>T6>T5>T3>T1>T2>T0.In the following wheat crop, all the treatments were statistically significant. T4 recorded highest spikelet length (15.2cm) and minimum with control (8.27cm).The order of spikelet length in wheat was T4>T6>T7>T5>T8>T3>T2>T1>T0.The data presented in Fig. (4.4.8 a,b,c,d).

4.4.8 a,b

4.4.8c,d

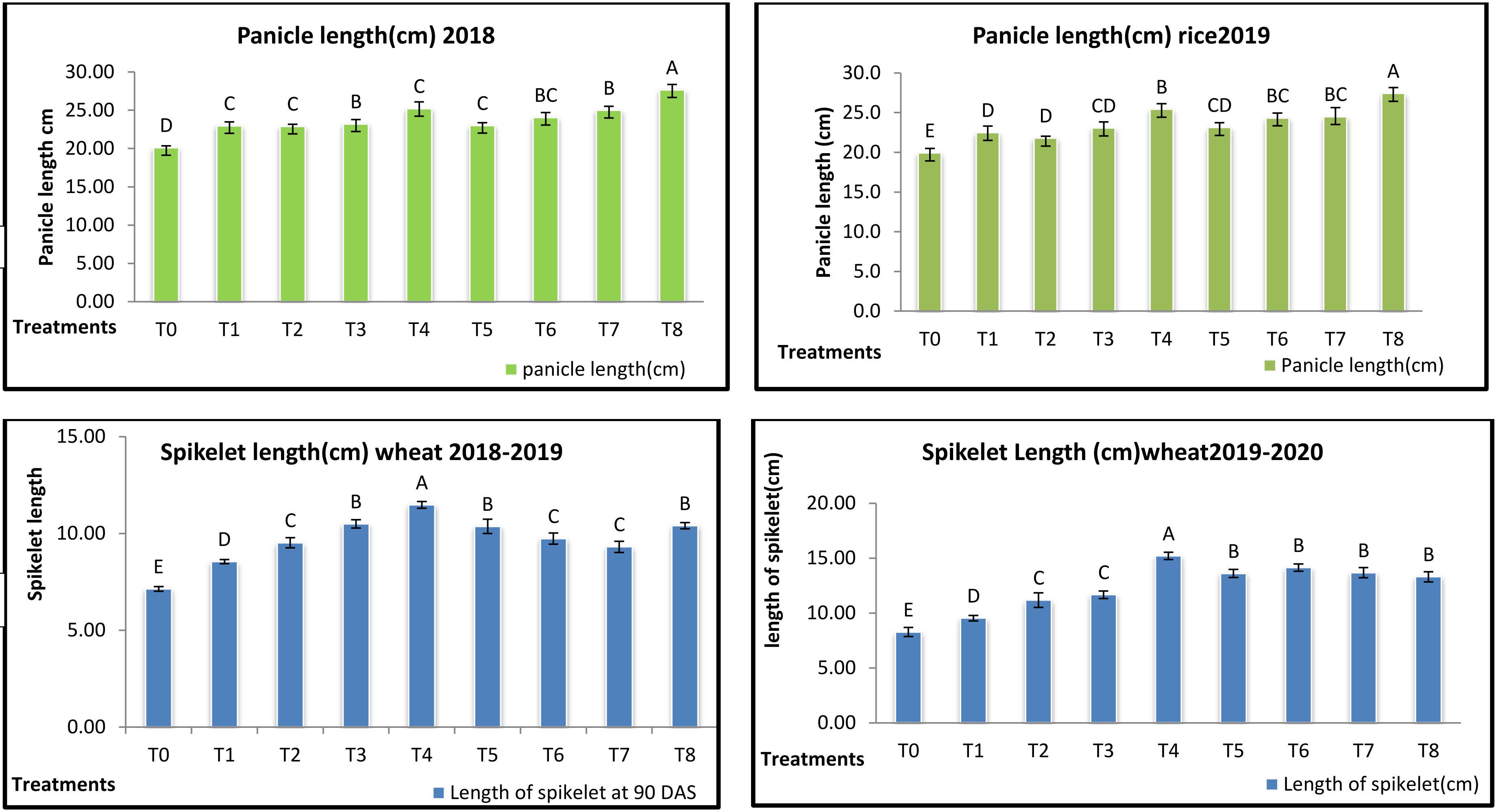


Fig.4.4.8 A&B representing the panicle length (cm) of rice crop and Fig. 4.4.8C&D representing spikelet length of wheat crop .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$

4.4.9 Number of grains per panicle/ spikelet: The grain is fertilized fully ripened ovule of a spikelet in a panicle which contributes to yield. In case of rice filled and unfilled grains per panicle were calculated. The data on number of filled and unfilled grains per panicle were calculated and presented in Table and Fig. The number of filled grains per panicle were recorded maximum with T8 (63.5) which was at par with T7 (61.2) during first year of study (2018) in rice crop. All the treatments except control recorded significantly more number of grains per panicle over control. During the second year of study the highest number of filled grains per panicle (66.63) recorded with T8 which was at par with T7 with 62.6 filled grains per panicle. The minimum number of filled grains per panicle was recorded with T0 (24, 26) during both years in rice crop. Biochar amended plots were comparable in case of unamended plots. The minimum number of unfilled grains per panicle were recorded during both years with T8 (6.87, 6.3) which was followed by T7 (8.9). The maximum number of unfilled grains (13.3, 13) was recorded with T0 during 2018 and 2019.In following wheat crop all the treatments recorded more number of grains per spikelet as compared to control. The highest (50, 50.67).number of grains per spikelet were recorded with T4 which was followed by T3 and T8 with 45.67 and 45 grains per spikelet in 2018-2019 and T3,T5,T6,T7 with 46.3,46,47.33,46 and 46.67 in 2019-2020. These treatments were at par with each other and non-significant among themselves. But superior to T2, T1 and T0.The minimum number of grains per spikelet (22, 24.3) was recorded with T0 during both years. The data of number of grains per spikelet was presented in table(4.4.8a,b) and Fig. (4.4.9 a,b,c,d)

4.4.9 a,b

4.4.9 c,d

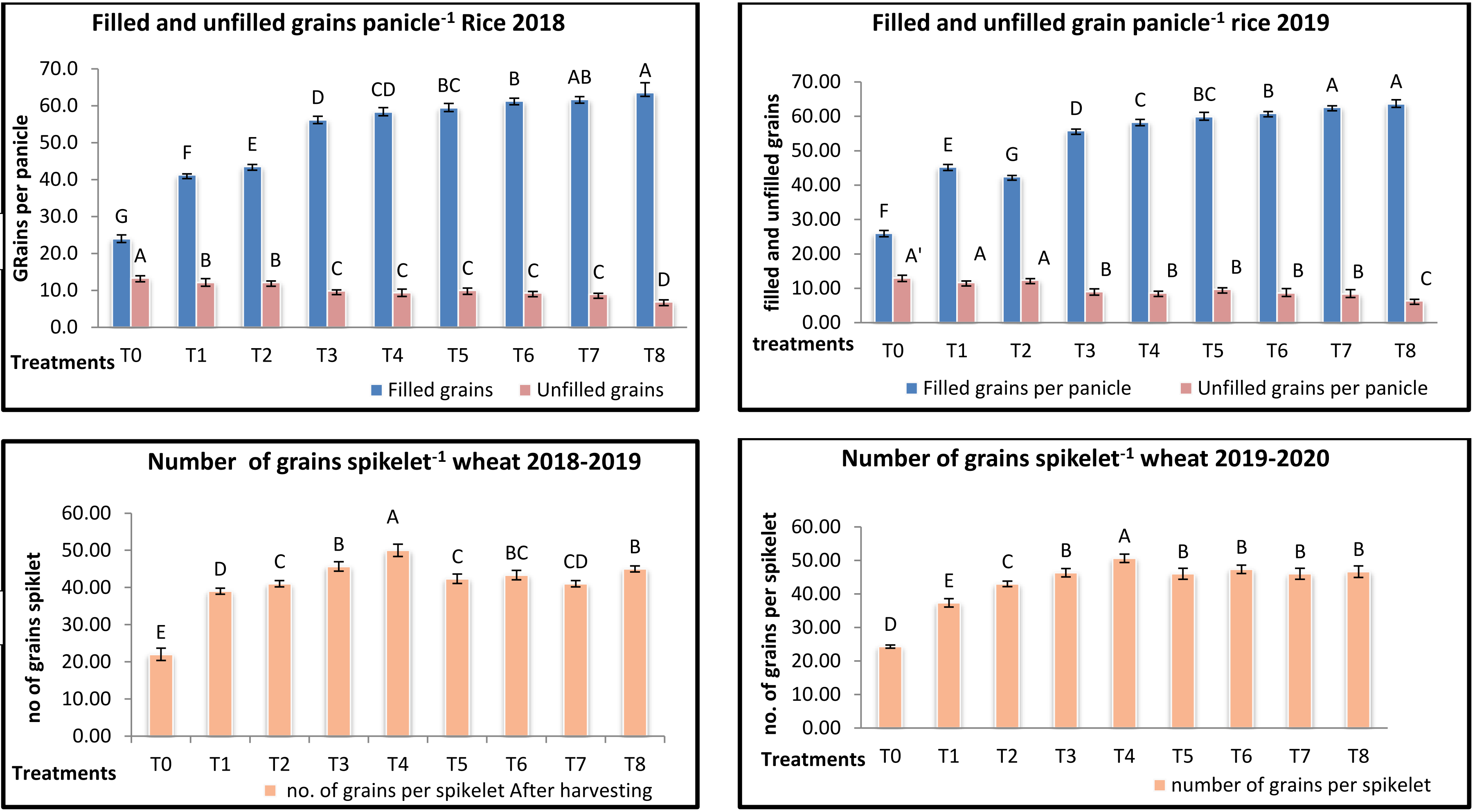


Fig. 4.4.9A&B representing the filled and unfilled grains per panicle in rice and Fig. 4.4.9 C&D representing number of grains per spikeltof wheat crop during 2018-19,2019-2020 .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.4.8(a) Effect of biochar based amendments on panicle length of rice, filled grains per panicle and unfilled grains per panicle in rice

	2018			2019		
Treatments	Panicle length(cm)	Filled grains	Unfilled grains	Panicle length(cm)	Filled grains	Unfilled grains
T0- Control (no fertilizer)	20.13 ±0.24D	24.0±1.00G	13.33±0.61A	19.93±0.54E	26.00±0.82F	13.0±0.82A
T1-100%RDF	22.99±0.50C	41.3±0.31F	12.10±1.05B	22.50±0.82D	45.23±0.82E	11.7±0.47A
T2- 50%RDF + Biochar	22.92±0.25C	43.5±0.58E	12.13±0.42B	21.80±0.24D	42.43±0.42G	12.3±0.47A
T3-50%RDF+25%FYM+Biochar	23.23 ±0.57C	56.2±1.00D	9.87±0.31C	23.07±0.76CD	55.80±0.51D	9.0±0.82B
T4-50%RDF+50%FYM+Biochar	25.23±0.87B	58.3±1.21CD	9.33±1.03C	25.43±0.69B	58.27±0.82C	8.7±0.47B
T5-50%RDF+ 25%Vermi-compost + Biochar	23.01±0.36C	59.5±1.21BC	9.97±0.68C	23.13±0.59CD	59.90±1.26BC	9.7±0.47B
T6-50%RDF+ 50%Vermi compost+ Biochar	24.07±0.63BC	61.3±0.80B	9.27±0.42C	24.33±0.61BC	60.87±0.49B	8.7±1.25B
T7-50%RDF+ 25%poultry manure+ Biochar	25.00±0.54B	61.7±0.82AB	8.90±0.30C	24.50±1.14BC	62.60±0.45A	8.3±1.25B
T8-50%RDF+50% poultry manure+ Biochar	27.67±0.70A	63.5±2.73A	6.87±0.60D	27.43±0.74A	63.63±1.19A	6.3±0.47C

Table 4.4.8(b) Effect of biochar based amendments oflag leaf length of wheat, grains perspikelet and spikelt length (mean± S.E) during 2018-19 and 2019-20

Treatments	2018				2019			
	Flag leaf length(cm) 60DAS	Flag leaf length(cm) 75DAS	Spikelet length(cm)	Number of grains per spikelet	Flag leaf length(cm) 60DAS	Flag leaf length(cm) 75DAS	Spikelet length(cm)	Number of grains per spikelet
T0- Control (no fertilizer)	26.57±0.49E	30.57±0.49F	7.14±0.12E	22.00±1.63E	21.43±0.42F	27.53±0.92F	8.27±0.41E	24.33±0.47E
T1-100%RDF	30.83±0.45D	35.33±0.78E	8.55±0.11D	39.00±0.82D	24.07±0.26E	29.40±0.75E	9.53±0.25D	37.33±1.25D
T2- 50%RDF + Biochar	31.43±0.46CD	35.37±0.54E	9.52±0.26C	41.00±0.82CD	25.57±0.61D	29.57±0.53E	11.17±0.66C	43.00±0.82C
T3-50%RDF+25%FYM+ Biochar	33.13±0.82B	36.90±0.57D	10.49±0.21B	45.67±1.25B	29.13±0.86BC	32.10±0.73D	11.67±0.34C	46.33±1.25B
T4-50%RDF+50%FYM+Biochar	34.97±0.66A	38.80±0.24A	11.47±0.18A	50.00±1.63A	32.07±0.45A	38.50±0.57A	15.20±0.33A	50.67±1.25A
T5-50%RDF+ 25%Vermi-compost + Biochar	32.30±0.45BC	37.60±0.43BC	10.36±0.37B	42.33±1.25C	30.30±0.70B	34.30±0.67C	13.60±0.37B	46.00±1.63B
T6-50%RDF+ 50%Vermi compost+ Biochar	32.77±0.29B	38.20±0.59AB	9.73±0.29C	43.33±1.25BC	29.33±0.74BC	36.30±0.62B	14.13±0.34B	47.33±1.25B
T7-50%RDF+ 25%poultry manure+ Biochar	30.63±0.53D	35.70±0.37DE	9.31±0.29C	41.00±0.82CD	28.67±0.65C	33.13±0.82CD	13.67±0.46B	46.00±1.63B
T8-50%RDF+50% poultry manure+ Biochar	32.10±0.57BC	36.57±0.31CD	10.40±0.16B	45.00 ±0.82B	30.40±0.70B	37.20±0.70AB	13.30±0.45B	46.67±1.70B

4.4.9 Test weight (g): The weight of 1000 grains weight is called test weight which is an important yield attribute which gave the information regarding the efficiency of grain filling process. 1000 grain weight is the desired output which referred as one of the most important agronomic parameters which contributes in grain yield. Data pertaining to 1000 grain weight is presented in table 4.4.9(a) and Fig 4.4.9(a). In 2018 and 2019 rice, highest (20.9, 20.83 g) test weight was recorded with T8 which was followed by T7 with 20.07 and 19.83g during both years. Remaining all treatments was significantly different from each other. The minimum test weight (12.9, 14.1g) during both years was recorded with T0. The maximum test weight in rice crop was in order T8>T7>T6>T4>T5>T3>T1>T2>T0. Similarly in succeeding wheat crop different treatments differ significantly among themselves. The test weight of wheat ranged from 28.27 to 45.31g in 2018-2019 and 27.5-42.2 g. Highest test weight (45.31g and 42.2g) recorded with the application of 50% RDF+50%FYM+Biochar-T4 during both years which was at par with T8 having (44.2,41.6g) These two treatments were non-significant among themselves but superior to rest of treatments. The minimum test weight (28.27, 27.5g) was recorded with control during both years. The maximum test weight order in wheat was T4>T8>T7>T6>T5>T3>T1>T2>T0 in2018-2019 and T4>T8>T6>T3>T5>T7>T1>T2>T0 in 2019-2020. The test weight of wheat during both years was presented in Table 4.4.9a,b and Fig**.** 4.4.9a,b,c&d.

4.4.9 a,b

4.4.9c,d

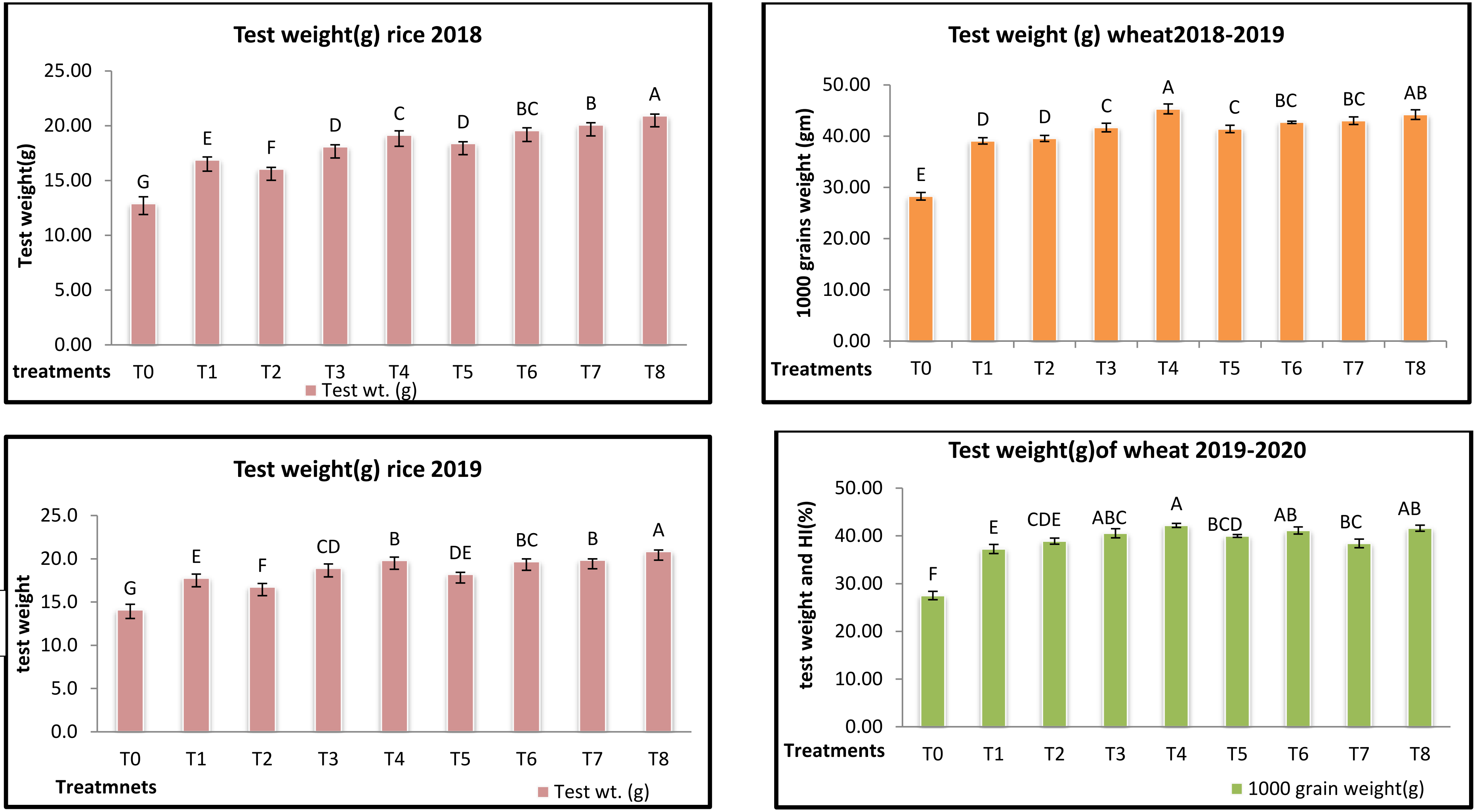


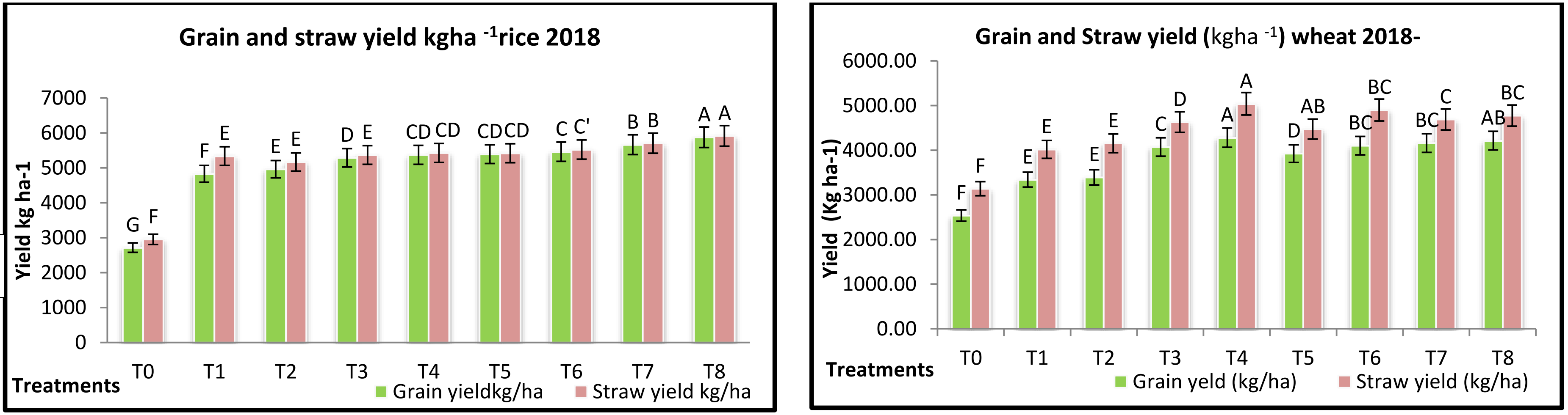
Fig. 4.4.9A&B,C,D representing test weight (g) of rice and wheat crop during 2018-2019& 2019-2020 .Data shown as mean of S.E. Means with similar letters for each Fig. are not significantly different according to LSD at $p<0.05$.

4.4.10 Grain yield: Grain yield is a function of the different parameters like productive tillers, dry weight of plant, number of grains per panicle, panicle length/spikelet length, and test weight. Grain yield is the most important criteria for determining the effect of applied treatments. Crop productivity is the rate at which crop accumulates biomass based on photosynthesis and transformation of energy by plants. Grain yield of rice and wheat crop of two consecutive years are presented in table 4.4.9(A) and Fig. 4.4.10(a). During 2018-2019 rice crop the grain yield ranged from 2714-5876 kg ha^{-1}. Application of 50% RDF+50% PM+ Biochar recorded maximum (5876 kgha^{-1}) grain yield which was followed by T7 with 5662.67 kg ha^{-1} grain yield. The rest of the treatments also showed more grain yield as compared to control. The minimum (2714.3 kgha^{-1}) grain yield was resulted with control. In succeeding wheat crop all the treatments were statistically significantly different among themselves. 50% RDF+50% FYM+ Biochar recorded maximum (4282 kgha^{-1}) grain yield which was immediately followed by T8 (4214 kgha^{-1}). The other treatments also showed more grain yield over control. The lowest grain yield was recorded with control (2536 kgha-1) which was followed by T1 (100% RDF) having grain yield (3340 kgha^{-1}). In the next year (2019-2020) all the treatments were statistically different from each other in rice yield. Highest grain yield (5666 kgha^{-1}) resulted with T8 which was followed by T7 with 5589 kgha^{-1} grain yield (2909 kgha^{-1}). The maximum order of grain yield was T8>T7>T6>T5>T4>T3>T1>T2>T0. In succeeding wheat crop, the grain yield ranged from 2687-4317 kgha^{-1}. Maximum (4317 kg ha-1) grain yield was recorded with T4. Second highest grain yield was recorded with T8 (4165 kgha^{-1}) which was at par with T7 and T3 with 4143 and 4157 kgha-^{1} grain yield. The lowest grain yield was recorded with control (2687 kg ha^{-1}).

4.4.**11Straw yield (kgha^{-1})**: Straw yield is the result of crop biomass produced during the crop growth period. Straw yield of rice and wheat crop of two consecutive years depicted in table (4.4.9a) and Fig. 4.4.10 (a).The data presented in table 4.4.9(a) showed that straw yield was greatly influenced by the different Biochar based amendments. During 2018-19 and 2019-2020, rice crop the highest straw yield (5917 kgha^{-1}) recorded by T8 and 5799 kg ha-1 in 2019-2020. This treatment was immediately followed by T7 during both years were 5662 and 5688 kg ha^{-1}. The unamended plot (T0) recorded lowest straw yield (2952.33 kgha^{-1}), 2909kgha^{-1}during 2018-19 and 2019-20. The order of different applied treatments in straw yield in rice was- T8>T7>T6>T5>T4>T3>T1>T2>T0. In succeeding wheat crop the straw yield was significantly affected by the application of Biochar based amendments. All the treatments were significantly different from each other. It was evident from data that maximum straw yield (5038 kgha^{-1}) was recorded by the application of 50% RDF+50% FYM +Biochar during 2018-2019 and same trend was followed in next year with 4942 kgha-^{1} straw yield. The differences in straw yield due to different Biochar based amendments proved significant. The straw yield increased significantly with every Biochar based amendments. However, T4 was significantly superior (5038kgha^{-1}) over rest of the treatments. The second highest straw yield (4901.6 kgha^{-1}) was recorded with T6 during 2018-19 and T3 (4514 kgha^{-1}) during 2019-2020.The lowest straw yield (3138 and 3033 kgha^{-1}) was recorded with T0 during the course of study. The increased straw yield in wheat crop was T4>T6 >T8>T7 >T3 >T5 >T2 >T1 >T0 .

4.4.12: Harvest index (%): Harvest index is an important parameter representing the efficiency in partitioning of dry matter to economic part of the crop. Statistically higher harvest index is the economic return of the crop. The data of harvest index of rice was presented in table (4.4.9a) and Fig. 4.4.12(a). Data presented in the table revealed that the Biochar amended plots results more HI over control during year of study. During the year 2018-2019 and 2019-2020of study highest harvest index of 49.83% and 49.42% was recorded with the application of 50% RDF+50% PM+ Biochar.T8 was at par with T7,T6,T5,T4,T3,T3,T2. These treatments were non- significant among themselves. The minimum HI was recorded in control having 47.89 and 47.51%. In succeeding wheat crop, during 2018-2019 highest harvest index was (47.03%) recorded with T7 and (49.10%) during 019-20. The treatments were at par with T5 and T3 with 46.79% and 46.74% HI. The lowest harvest index was recorded with control (44.7% and 45.17%) during both years. All the treatments were significantly superior to control. The maximum order of HI (%) was T7>T3>T5>T8>T6>T4>T2>T1>T0. The data of HI in wheat was presented in table (4.4.9b) and Fig. 4.4.12(b). There was a slight variation in HI (%) with different treatments.

4.4.10 a,b



4.4.10 c,d

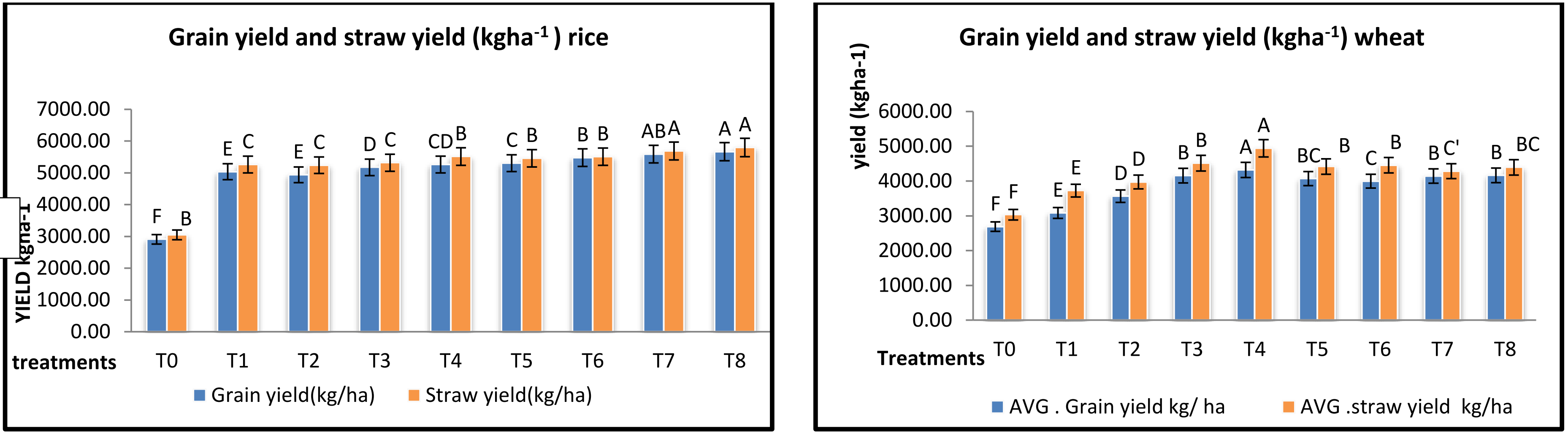


Fig4.4.10a,b. c,d representing the grain yield and straw yield of rice and wheat crop .Data shown as mean of S.E. Means with different letters for each Fig. are significantly different according to LSD at $p<0.05$.

4.4.1.2 a,b

4.4.1.2 c,d

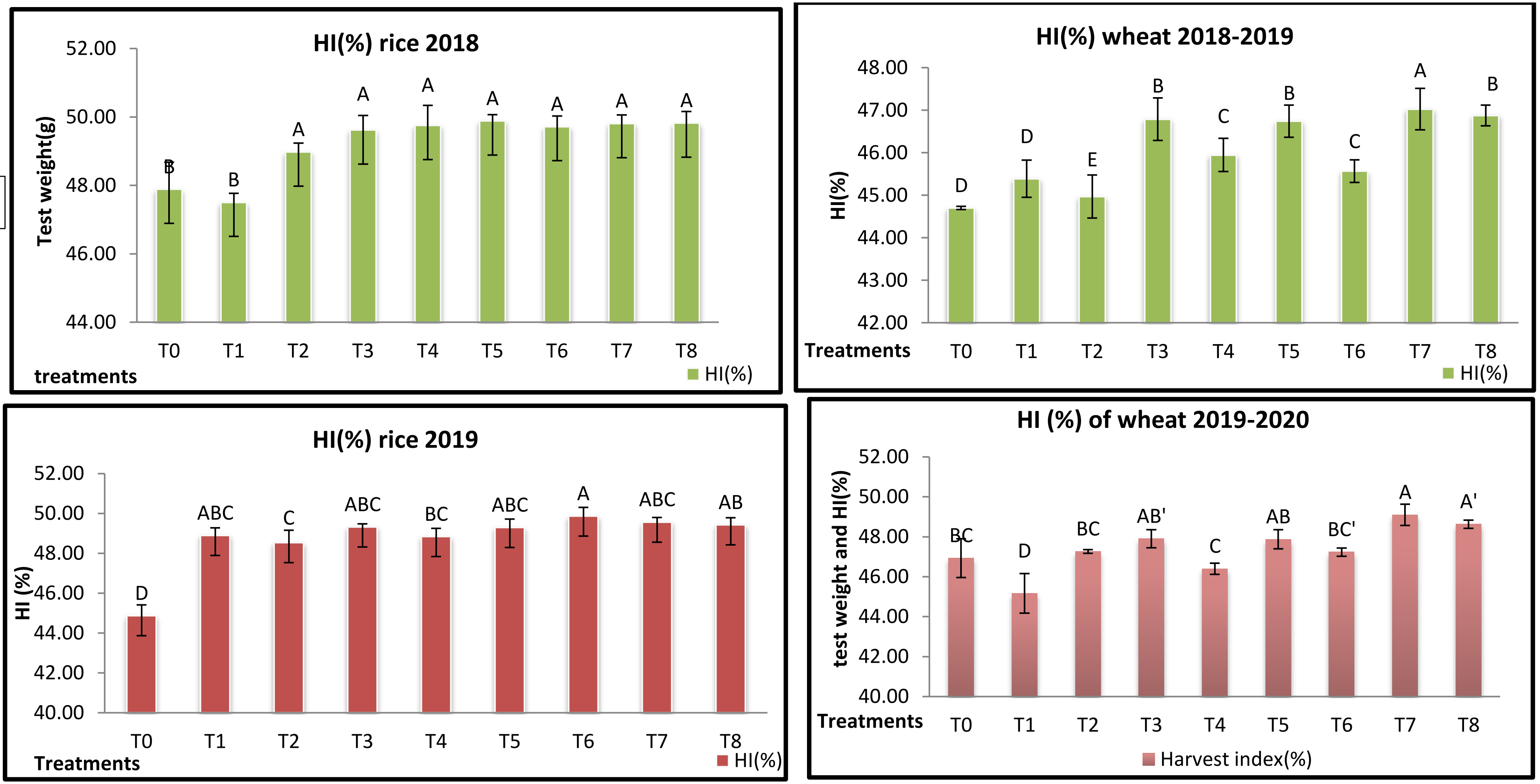


Fig. 4.4.1.2A&B ,C&D representing harvest index of rice and wheat crop during 2018-19,2019-2020..Data shown as mean of S.E. Means with common letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.4.9(a) Effect of biochar combined fertilizers on test weight(g), grain yield(kgha^{-1}), straw yield(kgha^{-1}) and Harvest index(%) of rice crop during 2018-2019.

	2018				**2019**			
Treatments	Test weight(g)	Grain yield(kg ha^{-1})	Straw yield(kg ha^{-1})	Harvest index (%)	Test weight(g)	Grain yield(kg ha^{-1})	Straw yield(kg ha^{-1})	Harvest index (%)
T0- Control (no fertilizer)	12.90±0.62G	2714.33±107.75G	2952.33±48.79F	47.89±0.79B	14.10±0.64G	2909.00±86.65F	3047±54.99B	44.87±0.54D
T1-100%RDF	16.87±0.29E	4831.3±109.20F	5337.67±65.77E	47.51±0.26B	17.7±0.45E	5033.67±71.43E	5262±38.21C	48.89±0.39ABC
T2- 50%RDF + Biochar	16.03±0.17F	4962.33±61.83E	5169.33±48.95E	48.98±0.26A	16.73±0.42F	4940.67±73.92E	5240±54.93C	48.53±0.63C
T350%RDF+25%FYM+Biochar	18.07±0.21D	5289.67±71.60D	5369.67±43.36E	49.62±0.42A	18.90±0.49CD	5175.33±38.85D	5319±19.03C	49.31±0.17ABC
T450%RDF+50%FYM+Biochar	19.13±0.40C	5373.33±56.41CD	5426.33±97.50CD	49.76±0.58A	19.80±0.41B	5263.00±44.77CD	5515±81.76B	48.83±0.42BC
T5-50%RDF+ 25%Vermi-compost + Biochar	18.37±0.17D	5392.33±11.59CD	5417.33±58.18CD	49.89±0.18A	18.20±0.24DE	5308.00±12.75C	5461±80.03B	49.29±0.43ABC
T6-50%RDF+ 50%Vermi compost+ Biochar	19.57±0.25BC	5462.07±45.29C	5523.67±54.60C	49.72±0.30A	19.67±0.33BC	5480.00±38.61B	5509±70.05B	49.87±0.43A
T7-50%RDF+ 25%poultry manure+ Biochar	20.07±0.21B	5662.67±33.23B	5706.00±96.25B	49.81±0.25A	19.83±0.17B	5589.33±14.38AB	5688±46.11A	49.56±0.24ABC
T8-50%RDF+50% poultry manure+ Biochar	20.90±0.16A	5876.00±36.17A	5917.67±111.20A	49.83±0.34A	20.83±0.17A	5666.00±33.18A	5799±64.75A	49.42±0.37AB

Table 4.4.9(b) Effect of biochar combined fertilizers on test weight(g), grain yield(kgha^{-1}), straw yield(kgha^{-1}) and Harvest index(%) ofwheat crop during 2018-2019 & 2019-2020.

Treatments	2018-2019				2019 -2020			
	Test weight(g)	Grain yield(kg ha^{-1})	Straw yield(kg ha^{-1})	Harvest index (%)	Test weight(g)	Grain yield(kg ha^{-1})	Straw yield(kgha^{-1})	Harvest index (%)
T0- Control (no fertilizer)	28.27±0.74E	2536.67±84.92F	3138.00±108.53F	44.70 ±0.037D	27.50±0.86F	2687.67±65.83F	3033.00±68.18F	46.93±0.97BC
T1-100%RDF	39.07±0.62D	3340.67±56.03E	4019.67±87.78E	45.39±0.436D	37.27±0.95E	3084.3 ±54.01E	3724.00±95.33E	45.17±0.99D
T2- 50%RDF + Biochar	39.54±0.59D	3395.67±16.74E	4155.67±65.14E	44.97±0.509D	38.90±0.62CDE	3564.67±41.00D	3972.33±34.87D	47.27±0.09BC
T3-50%RDF+25%FYM+Biochar	41.67±0.83C	4073.00±41.53C	4632.00±46.07D	46.79±0.501B	40.53±0.95ABC	4157.33±35.12B	4514.00±44.14B	47.90±0.45AB
T4-50%RDF+50%FYM+Biochar	45.31±0.95A	4282.00 ±39.23A	5038.00±101.23A	45.95±0.392C	42.20±0.43A	4317.00±67.89A	4942.33±68.52A	46.40±0.28C
T5-50%RDF+ 25%Vermi-compost + Biochar	41.40±0.71C	3924.67±43.68D	4471.67±76.39AB	46.74±0.379B	39.97±0.29BCD	4068.3±46.43BC	4418.33±69.41B	47.88±0.48AB
T6-50%RDF+ 50%Vermi compost+ Biochar	42.69±0.25BC	4104.00±67.19BC	4901.67±44.00BC	45.57±0.267C	41.13±0.74AB	3995.33±22.31C	4454.67±52.75B	47.23±0.21BC
T7-50%RDF+ 25%poultry manure+ Biochar	43.00±0.75BC	4162.33±58.97BC	4688.67±42.91C	47.03±0.489A	38.40±0.91CD	4143.67±50.68B	4283.67±60.14C	49.10± 0.54A
T8-50%RDF+50% poultry manure+ Biochar	44.20±0.94AB	4214.00±10.98AB	4775.67±38.94BC	46.88±0.246B	41.60±.65AB	4165.33±45.39B	4394.33±12.55BC	48.63±0.21A

4.5 Effect of Biochar based amendments on nutrient uptake and nutrient use efficiency:

The grain and straw samples after harvesting were analysed for N, P, K content. The results of N, P,K content of grain and straw has been discussed under following sub headings:

4.5.1 Nitrogen uptake in grain and straw(Kgha^{-1}): The scrutiny of data on N uptake by grain and straw presented in table 4.5.1(a) and depicted in Fig 4.5.1(a) reveals that different Biochar based amendments significantly affect the N uptake by grain and straw. During rice crop of 2018-2019 all treatment gave significantly more grain N content over the control. Highest grain N (84.22 kgha^{-1}) was recorded in T8 which was immediately followed by T7 having 79.27 kgha^{-1} . Lowest N uptake by grain was (17.37kg ha^{-1}) recorded in control. In following wheat crop grain N content in all treatments were statistically different from each other. The highest N content was found in T4 (88.4) which was followed by T6 (82.93 kgha-^{1}). The lowest (20.47 kgha^{-1})was recorded with control. During next year (2019-20) N uptake by grain ranged from 15.2- 53.4 kgha^{-1}. The significantly highest N uptake by grain (53.4kgha^{-1}) recorded with the application of 50% RDF+50%PM+ Biochar which was followed by T& with49.8 kgha^{-1}N. The lowest N uptake by grain was recorded with control (17.18 kg ha^{-1}). In succeeding wheat crop N uptake by grain ranged from 20-88.27 kgha^{-1}. The highest (88.27kgha^{-1}) N uptake by grain recorded with T4 which was followed by T6 with 83.10kgha^{-1}. Lowest N uptake (20.4kgha^{-1}) by grain was recorded with control. The order of N uptake in wheat crop was T4>T6>T8>T3>T5>T7>T2>T1>T0. The straw N content in rice due to different amendments ranged from 15.43-51.33 kgha^{-1}. In contrast to N content in straw was highest with T8 (51.33 kgha-^{1}) during rice crop. The second highest N uptake by straw recorded in T7 (48.67 kgha^{-1}). All the treatments were significantly better than control. The lowest uptake (15.43kgha^{-1}) recoded by control. In following wheat crop maximum N uptake by straw (54.57kgha^{-1}) was recorded by T4 followed by T6 (53). Lowest uptake (14.47 kg ha^{-1}) recorded with T0. Rice crop during 2019-2020 gave similar trend in straw N content that observed in 2018-2019. Highest N content was recorded with T8 and lowest in T0 **.** All treatments were significantly better than control. Straw N content in succeeding wheat crop was also highest with 50%RDF+50%FYM+Biochar (54.23 kgha^{-1} and lowest (15.2 kgha^{-1}) in control. The order of N content in straw of wheat was T4 >T6 >T8>T3>T5>T7>T1>T2>T0.

4.5.1 a,b

4.5.1 c,d

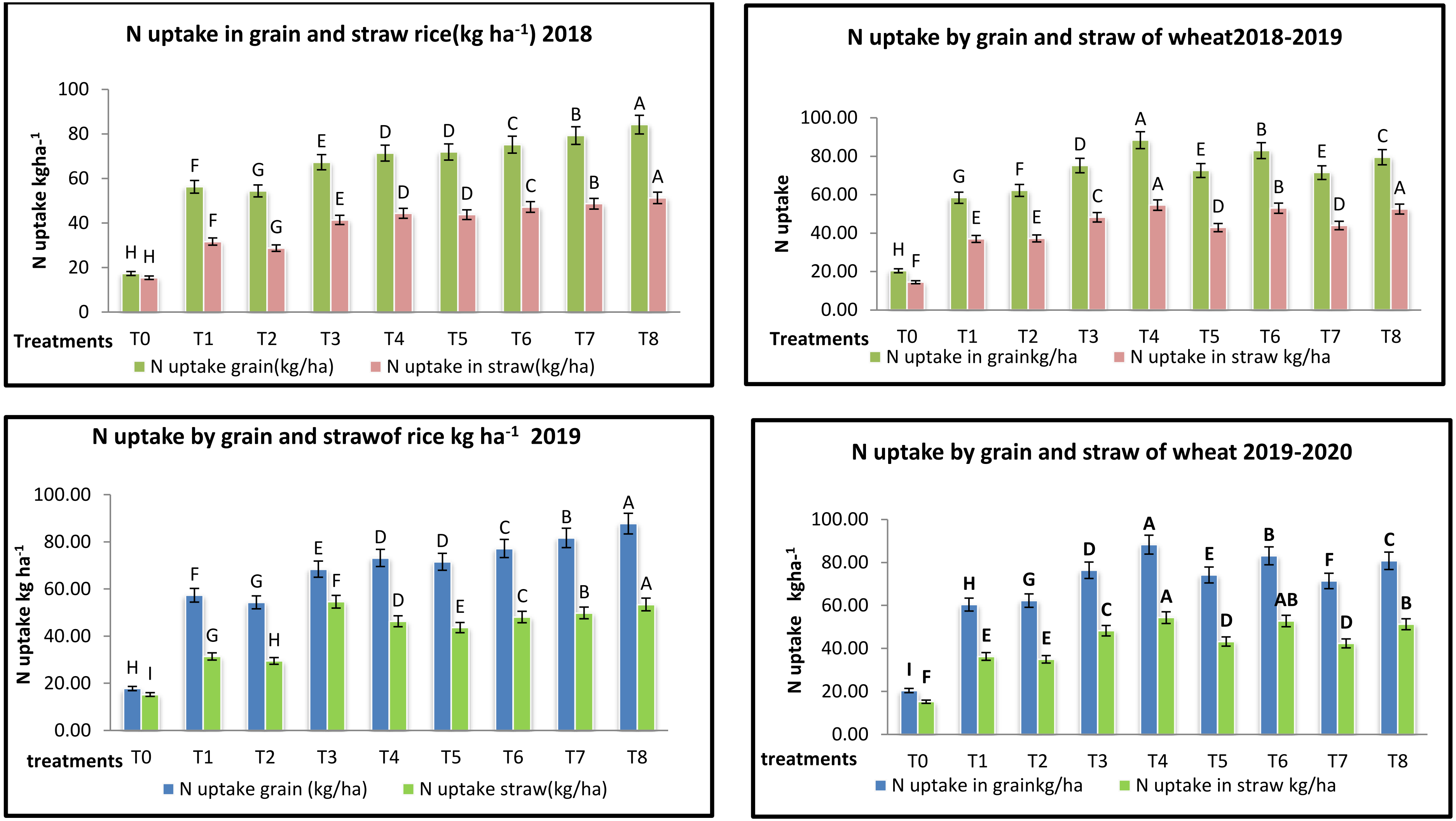


Fig.4.5.1 A&B , C&D representing the N uptake by grain and straw of rice and wheat crop during 2018-2019, 2019-2020 .Data shown as mean of S.E. Means with different letters for each Fig. are significantly different according to LSD at $p<0.05$

4.5.2. P uptake by grain and straw: The data on phosphorous content estimated at harvest of rice and wheat (Table 4.5.1(a) and Fig 4.5.2(a) revealed that P content in grain and straw were influences significantly due to different Biochar based amendments during both years. Table (4.5.1a) indicates that P content was two times more in grain as compared to straw. During rice crop of 2018-19 highest P content in grain (47.17kgha^{-1}) was recorded in T8 which was followed by T7 with 44.9 kgha^{-1}.All the treatments were statistically significantly superior over control in case of P uptake by grain. The lowest P uptake (1.67 kg ha^{-1}) in grain was recorded with control. In successive wheat crop all the Biochar amended plots recorded significantly more P content in wheat grain as compared to control. Application of 50%RDF+50%FYM+biochar resulted significantly more P uptake in grain (42.47) which was followed by T6(39.53 kgha^{-1}) uptake by grain. T0 (control) recorded lowest (12.73kg ha^{-1})P uptake by grain which was followed by T1(100% RDF) with 15.37 kgha^{-1} uptake. In the second year of study, P content in rice ranged from 12.17-46.5 kgha^{-1}. Highest (46.5 kgha-^{1})P content in rice grain was recorded with T8 which was followed by T7 with 44.7 Kgha^{-1} uptake. The same trend was followed as of previous year in P uptake by grain. Lowest was recorded (12.17kgha^{-1}) with unamended plots (T0) which was followed by T2 with 32.13 kgha^{-1} P uptakes in grain. The order of P uptake in rice crop with different treatments was significantly affected by the Biochar based amendments. During 2018-19 highest P uptake (7.31) in rice straw was recorded with the application of 50% RDF+50%PM+biochar) which was followed by T7 (6.26 kgha^{-1}). The lowest P(1.67) content was recorded with control which was followed by T2(2.70 kgha-^{1}).All the treatments were significantly different from each other. In succeeding wheat crop, the Biochar amended treatments gave more P content in straw. T4 recorded highest P uptake (5.25 kgha^{-1}) Lowest (2.80 kgha^{-1}) was recorded with control. In the next year (2019-20) rice crop indicated similar trend in straw P content that noticed in 2018-2019 rice crop. The P uptake in rice straw ranged from 2-7.27 kgha^{-1}. Highest P uptake in straw (7.27 kg ha^{-1}) recorded with T8 and lowest (2) with control. The order of P uptake in straw of rice was T8>T7>T6>T4>T5>T3>T1>T2>T0.In following wheat crop P uptake in straw ranged from 2.63-6.37 kgha-1.Highest P uptake (6.3 kgha-^{1})recorded with the application of 50% RDF+50%FYM+biochar which was followed by T6 with 5.36 kgha^{-1}. The lowest P content was recorded with control (2.63) .The order of P uptake by straw was T4> T6> T8> T5> T3> T7> T1> T2> T0.

4.5.2a,b

4.5.2 c,d

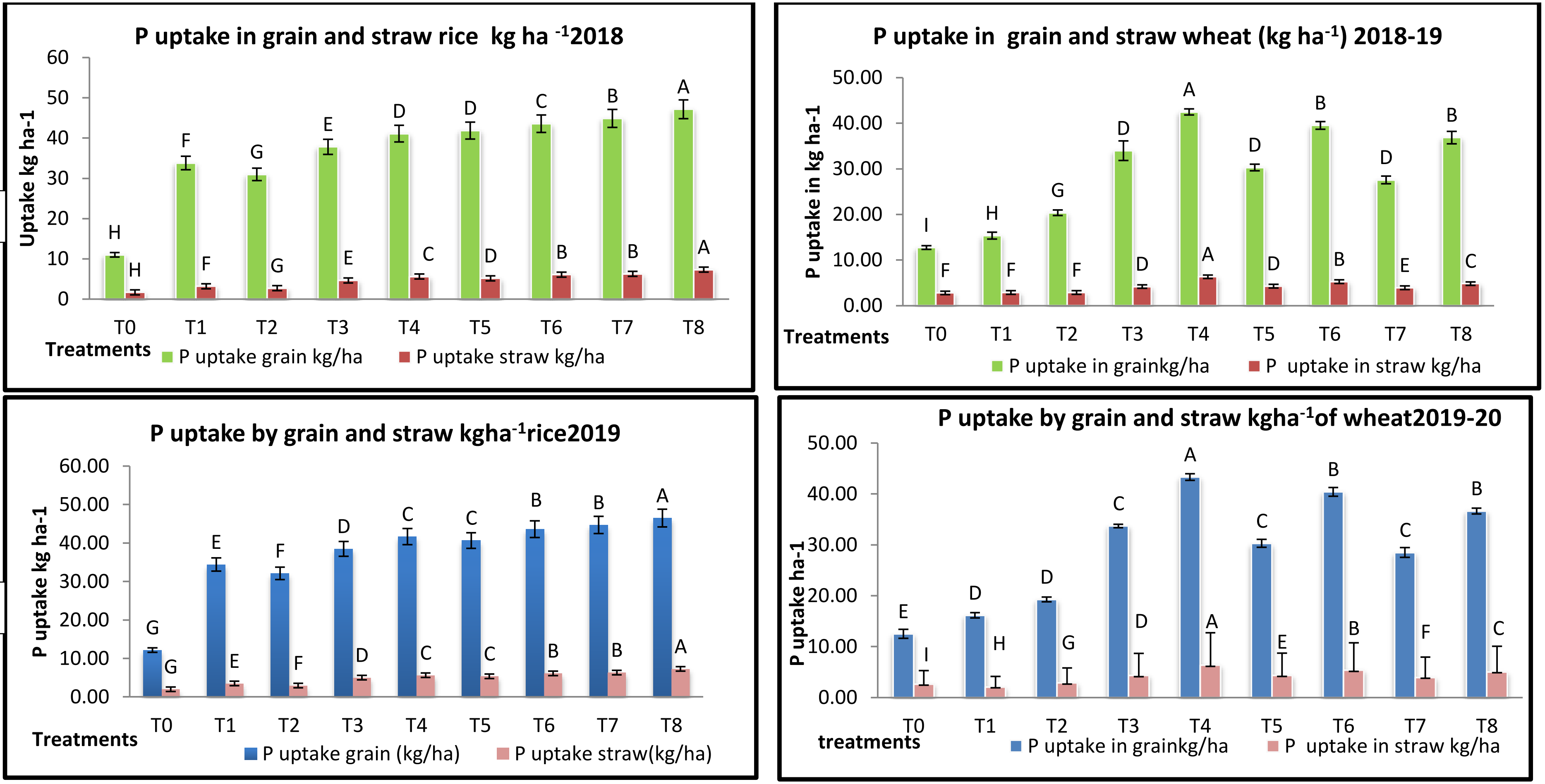


Fig. 4.5.2 A&B ,C&D representing P uptake by grain and straw rice and wheat crop .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

4.5.3Po**tassium uptake by grain and straw**: The study of data on K content at harvest of rice and wheat revealed that K content at all stages were significantly affected by Biochar based amendments during both years. Among all the treatments, the maximum K(25.73,26.3 kg ha^{-1}) uptake during 2018-2019 rice crop were observed from the treatment 50% RDF+50% PM+ Biochar which was significantly more as compared to rest of treatments(control) gave the lowest K content at harvest (7.3,7.83 kgha^{-1}) during both years of study. T8 was followed by T7 during both years in case of K uptake in grain (22.5, 22.73 kgha^{-1}). Order of K content in rice was T8>T7>T6>T4>T5>T3>T1>T2>T0. In following wheat crop all the treatments were significantly different from each other. Highest K uptake in grain of wheat during both years of study was observed with- 50% RDF+50% FYM+ Biochar (24.03, 23.8 kgha^{-1}). The K uptake in grain of wheat ranged from 9-24 kgha^{-1} in 2019-2020. T4 was followed by T6 with 21 and 20.6 kgha$^{-1.}$ K uptake during both years. Lowest K uptake was (9, 8.9 kgha^{-1}) recorded with T0 (control).The order of K content in grain was- T4>T6>T8>T3>T5>T7>T2>T1>T0.The data of K uptake in wheat grain was presented in table 4.5.1(b) and Fig. 4.5.3(c, d). In contrast to K content in grain, K content in straw was also recorded. During 2018-2019 and 2019-2020 the K uptake in rice straw was ranged from 440.87 to 76.17 kg ha^{-1} and 42.03- 78.23kgha^{-1}. The highest K uptake in straw (76.17, 78.23 kgha^{-1}) was recorded with the application of 50% RDF+50% PM+ Biochar during both years of study. This treatment was followed by T7 with 73.57 and 74.77 kgha^{-1} uptake by straw. The lowest K uptake in rice straw was T8> T7> T6> T4> T5> T3> T2> T1>T0. In successive wheat crops during both years the K uptake by wheat straw was significantly more in Biochar amended plots over control. The K uptake in straw ranged from 54.37 to 80.37 kg ha^{-1} and 55.13 to 80.07 kgha^{-1}.The highest K content (88.3,89.33 kgha-^{1})was recorded with the application of 50% RDF+50% FYM+ Biochar- T4 which was followed by T6 with 80.37 and 81.7 kgha^{-1}K uptake by straw . The lowest K uptake (54.37, 55.13 kg ha^{-1}) was recorded with control. The maximum order of K uptake by straw was T4>T6>T8>T3>T5>T7>T2>T1>T0 during both years. The data presented in Fig 4.5.3(c, d).

4.5.3 a,b

4.5.3c,d

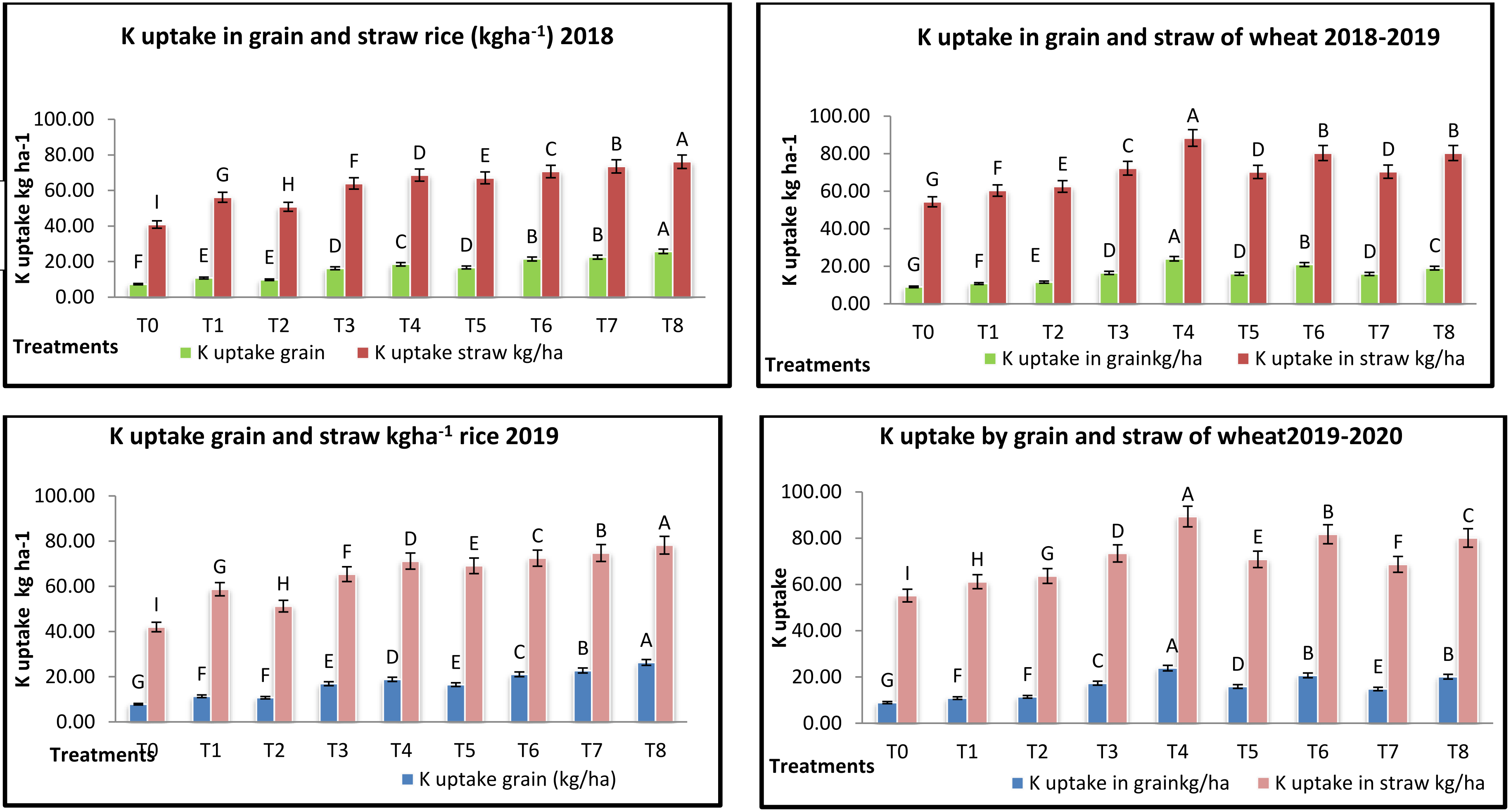


Fig. 4.5.3 A&B ,C&D representing Kuptake by grain and straw rice and wheat crop during 2018-19,2019-2020. .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.5(a) Impact of biochar based amendments on nutrient uptake by grain and straw (N,P,K) of rice .

Treatments	2018						2019					
	N uptake grain(kg ha^{-1})	N uptake straw(kg ha^{-1})	P uptake grain(kg ha^{-1})	P uptake straw(kg ha^{-1})	K uptake grain(kg ha^{-1})	K uptake straw(kg ha^{-1})	N uptake grain(kg ha^{-1})	N uptake straw(kg ha^{-1})	P uptake grain(kg ha-^{1})	P uptake straw(kg ha^{-1}	K uptake grain(kg ha^{-1})	K uptake straw(kg ha^{-1})
T0- Control (no fertilizer)	17.37±0.69H	15.43±0.58H	11.00±0.36H	1.67±0.17H	7.30±0.19F	40.87±0.29I	17.8±1.2H	15.20.8I	12.17±0.29G	2.00±0.16G	7.83±0.17G	42.03±0.21
T1-100%RDF	56.27±0.90F	31.67±0.31F	33.80±0.29F	3.20±0.16F	10.79±0.31E	56.20±0.78G	57.3±0.9F	31.4±0.5G	34.40±0.67E	3.47±0.12E	11.37±0.39F	58.77±0.42G
T2- 50%RDF + Biochar	54.40±0.57G	28.73±0.41G	30.97±0.59G	2.70±0.08G	9.79±0.58E	50.87±0.68H	54.3±1.0G	29.5±0.5H	32.13±0.74H	2.93±0.12F	10.73±0.41F	51.27±0.90H
T3-50%RDF+25%FYM+Biochar	67.30±0.99E	41.40±.54E	37.83±0.29E	4.65±0.13E	16.23±0.75D	63.93±0.54F	68.4±0.9E	41.3±0.7F	38.50±0.90D	5.00±0.08D	16.93±0.25E	65.40±0.59F
T4-50%RDF+50%FYM+Biochar	71.40±1.07D	44.33±0.5D	41.10±0.78D	5.60±0.27C	18.50±0.24C	68.60±0.86D	73.1±0.9D	46.3±0.8D	41.67±0.34C	5.60±0.16C	18.83±0.29D	71.13±0.74D
T5-50%RDF+ 25%Vermi-compost + Biochar	71.90±0.14D	43.77±0.21D	41.87±0.40D	5.17±0.02D	16.70 ±0.51D	67.07±0.86E	71.5±0.9D	43.6±0.3E	40.67±0.34C	5.37±0.17C	16.50±0.64E	69.10±0.67E
T6-50%RDF+ 50%Vermi compost+ Biochar	75.17±0.82C	47.20±0.73C	43.57±0.58C	6.09±0.08B	21.47±1.18B	70.67±0.39C	77.1±0.9C	48.1±0.7C	43.60±0.37B	6.13±0.09B	21.03±0.74C	72.47±0.29C
T7-50%RDF+ 25%poultry manure+ Biochar	79.27±0.79B	48.67±0.59B	44.90±0.36B	6.26±0.05B	22.50±0.82B	73.57±0.66B	81.7±0.3B	49.8±0.4B	44.70±0.22B	6.33±0.12B	22.73±0.49B	74.77±0.42B
T8-50%RDF+50% poultry manure+ Biochar	84.20±0.82A	51.33±0.74A	47.17±0.25A	7.31±0.17A	25.73±0.82A	76.17±0.74A	87.8±0.4A	53.4±0.8A	46.50±0.42A	7.27±0.17A	26.30±0.62A	78.23±0.53A

Table 4.5 b Impact of biochar based amendments on nutrient uptake by grain and straw (N,P,K) of wheat

	2018						2019					
Treatments	N uptake grain(kg ha-^{1})	N uptake straw(kg ha^{-1})	P uptake grain(kg ha^{-1})	P uptake straw(kg ha^{-1})	K uptake grain(kg ha^{-1})	K uptake straw(kg ha^{-1})	N uptake grain(kg ha^{-1})	N uptake straw(kg ha^{-1})	P uptake grain(kg ha^{-1})	P uptake straw(kg ha^{-1}	K uptake grain(kg ha-^{1})	K uptake straw(kg ha^{-1})
T0- Control (no fertilizer)	20.47±0.62H	14.47±0.60F	12.73±0.41I	2.80±0.11F	9.0±0.2G	54.37±0.87G	20.40±0.67I	15.2±0.80F	12.50±0.88E	2.63±0.21I	8.9±0.4G	55.13±0.86I
T1-100%RDF	58.47±0.98G	36.97±0.66E	15.37±0.74H	2.90±0.04F	10.8±0.2F	60.40±0.59F	60.37±0.62H	36.27±0.90E	16.13±0.52D	2.06±0.18H	10.9±0.3F	61.17±0.78H
T2- 50%RDF + Biochar	62.27±1.59F	37.27±0.56E	20.37±0.60G	2.89±0.02F	11.6±0.2E	62.6 ±0.45E	62.25±0.76G	34.97±0.61E	19.2±0.48D	2.90±0.24G	11.5±0.4F	63.67±1.29G
T3-50%RDF+25%FYM +Biochar	75.23±0.82D	48.26±1.36C	33.97±2.15D	4.19±0.07D	16.5±0.4D	72.27±0.78C	76.37±0.86D	48.23±0.78C	33.70±0.36C	4.33±0.25D	17.3±0.3C	73.40±1.02D
T4-50%RDF+50%FYM +Biochar	88.40±0.70A	54.57±0.61A	42.47±0.66A	6.34±0.11A	24.0±0.3A	88.3 ±0.90A	88.27±0.82A	54.37±1.11A	43.32±0.63A	6.37±0.23A	23.8±0.3A	89.33±0.74A
T5-50%RDF+ 25%Vermi-compost + Biochar	72.57±0.92E	42.90±1.35D	30.30±0.70D	4.28±0.03D	16.0±0.5D	70.27±0.82D	74.20±0.82E	43.20±0.73D	30.27±0.78C	4.34±0.22E	15.9±0.5D	70.87±0.25E
T6-50%RDF+ 50%Vermi compost+ Biochar	82.93±1.73B	53.00±0.99B	39.53±0.86B	5.25±0.04B	21.0±0.4B	80.37±0.70B	83.10±0.82B	52.80±0.67AB	40.42±0.85B	5.36±0.22B	20.6±0.5B	81.70±0.37B
T7-50%RDF+ 25%poultry manure+ Biochar	71.53±0.97E	44.00±0.37D	27.57±0.86D	3.92±0.14E	15.9±0.2D	70.43±0.63D	71.43±0.90F	42.33±0.84D	28.48±0.97C	3.95±0.20F	14.8±0.3E	68.67±0.46F
T8-50%RDF+50% poultry manure+ Biochar	79.50±0.80C	52.53±0.53A	36.87±1.35B	4.83±0.07C	19.1±0.4C	80.37±1.32B	80.80±0.94C	51.27 ±0.69B	36.65 ±0.56B	5.02±0.13B	20.1±0.4B	80.07±0.45C

4.5.4 Nitrogen use efficiency: Nitrogen use efficiency shows the response of rice –wheat plants in terms of grain yield to fertilizers. The data computed for NUE (%) of NPK of rice crop presented in table 4.5.4(a) and wheat crop presented in table 4.5.4(b). In case of N during 2018-2019, N use efficiency ranged from 41.9-85.6% and 42.3-90.17%. The maximum N use efficiency (85.6, 90.17%) was recorded under application of 50% RDF+50% PM+ Biochar-T8 in 2018-19 and 2019-2020 respectively. Lowest N (41.91% and 42.36%) recovery was recorded with T2 (50% RDF+ Biochar). All the treatments were significantly better than control. The N use efficiency order in rice- during both years was T8> T7> T6> T5> T4> T3> T2> T1>T0. In succeeding wheat crop N use efficiency (%) ranged from 49.5%-89.53% during 2018-2019 and 50.83%-89.16% during 2019-2020.Highest N use efficiency (89.53, 89.16 kgha-1) was recorded with the application of 50% RDF+50% FYM+ Biochar-T4 followed by T6 (83.56, 83.53%) NUE. The lowest (49.5, 50.83%) N use efficiency was recorded in control. All the treatments were significantly better than control. The order of N use efficiency in wheat crop was T4>T6>T8>T3>T5>T7>T2>T1>T0.

4.5.5. Phosphorous use efficiency (PUE %): Data regarding use efficiency of P presented in table 4.5.4 revealed that PUE ranged from 35-69.7% and 35.46-66.01% during 2018-2019 and 2019-2020. Highest PUE (69.7, 66.01%) was recorded with the application of 50% RDF+50% PM+ Biochar-T8 which was followed by T7 (64.2, 61.44%). All the treatments were significantly better than control in case of PUE. Lowest P recovery was recorded by T2(35%).The order of PUE in rice was T8> T7> T6> T5> T4> T3> T1> T2>T0.In following wheat crop, PUE ranged from 5-56.8% during 2018-2019 and 4.9-57.53% during 2019-2020. Highest PUE (56.8, 57.5%) recorded in T4 followed by T6 (50.9, 51.05%) during both years. Lowest PUE recorded (5, 4.9%) in T1 (100% RDF). Data depicted in Fig. 4.5.5(c, d).

4.5.6 Potassium use efficiency (KUE%): KUE shoes the response of rice-wheat plants in terms of grain yield to fertilizers. The data computed for KUE in rice and wheat crop presented in Fig. 4.5.6(a, b) and 4.5.6(c, d). In case of K during 2018,2019 the K use efficiency ranged from 20.8% to 89.6% and 20.2-91.11% during 2019-2020.Highest K use efficiency (89.6%,9.11%) recorded in T8 during both years which was followed by T7(79.8,79.39%). Lowest KUE recorded in T2 (20.81%, 20.22%). The order of KUE in rice crop was T8> T7> T6> T4> T5> T3> T1> T2>T0. In successive wheat crop the KUE during both years ranged from 11.2-57.27 kgha^{-1} and 11.57-79.13%. The highest KUE (79.13, 79.175) recorded with the application of 50% RDF+50% PM+ Biochar-T4 during both years which was followed by T6 with (60.43,60%). The lowest recovery of KUE (11.2, 11.57%) recorded with T1 (100% RDF). All the treatments were significantly different from each other.

4.5.4 a,b

4.5.4 c,d

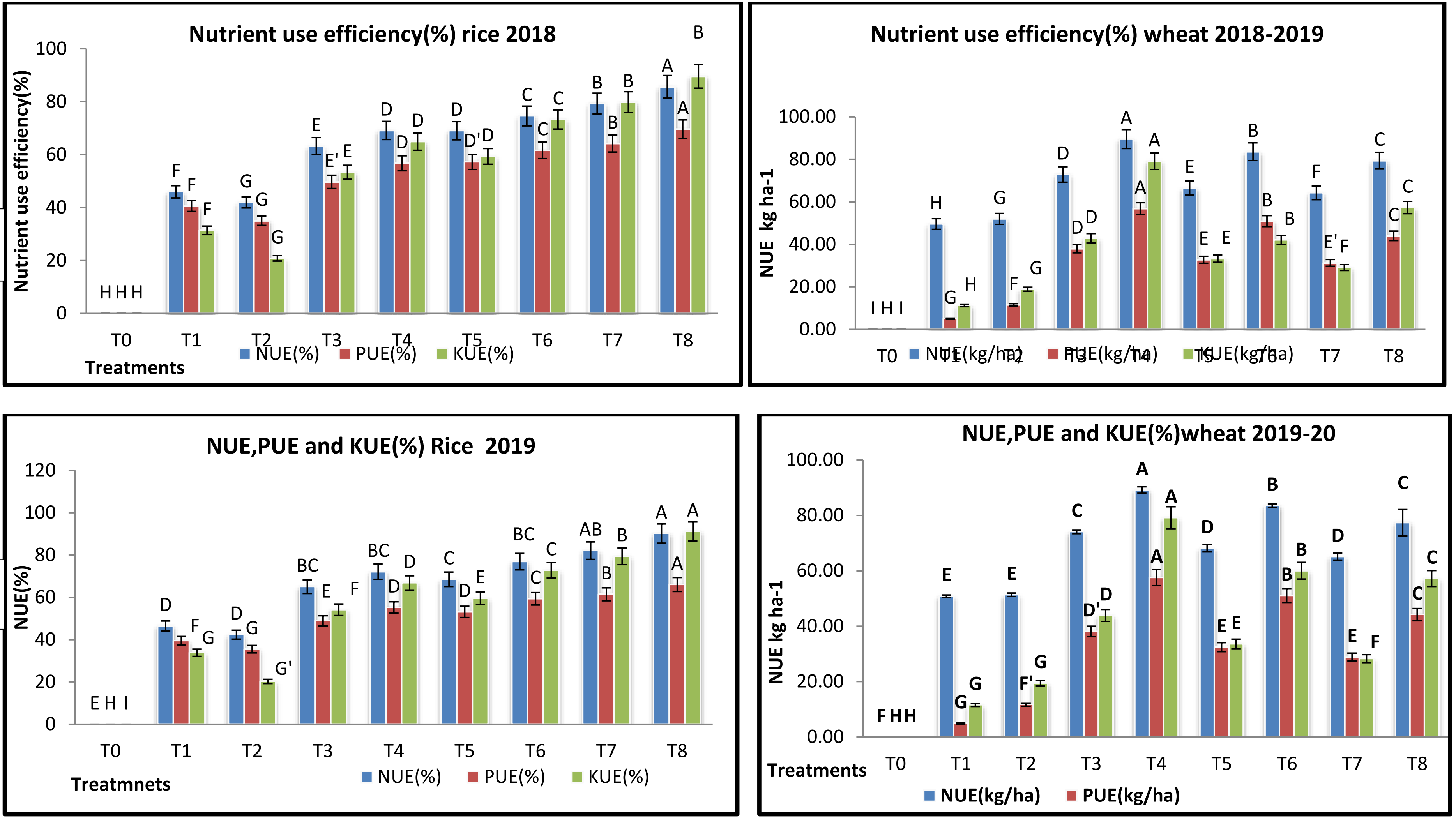


Fig.4.5.4 A&B, C&D representing Nutrient use efficiency(%) in rice and wheat crop during both years .Data shown as mean of S.E. Means with similar letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.5.4(a) Nutrient use efficiency (NUE5, PUE%, KUE%) of rice crop during 2018-2019(mean ± S.E).

	2018			**2019**		
Treatments	NUE (%)	PUE (%)	KUE (%)	NUE (%)	PUE (%)	KUE (%)
T0- Control (no fertilizer)	0±0.0H	0±0.0H	0.0±0.0H	0±0E	0±0H	0±0 I
T1-100%RDF	45.9±1.2F	40.6±1.3F	31.4±0.6F	46.44±0.68D	39.50±1.71F	33.78±1.1H
T2- 50%RDF + Biochar	41.9±1.4G	35.0±0.9G	20.8±1.3G	42.36±0.67D	35.46±0.98G	20.22±0.9G
T3-50%RDF+25%FYM+Biochar	63.3±0.4E	49.7±1.4E	53.3±1.7E	65.03±2.51BC	48.89±1.53E	54.11±0.8F
T4-50%RDF+50%FYM+Biochar	69.1±2.4D	56.7±1.1D	64.9±0.D	72.06±2.62BC	55.17±0.83D	66.83±1.2D
T5-50%RDF+ 25%Vermi-compost + Biochar	69.1±0.9D	57.3±0.2D	59.3±1.2D	68.50±2.26C	53.11±1.02D	59.56±1.1E
T6-50%RDF+ 50%Vermi compost+ Biochar	74.6±2.3C	61.6±1.7C	73.3±2.7C	76.89±2.68BC	59.28±0.34C	72.72±1.6C
T7-50%RDF+ 25%poultry manure+ Biochar	79.3±1.9B	64.2±1.2B	79.8±1.9B	82.08±1.74AB	61.44±0.42B	79.39±1.5B
T8-50%RDF+50% poultry manure+ Biochar	85.6±0.9A	69.7±1.1A	89.6±1.2A	90.17±2.30A	66.01±1.06A	91.11±1.6A

Table 4.5.4(b) Nutrient use efficiency (NUE%, PUE%, KUE%) of wheat crop during 2018-2019(mean ± S.E).

Treatments	**2018**			**2019**		
	NUE (%)	PUE (%)	KUE (%)	NUE (%)	PUE (%)	KUE (%)
T0- Control (no fertilizer)	0±0I	0±0H	0±0I	0.00±0.00F	0.00±0.00H	0.00±0.00H
T1-100%RDF	49.5±1.19H	5.00±1.39G	11.20±0.16H	50.83±0.44E	4.90±1.22G	11.57±0.05G
T2- 50%RDF + Biochar	51.93±0.50G	11.431.18F	18.90 ±0.08G	51.33±0.62E	11.67±1.41F	19.43±0.09G
T3-50%RDF+25%FYM+Biochar	72.87±0.74D	37.93±1.82D	42.90 ±0.22D	74.07 ±0.68C	38.10±1.64D	43.83±0.74D
T4-50%RDF+50%FYM+Biochar	89.53±0.50A	56.80±1.10A	79.13 ±0.57A	89.16 ±1.19A	57.53±0.45A	79.17±0.79A
T5-50%RDF+ 25%Vermi-compost + Biochar	66.52±0.79E	32.77±1.45E	33.23±0.81E	68.15±1.31D	32.43±2.19E	33.57±0.48E
T6-50%RDF+ 50%Vermi compost+ Biochar	83.56±0.72B	50.90±2.01B	60.43±0.82B	83.53±0.57B	51.05±2.59B	60.00±0.71B
T7-50%RDF+ 25%poultry manure+ Biochar	64.27±0.39F	31.23±5.70E	29.07±0.25F	65.07±1.27D	28.83±2.66E	28.27±0.45F
T8-50%RDF+50% poultry manure+ Biochar	79.37±0.68C	43.97±1.40C	57.27±0.39C	77.35±4.79C	44.17±0.96C	57.17±0.70C

4.6 Result of pot experiment:

4.6.1 Effect of Biochar application on crop growth of crops:

4.6.1.1: Plant height (cm): Plant height is the important characteristic which we used for observing the effect of different treatments. The data on periodic plant height of rice at 20, 40, 60 and 80 DAT and wheat crop at 30, 60, 90 and 120 DAS are presented in table 4.6.1.1 and Fig. 4.6.61.1(a) and 4.6.1.1(b). The analysis of variance of different treatments over mean was presented in Fig. Rice plant height ranged from 48.23 cm to 107.83 cm .All the treatments over control increased the plant height at all intervals over control. 50%RDF+50% poultry manure+ Biochar (T8) recorded highest plant height (65.93,80.70,94.6 and 107.83 cm) at 20, 40, 60 and 80 DAT. T8 was followed by T7(50%RDF+ 25%poultry manure+ Biochar) with 62.29,78.4,91.07 and 100.8 cm plant height and T4 (50%RDF+50%FYM+Biochar) with 61.2,75.17,92.4,101.23 cm at 20, 40, 60 and 80 DAT. T7 and T4 were at par and non -significant with each other. All the other treatments were significantly different from each other. The lowest plant height48.23,55.93,67.2 and 81.27 cm at 20, 40, 60 and 80 DAT recorded under T0(Control).In case of wheat crop the plant height ranged from 23.97 to 87

cm. The maximum plant height(32.3,65.86,82.53,87.63 cm) recorded by application of 50%RDF+50%FYM+Biochar (T4) at 30, 60, 90 and 120 DAS which was immediately followed by T8(50%RDF+50% poultry manure+ Biochar) with 32.07,64.39,80.71 and 84.67 cm and T6(50%RDF+ 50%Vermi compost+ Biochar) 31.83,61.56,78.96 and 82.34cm plant height respectively .The minimum plant height (23.97,51.21,65.98 and 69.26 cm) recorded under T0(control) which was followed by T1(100%RDF) with values- 28.93,52.11,71.32,78.43 cm respectively at 30, 60, 90 and 120 DAS.

Table 4.6.1. Avg. Plant height of rice and wheat(cm) (mean±S.E) at different intervals in pot experiment influenced by biochar based amendments.

Treatments	**Rice**				**Wheat**			
	20DAT	40DAT	60DAT	80DAT	30DAS	60DAS	90DAS	120DAS
T0- Control (no fertilizer)	48.23±2.15F	55.93±0.45F	67.2±0.82G	81.27±0.86F	23.97±2.47B	51.21±0.90G	65.98±0.24H	69.26±0.78
T1-100%RDF	55.37±0.45E	65.27±0.86E	81.40±0.83F	91.50±0.86E	28.93±2.90AB	52.11±0.36G	71.32±0.3G	78.43±0.56
T2- 50%RDF + Biochar	50.2±0.82D	64.07±0.84E	80.23±0.74F	90.23±0.78E	28.77±2.39AB	57.26±0.86F	74.10±0.50F	80.7±0.57
T3-50%RDF+25%FYM+Biochar	57.03±0.79DE	71.10±0.73D	89.03±0.60C	95.33±0.66D	29.43±3.16A	62.86±0.39C	79.0±0.45C	80.80±0.54
T4-50%RDF+50%FYM+Biochar	61.20±0.96B	75.17±0.33C	92.40±0.14B	101.23±0.86B	32.30±1.87A	65.86±0.54A	82.53±0.53A	87.63±0.54
T5-50%RDF+ 25%Vermi-compost + Biochar	58.90±0.29CD	70.93±0.52D	84.00±0.67E	96.33±0.78CD	29.53±2.19A	59.73±0.34E	75.08±0.23E	80.57±0.45
T6-50%RDF+ 50%Vermi compost+ Biochar	60.87±0.57BC	75.67±0.45C	87.10±0.83D	97.60±0.64C	31.83±1.39A	61.5±0.53D	78.96±0.61C	82.34±0.69
T7-50%RDF+ 25%poultry manure+ Biochar	62.29±0.56B	78.40±0.91B	91.07±0.34B	100.8 ±0.93B	29.80±2.26A	57.80±0.57F	77.64±0.33D	81.53±0.29C
T8-50%RDF+50% poultry manure+ Biochar	65.93±0.90A	80.70±0.45A	94.60±0.37A	107.83±0.61A	32.0±1.20A	64.39±0.29B	80.71±0.37B	84.67±0.39

4.6.1.2 Total tillers and productive tillers: The mean data of total tillers and productive tillers of rice and wheat crop presented in table 4.6.1.2. In rice crop total tillers were counted at 20, 40,60DAT and productive tillers at 80DAT. The total tillers ranged from 4.27 to 15.70. Maximum total tillers (8.40,12.73,15.70) find out in T8 with application of 50%RDF+50% poultry manure+ Biochar followed by T7 -50%RDF+ 25%poultry manure+ Biochar (7.84,11.83,14.60). The next highest total tillers after T7 recorded in T4 and T6. The least number of tillers 4.27, 7.7, 8.9 recorded in T0 (control) at 20, 40 and 60 DAT followed by T1 and T2. Maximum productive tillers (13.77) recorded in T8 followed by T7 (12.83) and T6 (11.87).The minimum productive tillers (6) recorded in T0 followed by T250%RDF + Biochar (7.7). The data of total tillers and productive tillers of rice are depicted in Fig. 4.6.1.2(a).

In wheat crop the total tillers recorded per pot. The total tillers ranged from 16.67 to 41. The maximum total tillers(41) and productive tillers(37.3) recorded with the application of 50%RDF+50%FYM+Biochar(T4) followed by T8(50%RDF+50% poultry manure+ Biochar) with 36 total tillers and 32 productive tillers. The minimum total and productive tillers (16.6, 12) computed under T0 followed by T2 (100% RDF) with 27 total tillers and 23.3 productive tillers. The data of total tillers and productive tillers of wheat are depicted in Fig. 4.6.1.2 (b).

4.6.1 a,b

4.6.2 a,b

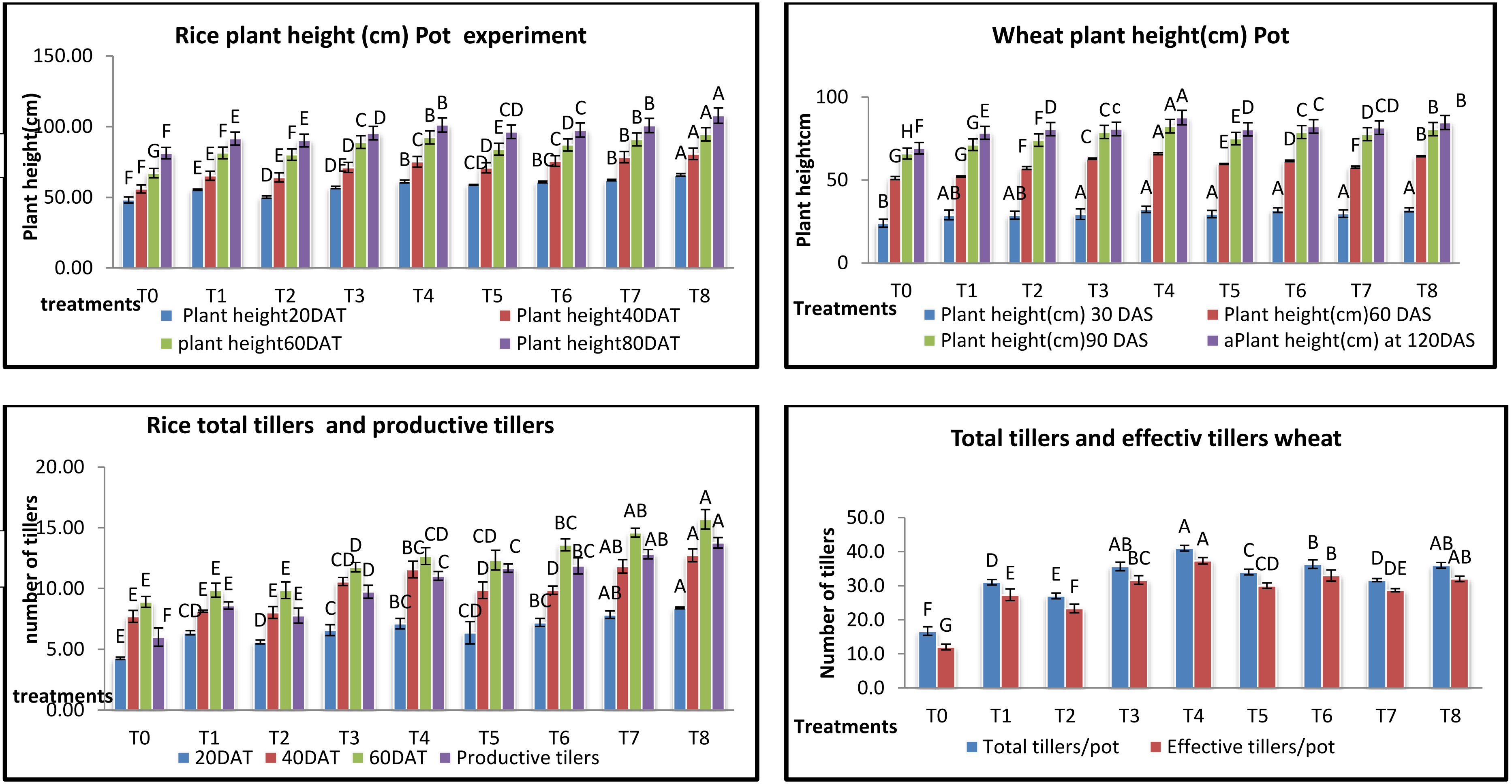


Fig. 4.6.1A&B representing theavg. plant height (cm) at different intervals and Fig.4.6.2 A&B representing total and effective tillers in rice and wheat crop in pot experiment.Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$.

Table 4.6.1.2 Effect of biochar based different treatments on total tillers and effective tillers(mean±S.E) of rice- wheat crop in pot experiment.

Treatments	Rice				Wheat	
	Tillers at 20DAT	Tillers at 40DAT	Tillers at 60DAT	Productive tillers	Total tillers	Productive tillers
T0- Control (no fertilizer)	4.27±0.09E	7.70±0.50E	8.90±0.45E	6.00±0.75F	16.67±1.25F	12.0±0.8G
T1-100%RDF	6.37±0.17CD	8.13±0.09E	9.87±0.57E	8.60±0.29bE	31.00±0.82D	27.3±1.7E
T2- 50%RDF + Biochar	5.60±0.16D	8.03±0.49E	9.87±0.68E	7.77±0.62E	27.00±0.82E	23.3±1.2F
T3-50%RDF+25%FYM+Biochar	6.57±0.45C	10.57±0.33CD	11.77±0.39D	9.73±0.52D	35.67±1.25AB	31.7±1.2BC
T4-50%RDF+50%FYM+ Biochar	7.10±0.4BC	11.57±0.68BC	12.67±0.70CD	11.03±0.37C	41.00±0.82A	37.3±0.9A
T5-50%RDF+ 25%Vermi-compost + Biochar	6.37±0.92CD	9.87±0.68D	12.33±0.82CD	11.67±0.34C	34.00±0.82C	30.0±0.8CD
T6-50%RDF+ 50%Vermi compost+ Biochar	7.20±0.33BC	9.87±0.34D	13.60±0.49BC	11.87±0.66BC	36.33±1.25B	33.0±1.6B
T7-50%RDF+ 25%poultry manure+ Biochar	7.84±0.31AB	11.83±0.56AB	14.60±0.36AB	12.83±0.39AB	31.67±083D	28.7±0.5DE
T8-50%RDF+50% poultry manure+ Biochar	8.40±0.08A	12.73±0.52A	15.70±0.80A	13.77±0.42A	36.00±0.82AB	32.0±0.8AB

4.6.1.3: Fresh weight and dry weight of plants: Fresh weight and dry weight of plant in rice crop recorded at 40 and 80 DAT and in wheat crop at 60 and 75 DAS presented in table 4.6.1.3. The fresh and dry weight of plant was significantly influenced by different treatments. This is the best indicator of crop growth. In rice crop maximum fresh weight and dry weight (67.33 g , 34.23 g) at 40 DAT and (122.3 and 65.33) at 80 DAT recorded with the application of 50%RDF+50% poultry manure+ Biochar- T8. The second highest fresh weight and dry weight (57.8, 30.13g) at 40 DAT and (111.3,51.0 g) at 80 DAT recorded under T7-50%RDF+ 25%poultry manure+ Biochar. All the treatments were significantly increased the weight of plants over control. The lowest fresh and dry weight (24, 11.97 g and 70.53, 32.73 g) recorded under T0 followed by T1 (46.87, 24.13, 90.17, 37.6 g) at 40 and 80 DAT. The data of fresh weight and dry weight of rice presented in Fig. 4.6.1.3(a) .In wheat crop the maximum fresh and dry weight (45.58, 22.4 g) at 60 DAS and (55.8, 35.62 g) at 75 DAS under T4-50%RDF+50%FYM+Biochar. T4 followed by T3 at 60 DAS with 20.3, 44.6 g fresh and dry weight and by T8 at 75DAS with- 49.41 and 31.56 g. The lowest fresh and dry weight (21.24, 10.6g and 26.32, 13.89g) at 60 and 75 DAS recorded under T0 followed by T1 (31.08, 15.7, 38.51, 20.58). The data of fresh weight and dry weight of wheat are presented inFig.4.6.1.3(b)

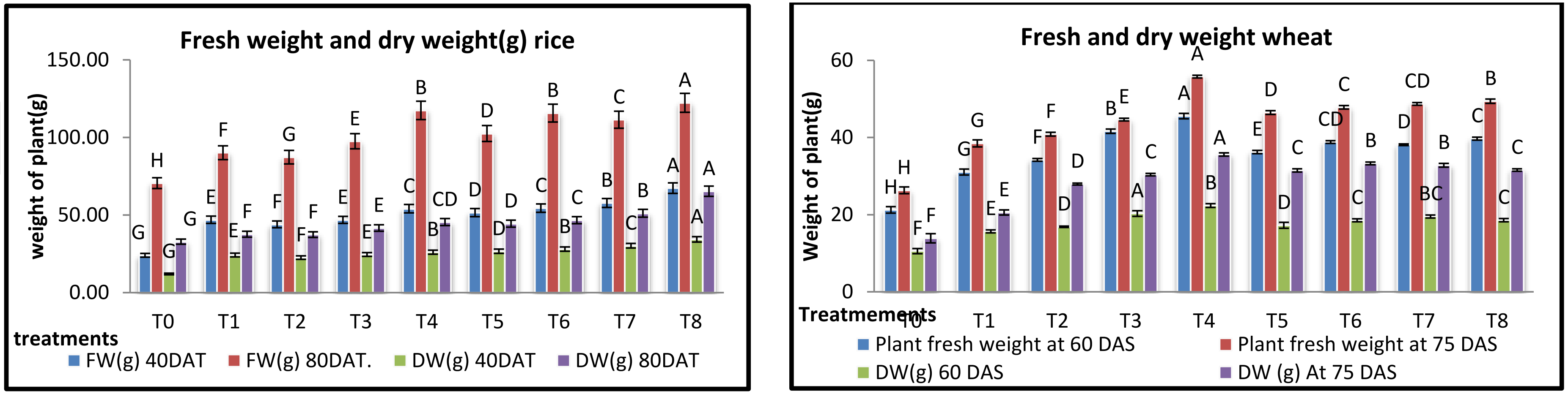
Table 4.6.1.3Effect of different biochar treatments on fresh and dry weight(g) (mean± S.E) of plants of rice wheat crop at different intervals in pot experiment.

Treatments	RICE				WHEAT			
	Fresh weight(g) 40DAT	Dry weight(g) 40 DAT	Fresh weight(g) 80DAT	Dry weight(g) 80DAT	Fresh weight(g) 60DAS	Dry weight(g) 60DAS	Fresh weight(g) 75DAS	Dry weight(g) 75DAS
T0- Control (no fertilizer)	24.00 ±0.65G	11.97 ±0.47G	70.53 ±0.92H	32.73 ±0.63G	21.24 ±0.82H	10.6 ±0.7F	26.32 ±0.90H	13.89 ±1.19F
T1-100%RDF	46.87 ±0.34E	24.13 ±0.53E	90.17 ±0.86F	37.60 ±0.37F	31.08 ±0.76G	15.7 ±0.4E	38.51 ±0.90G	20.58 ±0.65E
T2- 50%RDF + Biochar	43.90 ±0.51F	22.57 ±0.33F	87.32 ±0.92G	37.37 ±0.83F	34.2 ±0.33F	16.9 ±0.2D	40.88 ±0.48F	27.96 ±0.26D
T3-50%RDF+25%FYM+Biochar	46.83 ±0.39E	24.43 ±0.24E	97.50 ±0.82E	41.63 ±0.59E	41.62 ±0.55B	20.3 ±0.7A	44.66 ±0.32E	30.38 ±0.30C
T4-50%RDF+50%FYM+Biochar	54.03 ±0.60C	26.07 ±0.69D	117.47 ±0.90B	45.40 ±0.59CD	45.58 ±0.7A	22.4 ±0.5B	55.80 ±0.33A	35.62 ±0.41A
T5-50%RDF+ 25%Vermi-compost + Biochar	51.57 ±0.52D	26.60 ±0.57D	102.53 ±0.71D	44.40 ±0.67D	36.27 ±0.41E	17.3 ±0.8D	46.49 ±0.50D	31.48 ±0.44C
T6-50%RDF+ 50%Vermi compost+ Biochar	54.43 ±0.24C	27.93 ±0.50C	115.73 ±0.41B	46.63 ±0.42C	38.83 ±0.37CD	18.5 ±0.4C	47.84 ±0.47C	33.31 ±0.35B
T7-50%RDF+ 25%poultry manure+ Biochar	57.80 ±0.50B	30.13 ±0.86B	111.43 ±1.07C	51.10 ±0.22B	38.17 ±0.21D	19.5 ±0.4BC	48.71 ±0.36CD	32.82 ±0.48B
T8-50%RDF+50% poultry manure+ Biochar	67.33 ±0.79A	34.23 ±0.82A	122.30 ±1.80A	65.33 ±0.74A	39.73 ±0.39C	18.6 ±0.4C	49.41 ±0.58B	31.56 ±0.32C

4.6.1.4 Chlorophyindex: The chlorophyll indexof rice and wheat crop as influenced by different treatments of Biochar combined fertilizers predicted in table 4.6.1.4. The results reported that chlorophyll indexof rice and wheat crops increased with Biochar application. The maximum chlorophyll indexin rice crop (48.13, 52.97 SPAD) at 40 and 80 DAT recorded with the application of 50%RDF+50% poultry manure+ Biochar-T8 followed by T7-50%RDF+ 25%poultry manure+ Biochar(46.63,50.03 SPAD) and T4(45.3,50.93 SPAD) at 40 and 80 DAT .The minimum chlorophyll index(37.77,40 SPAD) recorded under T0 followed by T2(41.97,45.86 SPAD) and T1(41.97,45.86 SPAD). The data of rice chlorophyll indexwas presented in Fig. 4.6.14 (a). All the treatments significantly show superiority in chlorophyll indexover control. In wheat crop, the chlorophyll indexrecorded maximum(44.67,47.70 SPAD) recorded with 50%RDF+50%FYM+Biochar(T4) which was immediately followed by T6-50%RDF+ 50%Vermi compost+ Biochar (43.61,46.48 SPAD) and T8-50%RDF+50% poultry manure+ Biochar(42.74,46.72 SPAD).The lowest chlorophyll index(32.68,36.19 SPAD) recorded under T0 followed by T1 and T2. The data of chlorophyll indexwas presented in Fig. 4.6.1.4(b)

4.6.1.5: Leaf area: The leaf area of crop was significantly influenced by various combinations of Biochar combined fertilizers presented in Fig. 4.6.15(a) and 4.6.1.5(b). In rice crop significantly highest leaf area (66.27,78.40 cm^2) recorded under T8-50%RDF+50% poultry manure+ Biochar which was immediately followed by T7-50%RDF+25% poultry manure+ Biochar (65.93,73.93 cm^2) and T6 -50%RDF+ 50%Vermi compost+ Biochar(65.03,73.07 cm^2) at 40 and 80 DAT respectively. The least leaf area (56.5, 65.53 cm^2) recoded at 40 and 80 DAT under T0 followed by T2 (60.2, 68.77 cm^2). The leaf area of rice was depicted in Fig. 4.6.15 (a). In wheat crop the maximum leaf area (60.3, 71.2 cm^2) at 60 and 75 DAS recorded in T4-50%RDF+50%FYM+Biochar followed by T6-50%RDF+ 50%Vermi compost+ Biochar(57.2,67.9 cm^2). The other treatments also showed superiority in leaf area over control. T7 and T3 also showed more leaf area over other treatments. The minimum leaf area (31.8, 41.5 cm^2) recorded in T0 followed by T1 (41.2, 51.3 cm^2).

4.6.1.3 a,b



4.6.1.4 a,b

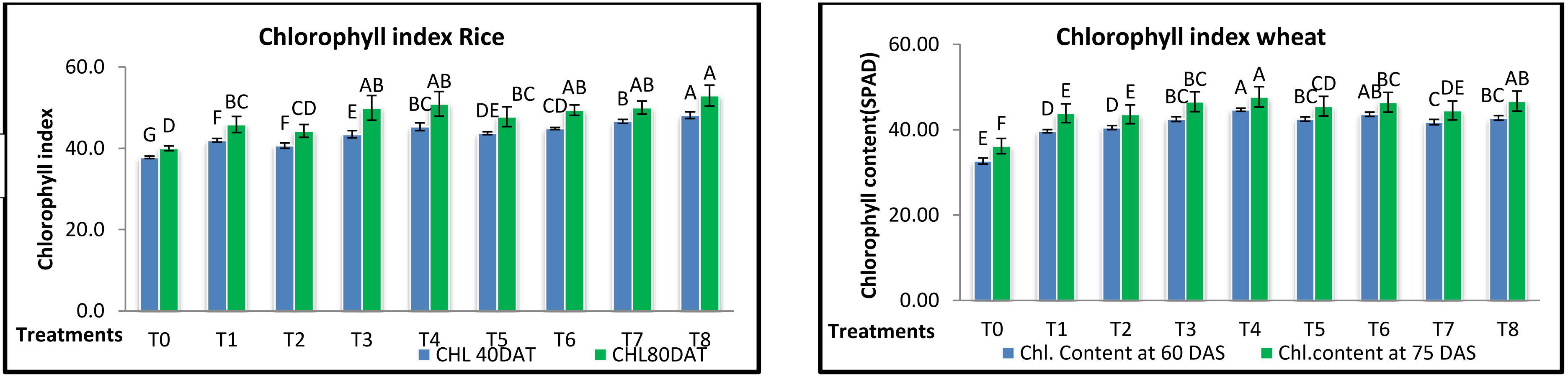
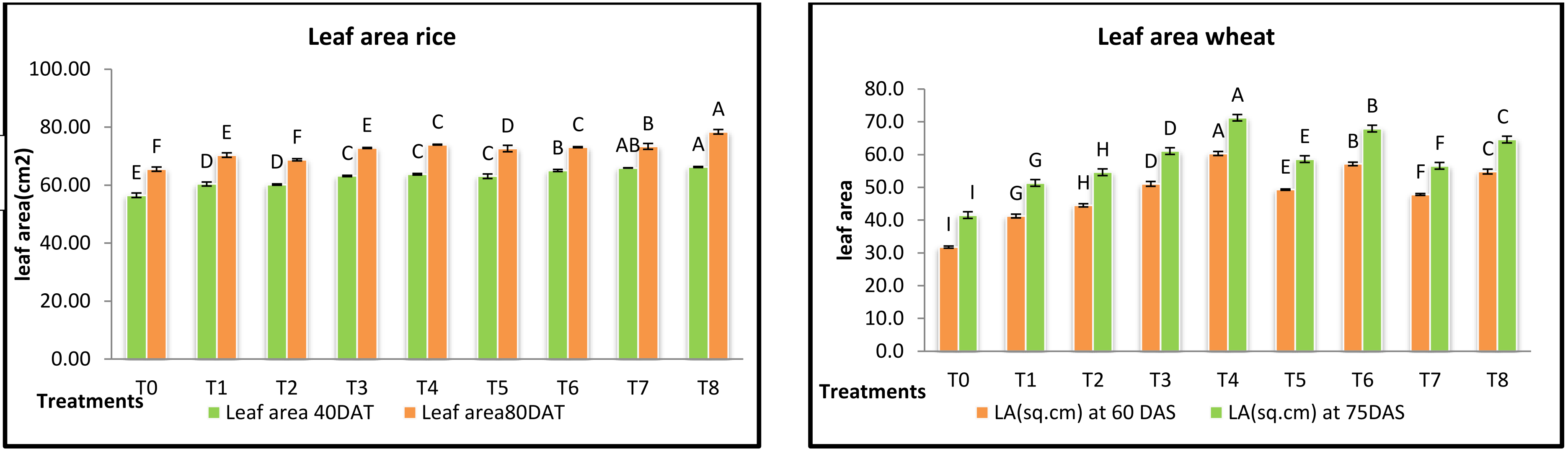


Fig.4.6.1.3 A&B representing the fresh weight and dry weight(g) at different intervals and Fig. 4.6.1.4 A&B representing chlorophyll index of rice and wheat crop in pot experiment .Data shown as mean of S.E. Means with comon letters for each Fig. are not significantly different according to LSD at $p<0.05$.

4.6.1.5 a,b



4.6.1.6 a,b

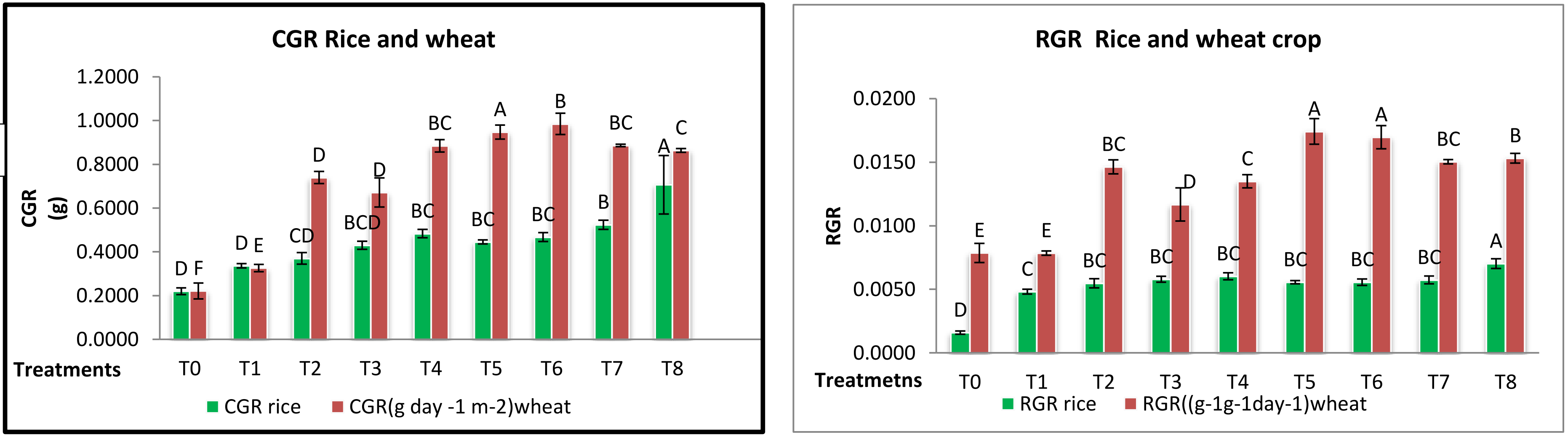


Fig.4.6.1.5 A&B representing the leaf area at different intervals and Fig.4.6.1.6 A&B representing CGR, RGR of rice and wheat crop .Data shown as mean of S.E. Means with same letters for each Fig. are not significantly different according to LSD at $p<0.05$

Table 4.6.1.3 Effect of biochar based amendments on chlorophyll index (SPAD) and leaf area (cm^2) of rice-wheat cropping system in pot experiment.

Treatments	RICE				WHEAT			
	Chlorophyll index(SPAD) 40DAT	Chlorophyll index (SPAD) 80DAT	Leaf area(cm^2) at 40 DAT	Leaf area (cm^2) at80DAT	Chlorophyll content (SPAD) 60DAS	Chlorophyll content SPAD) 75DAS	Leaf area(cm^2) at 60 DAS	Leaf area(cm^2) at 75DAS
T0- Control (no fertilizer)	37.77±0.31G	40.00±0.59D	56.50±0.78E	65.53±0.76F	32.68±0.74E	36.19±0.78F	31.8±0.3I	41.5±0.5I
T1-100%RDF	41.97±0.47F	45.86±2.00BC	60.40±0.70D	70.37±0.79E	39.66±0.39D	43.87±0.17E	41.2±0.6G	51.3±0.9G
T2- 50%RDF + Biochar	40.67±0.66F	44.27±1.58CD	60.20±0.24D	68.77±0.38F	40.51±0.49D	43.61±0.43E	44.5±0.5H	54.6±0.2H
T3-50%RDF+25%FYM+Biochar	43.43±0.90E	49.93±3.04AB	63.17±0.21C	72.83±0.17E	42.50±0.57BC	46.56±0.39BC	51.0±0.8D	61.1±0.7D
T4-50%RDF+50%FYM+Biochar	45.30±0.98BC	50.93±3.04AB	63.77±0.25C	73.97±0.12C	44.67±0.38A	47.70±0.36A	60.3±0.6A	71.2±0.6A
T5-50%RDF+ 25%Vermi-compost + Biochar	43.71±0.39DE	47.77±2.44BC	63.10±0.78C	72.63±1.08D	42.49±0.50BC	45.53±0.47CD	49.3±0.2E	58.6±0.3E
T6-50%RDF+ 50%Vermi compost+ Biochar	44.87±0.25CD	49.40±1.28AB	65.03±0.37B	73.07±0.9C	43.61±0.51AB	46.48±0.44BC	57.2±0.5B	67.9±0.4B
T7-50%RDF+ 25%poultry manure+ Biochar	46.63±0.51B	50.03±1.64AB	65.93±0.05AB	73.37±0.98B	41.82±0.64C	44.53±0.48DE	47.8±0.3F	56.6±0.3F
T8-50%RDF+50% poultry manure+ Biochar	48.13±0.79A	52.97±2.57A	66.27±0.21A	78.40±0.78A	42.76±0.53BC	46.72±0.57AB	54.8±0.7C	64.6±0.6C

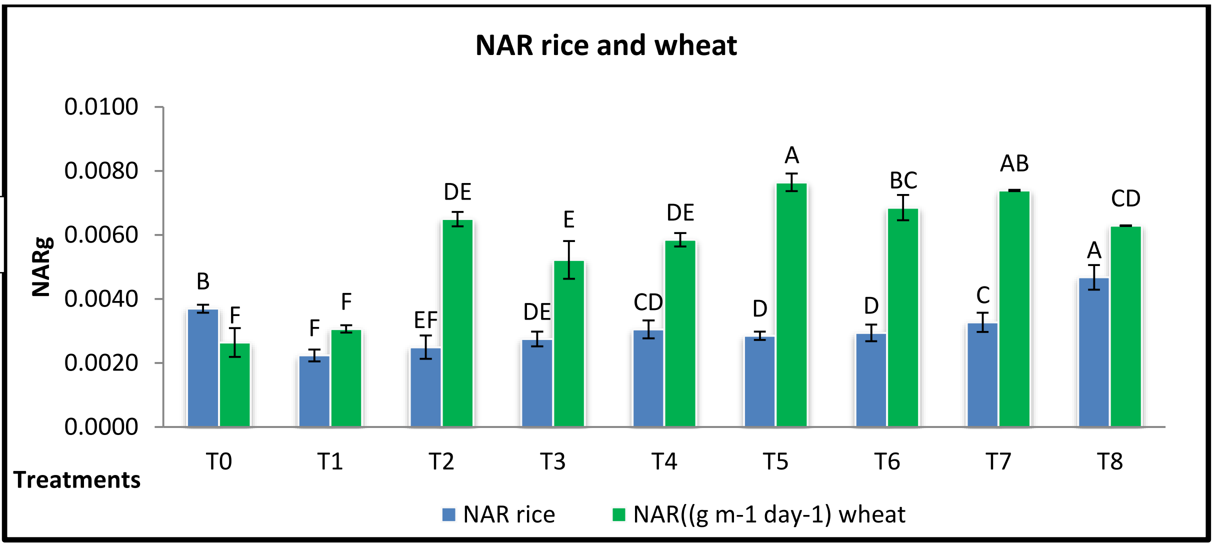
Table 4.6.1.4 Effect of biochar based amendments on chlorophyll index (SPAD) and leaf area (cm^2) of rice-wheat cropping system in pot experiment.

Treatments	RICE			WHEAT		
	CGR	RGR	NAR	CGR	RGR	NAR
T0- Control (no fertilizer)	0.22±0.01D	0.016±0.0024D	0.00370±0.00010B	0.22±0.036F	0.0079±0.0008E	0.00264±0.00045F
T1-100%RDF	0.34±0.01D	0.0048±0.0002C	0.00224±0.00009F	0.33±0.016E	0.0078±0.0002E	0.00307±0.00011F
T2- 50%RDF + Biochar	0.37±0.03CD	0.0055±0.0004BC	0.00250±0.00019EF	0.74±0.028D	0.0146±0.0005BC	0.00650±0.00022DE
T3-50%RDF+25%FYM+Biochar	0.43±0.02BCD	0.0058±0.0002BC	0.00275±0.00012DE	0.67±0.067D	0.0117±0.0013D	0.00522±0.00059E
T4-50%RDF+50%FYM+Biochar	0.48±0.02BC	0.0060±0.0003BC	0.00305±0.00012CD	0.88±0.028BC	0.0135±0.0005C	0.00585±0.00021DE
T5-50%RDF+ 25%Vermi-compost + Biochar	0.45±0.01BC	0.0056±0.0001BC	0.00285±0.00005D	0.98±0.033A	0.0174±0.0010A	0.00765±0.00028A
T6-50%RDF+ 50%Vermi compost+ Biochar	0.47±0.02BC	0.0056±0.0003BC	0.00294±0.00012D	0.94±0.049B	0.0170±0.0009A	0.00686±0.00039BC
T7-50%RDF+ 25%poultry manure+ Biochar	0.52±0.02B	0.0057±0.0003BC	0.00327±0.00015C	0.89±0.006BC	0.0150±0.0002BC	0.00739±0.00002AB
T8-50%RDF+50% poultry manure+ Biochar	0.71±0.13A	0.0070±0.0004A	0.00468±0.00022A	0.86±0.008C	0.0153±0.0004B	0.00630±0.00001CD

4.6.1.6 CGR, RGR and NAR: Data pertaining to CGR, RGR and NAR influenced by Biochar amendments presented in table 4.6.1.6. In rice crop maximum CGR, RGR and NAR (0.71,0.0070 and 0.00468g) recorded under T8-50%RDF+50% poultry manure+ Biochar which was immediately followed by T7-50%RDF+ 25%poultry manure+ Biochar(0.52,0.0057,0.00327g) and T4-50%RDF+50%FYM+Biochar(0.48,0.0060,0.00305g). The minimum CGR, RGR and NAR (0.34, 0.0048, 0.00224 g) recorded under T1- 100% RDF. The data of rice CGR, RGR and NAR was presented in Fig. 4.6.1.6 (a). In wheat crop CGR, RGR and NAR was significantly affected by various combinations as depicted in Fig. 4.6.1.6(b). The maximum CGR, RGR and NAR (0.95,0.0174,0.00765g) recorded by the application of 50%RDF+2 5%Vermi compost+ Biochar-T5 which was immediately followed by T6- 50%RDF+ 50%Vermi compost+ Biochar(0.94,0.0170,0.0686) .The minimum CGR,RGR and NAR(0.22,0.0079,0.00264 g) recorded under T0 followed by t1(0.33,0.0078,0.00307 g). All the treatments showed superiority in growth rates over control.

4.6.1.7: Flag leaf length (cm): In case of wheat crop flag leaf length recorded at 60 and 75 DAS presented in table 4.6.1.8 and Fig. 4.6.1.7. The highest leaf length (32.35, 38.8 cm) recorded under T4--50%RDF+50%FYM+Biochar at 60 and 75 Das. The second highest flag leaf length (30.6,37.6 cm) recorded under T5-50%RDF+ 25%Vermi-compost + Biochar and T8 -50%RDF+50% poultry manure+ Biochar(30.35,36.7 cm). The least flag leaf length (21.5, 30.57 cm) recorded in T0 followed by T1 (23.95, 35.33cm) at 60 and 75 DAS All the treatments increased flag leaf length over control.

4.6.1.6c



4.6.1.7

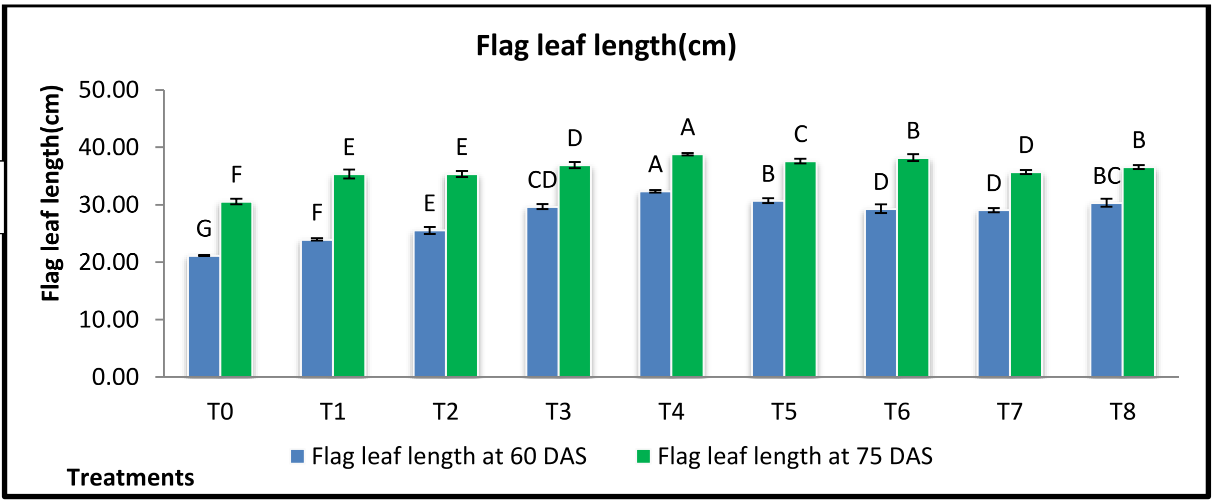


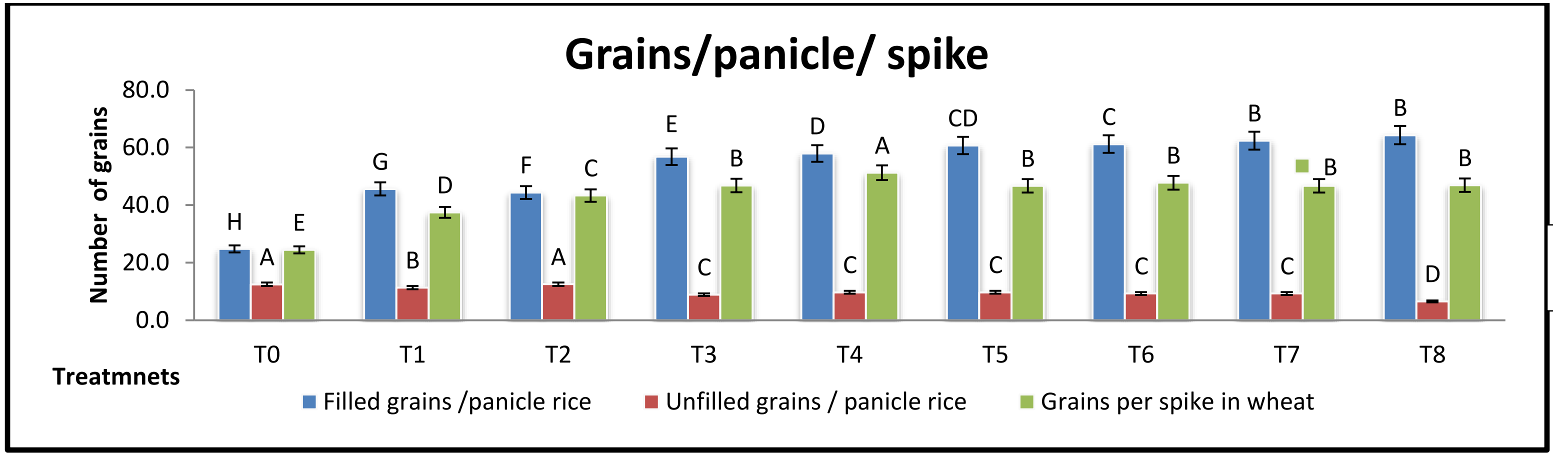
Fig. 4.6.1.6 c representing NAR and Fig. 4.6.1.7 representing flag leaf length (cm) in rice wheat crop in pot experiment.dfferent letters above the error bars indicate that treatments are non significant among themselves according to DMRT ($p<0.05$).

4.6.2 Yield attributing parameters:

4.6.2.1 .Panicle length: Panicle length and spikelet length was significantly affected by the Biochar amendments presented in table 4.6.2.1 and Fig. 4.6.2.1. The panicle length in rice (28.03 cm) recorded maximum in T8 followed by T4 (25.27 cm). T6-50%RDF+ 50%Vermi compost+ Biochar (23.97 cm) and T7-50%RDF+ 25%poultry manure+ Biochar (23.8) also recorded more panicle length over other treatments. The minimum panicle length (20.3 cm) recorded inT0. In wheat crop spikelet length varied from 8.1 to 15.2 cm. The longest spike (15.6cm) recorded in T4 which was immediately followed by T6-50%RDF+ 50%Vermi compost+ Biochar (14.2 cm). The minimum spikelet length (8.1 cm) observed in T0 followed by T1-9.6cm.All the treatments increased the spikelet length over control.

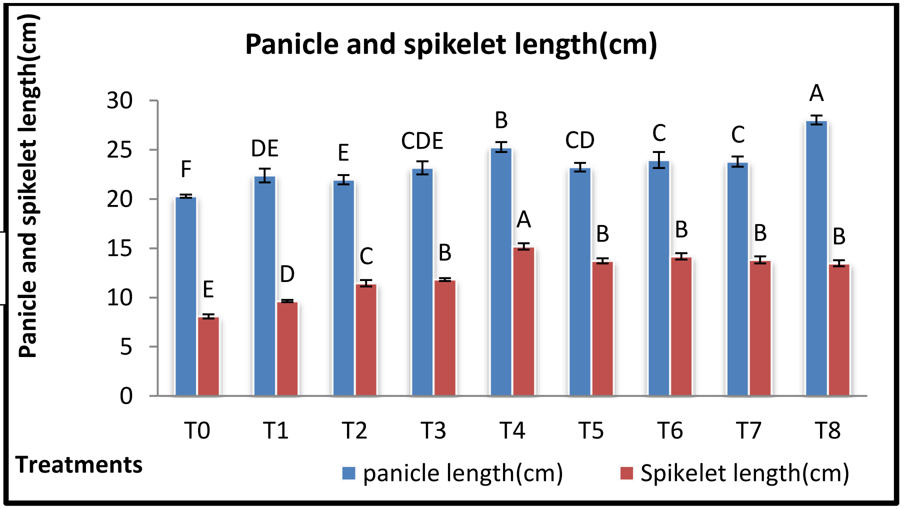
4.6.2.2 Grains per panicle /spike: The number of grains per panicle/spikelet counted in rice and wheat crop presented in table 4.6.2.1 and Fig. 4.6.2.2. In rice crop filled and unfilled grains per panicle counted which was significantly affected by Biochar amendments. The filled grains in rice ranged from 24.8 to 64.3 .The maximum filled grains per panicle (64.3) obtained in T8-50%RDF+50% poultry manure+ Biochar followed by T7-50%RDF+25% poultry manure+ Biochar (62.4) and T6- 50%RDF+ 50%Vermi compost+ Biochar (61.2).The minimum filled grains per panicle (24.8) recorded in T0 – control .All the treatments except control showed more number of filled grains per panicle. The minimum number of unfiled grains per panicle (6.6) recorded under T8 followed by T6 and T7 with 9.30 unfilled grains. The maximum unfilled grains per panicle recorded in T0 (12.5). In rice crop the grains per spike ranged from 24.4 to 51.2. The highest grains per spike recorded in T4-50%RDF+50%FYM+Biochar(51.2) followed by T6(47.8),T8(46.9),T7 and T5(46.7). The minimum grains per spike (24.4) counted under T0.

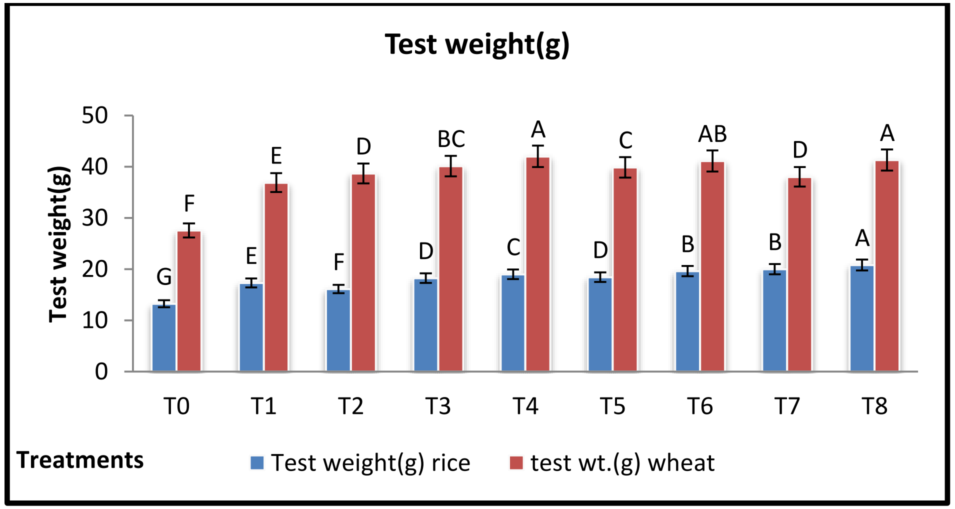
4.6.2.3 Test weight: Test weight is the important characteristic of the grain yield. Test weight of rice and wheat was significantly affected by the Biochar based amendments presented in Fig 4.6.2.3. In rice crop the test weight ranged from 13.23 g to 20.8 g. The highest test weight (20.8g) was recorded in T8 which was followed by T7(20 g) and T6-(19.6g). The minimum test weight (13.23g) recorded in control-T0 followed by t2-50%RDF + Biochar (16.10g) .In wheat crop the test weight ranged from 27.53g to 42 g. The maximum test weight (42g) recorded in T4 50%RDF+50%FYM+Biochar which was at par with T8-50%RDF+50% poultry manure+ Biochar (41.3 g) and followed by T6-50%RDF+ 50%Vermi compost+ Biochar (41.11 g) the lowest test weight (27.53 g) recorded in T0 which was followed by T1-100%RDF (36.86g) All the treatments grain have more weight over control.



4.6.2.2

4.6.2.1,





4.6.2.3

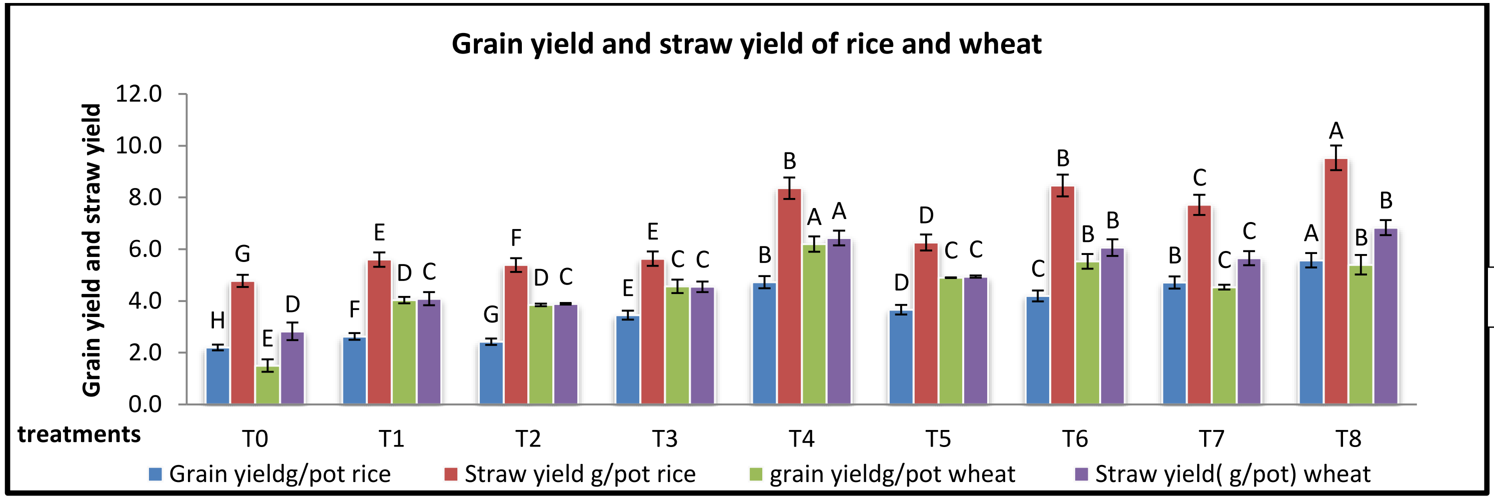
Fig.4.6.2.1 indicate number of grains per panicle/spike, 4.6.2.2 represent panicle and spikelt length(cm), and test weight(g) of rice wheat crop in pot experiment.Common letters indicate that treatments are non significant among themselves according to DMRT(p<0.05)

Table 4.6.2.1 Panicle length, filled grains, unfilled grains of rice and spikelet length,grains/ spike, flag leaf length of wheat in pot experiment

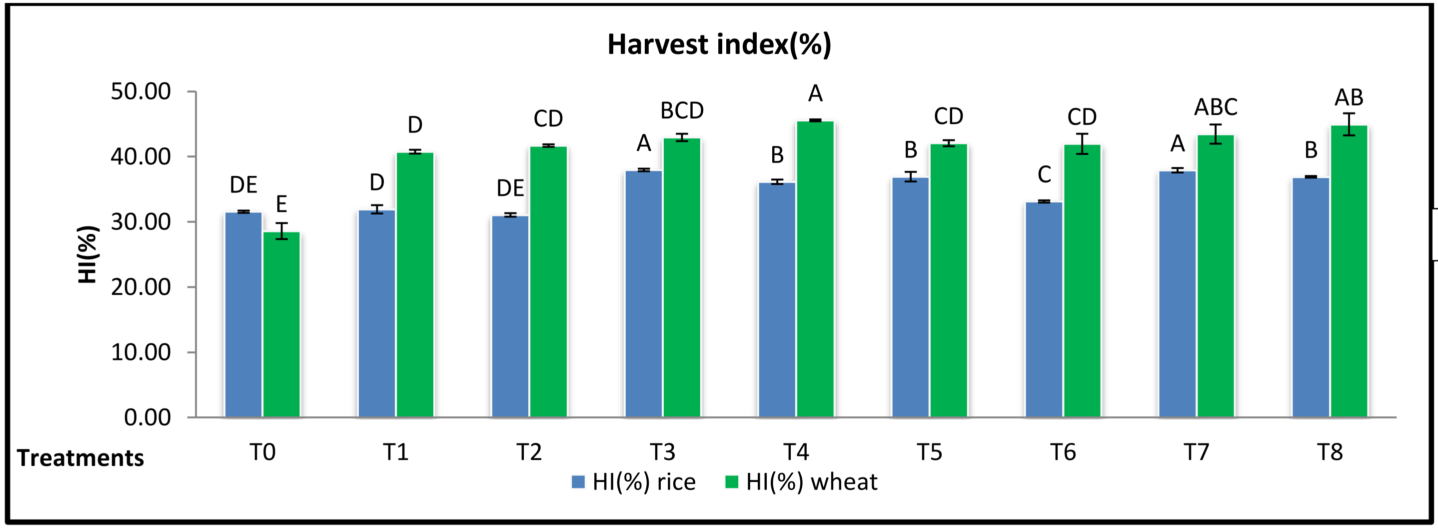
	Rice			wheat			
Treatments	Panicle length(cm)	Filled grains	Unfilled grains	Spikelet length(cm)	Grains/ spike	Flag leaf length 60 DAS	Flag leaf length 75 DAS
T0- Control (no fertilizer)	20.30±0.16F	24.8±0.68H	12.50±0.50A	8.1±0.2E	24.4±0.4E	21.15±0.12G	30.57±0.49F
T1-100%RDF	22.40±0.70DE	45.6±0.60F	11.33±0.58B	9.6±0.1D	37.4±1.2D	23.95±0.20F	35.33±0.78E
T2- 50%RDF + Biochar	21.97±0.46E	44.4±0.53G	12.53±0.50A	11.5±0.3C	43.3±0.5C	25.55±0.61E	35.37±0.54E
T3-50%RDF+25%FYM+Biochar	23.17±0.66CDE	56.8±0.47E	8.93±0.90C	11.8±0.1B	46.8±0.9B	29.65±0.45CD	36.9±0.57D
T4-50%RDF+50%FYM+Biochar	25.27±0.50B	57.9±0.64D	9.73±0.64C	15.2±0.3A	51.2±0.6A	32.35±0.20A	38.8±0.24A
T5-50%RDF+ 25%Vermi-compost + Biochar	23.24±0.44CD	60.7±0.46C	9.73±0.64C	13.7±0.3B	46.7±0.9B	30.70±0.41B	37.6±0.43C
T6-50%RDF+ 50%Vermi compost+ Biochar	23.97±0.82C	61.2±0.35C	9.30±0.26C	14.2±0.3B	47.8±0.9B	29.30±0.73D	38.2±0.59B
T7-50%RDF+ 25%poultry manure+ Biochar	23.80±0.51C	62.4±0.26B	9.30±0.61C	13.8±0.3B	46.7±0.9B	29.05±0.37D	35.7±0.37D
T8-50%RDF+50% poultry manure+ Biochar	28.03±0.45A	64.3±0.85A	6.60±0.53D	13.5±0.3B	46.9±1.6B	30.35±0.69BC	36.57±0.31B

4.6.2.4 Grain yield and straw yield: Grain and straw yield are the important parameters which are the interactive effect of crop growth and yield parameters. The data presented in Fig. 4.6.2.4(a) and 4.6.2.4(b). The scrutiny of data indicated that in rice crop grain and straw yield of rice crop recorded per pot. The grain yield and straw yield ranged from 4.73 to 5.57 g/pot and to 4.77 to 9.53g/pot. The maximum grain and straw yield (5.57g and9.53 g/pot) recorded under T8-50%RDF+50%PM+Biochar followed by T7(4.71) andT4(4.73) in grain yield and by T6(8.47) and T4(8.47) in straw yield. The minimum grain and straw yield (2.2 g and 4.77 g /pot) recorded under T0 followed by T2. In wheat crop the grain and straw yield ranged from 1.5 to 6.2 g/pot and 3.33 to 8.53 g/pot. Maximum grain and straw yield (6.20 g and 8.53 g) recorded in T4-50%RDF+50%FYM+Biochar followed by T7(7.17,44.94 g/pot) and T6(7.65,41.96 g/pot).The minimum grain and straw yield (1.5,3.33 g/pot) recorded under T0 followed by T2(3.85,5.38 g/pot). All the treatments were significantly different from each other.

4.6.2.5 Harvest index: Harvest index (%) influenced by various Biochar combined treatments. Harvest index data depicted in Fig.4.6.2.5. In rice crop harvest index ranged from 31.04 to 37.96 %. The harvest index recorded highest 37.96% and 37.93% in T3 and T7 followed by T5 (36.92%), T8 (36.89%) and T4(36.14%).The lowest harvest index31.04% and 31.55% recorded under T2 and T0.All the treatments showed superiority in case of harvest index over control. In wheat crop harvest index ranged from 24.59 to 45.98%. The highest harvest index (45.98%) recorded under T4 - 50%RDF+50%FYM+Biochar followed by T8 (44.94%) and T7(43.47%).The minimum harvest index (28.59%) recorded in T0.



4.6.2.4



4.6.2.6

Fig. 4.6.2.4(a) represent grain yield and straw yield of rice wheat and 4.6.2.6 represent harvest index(%) of rice wheatcrop.

Table 4.6.2.4 Effect of biochar on test weight(g), grain yield, straw yield and harvest index(%) of rice- wheat crop in pot experiment.

Treatments	**Rice**				**Wheat**			
	Test weight(g)	Grain yield(g/pot)	Straw yield(g/pot)	Harvest index (%)	Test weight(g)	Grain yield(g/pot)	Straw yield(g/pot)	Harvest index (%)
T0- Control (no fertilizer)	13.2±0.37G	2.20±0.04H	4.77±0.12G	31.55±0.18DE	27.53±0.86F	1.50±0.24E	3.33±0.34D	28.59±1.21E
T1-100%RDF	17.30±0.37E	2.63±0.05F	5.60±0.10E	31.93±0.65D	36.86±0.47E	4.03±0.12D	5.87±0.25C	40.75±0.28D
T2- 50%RDF + Biochar	16.10±0.22F	2.43±0.03G	5.39±0.07F	31.04±0.27DE	38.67±0.40D	3.85±0.05D	5.38±0.03C	41.70±0.19CD
T3-50%RDF+25%FYM+Biochar	18.23±0.09D	3.45±0.03E	5.63±0.03E	37.96±0.18A	40.11±0.44BC	4.57±0.26C	5.93±0.21A	42.94±0.57BCD
T4-50%RDF+50%FYM+Biochar	19.00±0.22C	4.73±0.01B	8.36±0.14B	36.14±0.34B	42.00±0.16A	6.20±0.29A	8.53±0.29C	45.58±0.15A
T5-50%RDF+ 25%Vermi-compost + Biochar	18.43±0.17D	3.66±0.05D	6.26±0.13D	36.92±0.73B	39.86±0.18C	4.90±0.01C	5.85±0.04C	42.07±0.48CD
T6-50%RDF+ 50%Vermi compost+ Biochar	19.60±0.24B	4.20±0.01C	8.47±0.06B	33.14±0.17C	41.11±0.74AB	5.53±0.29B	7.65±0.32B	41.96±1.53CD
T7-50%RDF+ 25%poultry manure+ Biochar	20.00±0.22B	4.71±0.02B	7.7h2±0.09C	37.90±0.35A	38.00±0.43D	4.53±0.10C	5.56±0.27C	43.47±1.48ABC
T8-50%RDF+50% poultry manure+ Biochar	20.80±0.22A	5.57±0.02A	9.53±0.05A	36.89±0.11B	41.30±0.24A	5.40±0.37B	7.17±0.29B	44.94±1.7AB

4.6.3 Nutrient uptake by grain and straw:

4.6.3.1 N uptake by grain and straw: The data of nitrogen uptake by grain and straw after harvesting of rice and wheat crop presented in table 4.6.3.1 and Fig 4.6.3.1(a) and 4.6.3.1(b).The data revealed that Biochar based amendments influenced the N uptake. In rice crop the N uptake by grain is more as compared to straw .The maximum N uptake by grain and straw (877.67g and 518 g/pot) recorded under T8-50%RDF+50% poultry manure+ Biochar followed byT7- . 50%RDF+25% poultry manure+ Biochar(813,492.33 g/pot) The minimum N uptake by grain and straw (168.67g and 158.67 g /pot recorded in T0 followed by T2 (537.6 and 315.67 g/pot). In wheat crop the maximum N uptake by grain and straw (882.32 g and 542.2 g/pot) recorded in T4-50%RDF+50%FYM+Biochar followed by T6-50%RDF+ 50%Vermi compost+ Biochar(830.33 g and 526.33g/pot) .The lowest N uptake by grain and straw(197.67,151.3 g/pot) recorded in T0. All the treatments were significantly different from each other.

4.6.3.2 P uptake by grain and straw: The data of phosphorous uptake by grain and straw after harvesting of rice and wheat crop presented in table 4.6.3.1 and Fig 4.6.3.2(a) and 4.6.3.2(b).The data indicated that Biochar based amendments influenced the P uptake. In rice crop the P uptake by grain is more as compared to straw .The maximum P uptake by grain and straw (46.8 g and 7.28 g/pot) observed under T8-50%RDF+50% poultry manure+ Biochar followed by . T7-50%RDF+ 25%poultry manure+ Biochar (44.7, 6.34 g/pot). The minimum P uptake by grain and straw (11.73g and 1.50 g /pot recorded in T0 followed by T2 (34.03 g and 3.37 g/pot). In wheat crop the maximum P uptake by grain and straw (43.1 g and 6.45 g/pot) recorded in T4-50%RDF+50%FYM+Biochar followed by T6-50%RDF+ 50%Vermi compost+ Biochar(40.05 g and 5.42g/pot) .The lowest P uptake by grain and straw(12.1,2.71 g/pot) recorded in T0. All the treatments were significantly different from each other.

4.6.3.3 K uptake by grain and straw: The data of potassium uptake by grain and straw after harvesting of rice and wheat crop presented in table 4.6.3.1 and Fig 4.6.3.3(a) and 4.6.3.3(b).The data pertained in table indicate that Biochar based amendments influenced K uptake. In rice crop the K uptake by straw is more as compared to grain. The maximum K uptake by grain and straw (266 g and 774.3 g/pot) observed under T8-50%RDF+50% poultry manure+ Biochar followed by T7-50%RDF+ 25%poultry manure+ Biochar

(235,751 g/pot). The minimum K uptake by grain and straw (78.2, 415.3 g /pot recorded in 50%RDF+50%FYM+Biochar followed by T6-50%RDF+ 50%Vermi compost+ Biochar(208.11g and 815.67 g/pot) .The lowest K uptake by grain recorded in T0 followed by T2 (108.6 g and 509 g/pot). In wheat crop the maximum K uptake by grain and straw (237g and 897 g/pot) recorded in T4-in and straw(87.73,547.78 g/pot) recorded in T0. All the treatments showed superiority over control in case of potassium uptake.

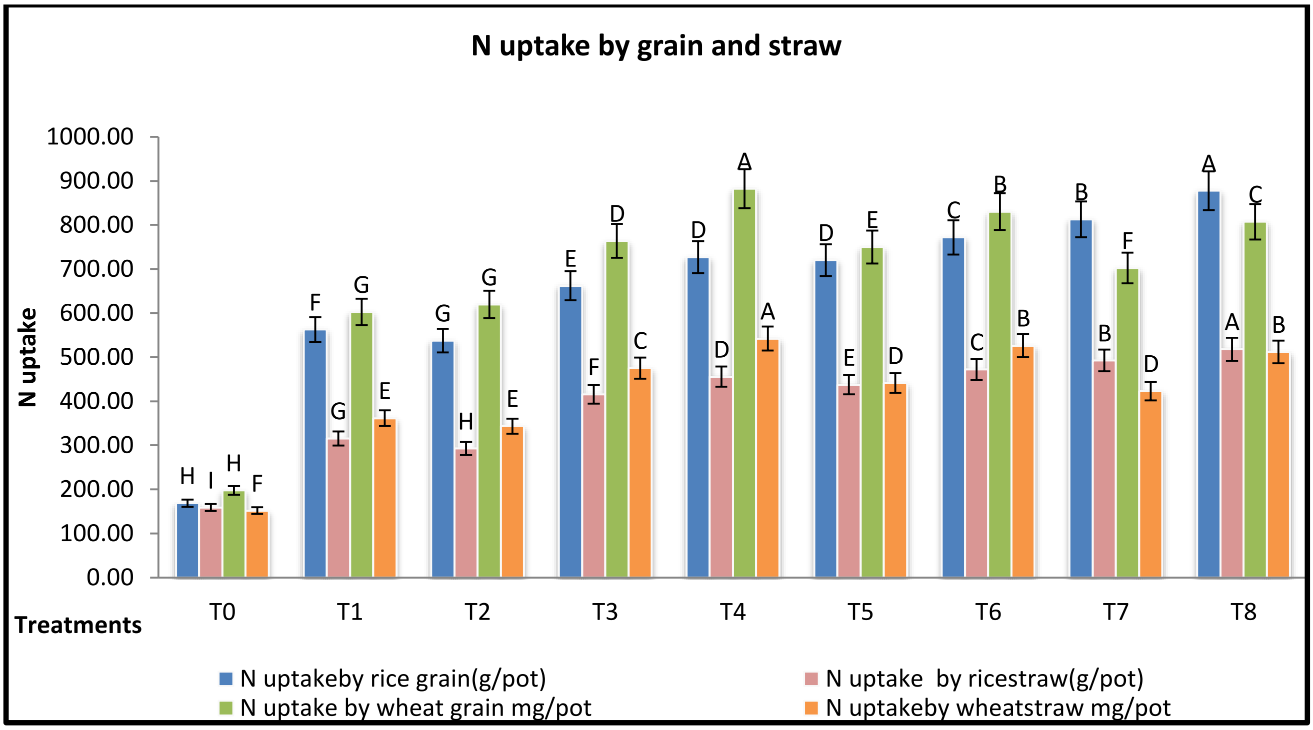


Fig.4.6.3.1 depicting N uptake by grain and straw of rice & wheat in pot experiment. Different letters above the error bars indicate that treatments are non significant among themselves.

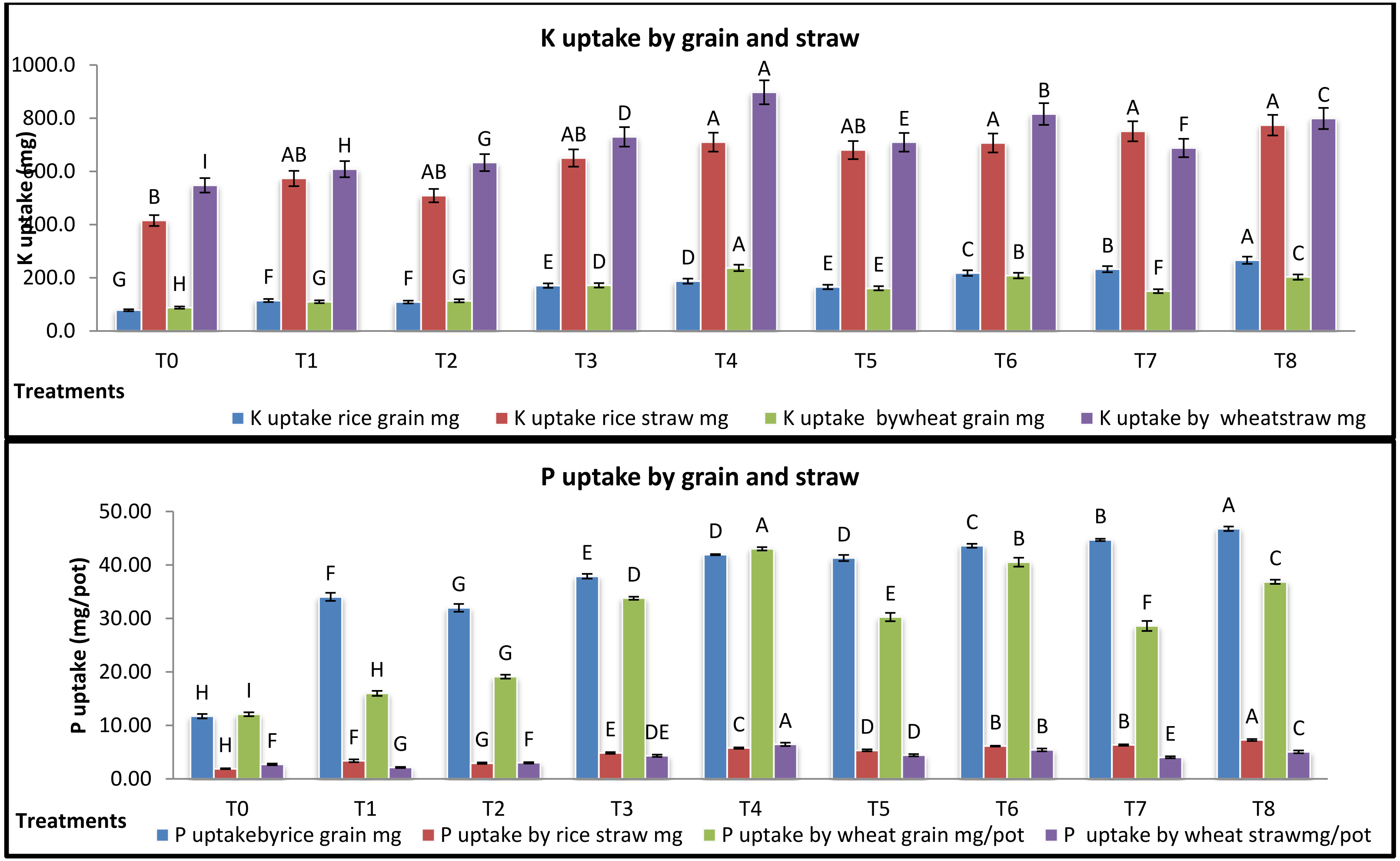


Fig. 4.6.3.2& 4.6.3.3 represent P & K uptake by grain and straw of rice- wheat in pot experiment. Different letters above the error bars indicate that treatments are non significant among themselves according to DMRT($p<0.05$).

Table 4.6.3.3 Effect of different combination of biochar on Nutrient uptake (mean±S.E) of rice and wheat crop in pot experiment.

Treatments	Rice						Wheat					
	N uptake grain(mg/pot)	N uptake straw(mg/pot)	P uptake grain(mg/pot)	P uptake straw(mg/pot)	K uptake grain(mg/pot)	K uptake straw(mg/pot)	N uptake grain(mg/pot)	N uptake straw(mg/pot)	P uptake grain(mg/pot)	P uptake straw(mg/pot)	K uptake grain(mg/pot)	K uptake straw(mg/pot)
T0- Control (no fertilizer)	168.6±6.65 H	158.67 ±4.71	11.73 ±0.41H	1.90 ±0.08H	78.20 ±1.88G	415.33 ±2.49B	197.67 ±2.05H	151.73 ±1.27F	12.1 ±0.4I	2.71 ±0.13F	87.73 ±1.93H	547.78 ±4.79I
T1-100%RDF	562.7 ±8.9F	315.67 ±3.86G	34.03 ±0.75F	3.37 ±0.26F	114.43 ±3.23F	573.67 ±1.25AB	602.56 ±0.79G	361.56 ±1.13E	16.0 ±0.5H	2.12 ±0.13G	109.89 ±2.22G	608.56 ±4.64H
T2- 50%RDF + Biochar	537.67 ±4.19G	292.67 ±7.93H	32.00 ±0.75G	2.93 ±0.12G	108.60 ±2.57F	509.00 ±2.94AB	619.51 ±4.61G	343.56 ±1.93E	19.1 ±0.4G	3.00 ±0.14F	113.22 ±2.28G	633.22 ±2.73G
T3-50%RDF+25%FYM+Biochar	662 ±0.82E	415.67±4.50F	37.90 ±0.45E	4.85 ±0.15E	170.60 ±0.99E	650.00 ±1.63AB	763.96 ±0.76D	475.33 ±2.87C	33.8 ±0.3D	4.31 ±0.25DE	171.67 ±1.89D	730.00 ±6.38D
T4-50%RDF+50%FYM+Biochar	727 ±4.55D	455.67 ±6.65D	41.93 ±0.09D	5.76 ±0.12C	187.33 ±3.30D	710.33 ±1.25A	882.32 ±1.53A	542.22 ±1.10A	43.0 ±0.3A	6.45 ±0.16A	237.07 ±1.46A	897.78 ±3.54A
T5-50%RDF+ 25%Vermi-compost + Biochar	720.33 ±3.3D	437.33 ±3.77E	41.30 ±0.57D	5.33 ±0.19D	165.67 ±6.94E	680.67 ±1.70AB	750.00 ±1.63E	441.33 ±1.25D	30.3 ±0.8E	4.42 ±0.15D	160.67 ±3.09E	709.56 ±1.75E
T6-50%RDF+ 50%Vermi compost+ Biochar	771.67 ±8.2C	472.00 ±8.16C	43.60 ±0.37C	6.13 ±0.09B	217.67 ±4.99C	706.67 ±3.40B	830.33 ±0.94B	526.33 ±1.25B	40.5 ±0.8B	5.42 ±0.19B	208.11 ±3.50B	815.67 ±2.62B
T7-50%RDF+ 25%poultry manure+ Biochar	813 ±8.52B	492.33 ±8.18B	44.70 ±0.22B	6.34 ±0.12B	232.00 ±2.94B	751.00 ±0. 82AB	702.33 ±1.25F	423.11 ±0.83D	28.6 ±0.9F	4.03 ±0.12E	149.33 ±1.89F	688.22 ±3.45F
T8-50%RDF+50% poultry manure+ Biochar	877.67 ±4.03A	518.00 ±4.55A	46.80 ±0.42A	7.28 ±0.18A	266.0 ±3.74A	774.33 ±1.25AB	807.33 ±1.70C	511.89 ±1.34B	36.8 ±0.4	5.07 ±0.10C	202.78 ±2.28C	798.9 ±2.83C

4.6.4 Nutrient use efficiency: The nutrient us re efficiency represents the response of applied fertilizers to crop. In rice crop NUE, PUE and KUE ranged from 0 to 89%, 0 to 40.5% and 0 to 90.8%. Highest NUE (89%), PUE(40.5%) and KUE(90.8%) recorded with the application of 50%RDF+50% poultry manure+ Biochar(T8) followed by T7 with 81.5%,37.4% and 80.4% NUE,PUE,KUE. T6-50%RDF+ 50%Vermi compost+ Biochar(76.4%,36.1%,73.5%) and T4-50%RDF+50%FYM+Biochar(71.3,34.1,66.6%) also recorded more NUE,PUE and KUE. The lowest use efficiency over control recorded under T2-50%RDF + Biochar with 41.9%,21.3% and21.1% NUE,PUE and KUE respectively. The data of NUE,PUE and KUE of rice pot crop presented in table 4.6.4 and Fig 4.6.4(a).In wheat crop the maximum NUE(88.82%),PUE(57.74%) and KUE(78.89%) recorded with the application of 50%RDF+50%FYM+Biochar-T4 followed by T6-50%RDF+ 50%Vermi compost+ Biochar(83.31%,51.9%,59.67%- NUE,PUE and KUE).The next highest NUE,PUE and KUE(79.6,45.12,57.22%) recorded in T8-50%RDF+50% poultry manure+ Biochar. All the treatments were show superiority over control in case of nutrient use efficiency. The minimum N, P, K use efficiency over control (51.02, 5.27,11.56%) recorded under T1 which followed by T2(51.28,12.12,19.41%). The data of wheat crop nutrient use efficiency presented in Fig. 4.6.4(b).

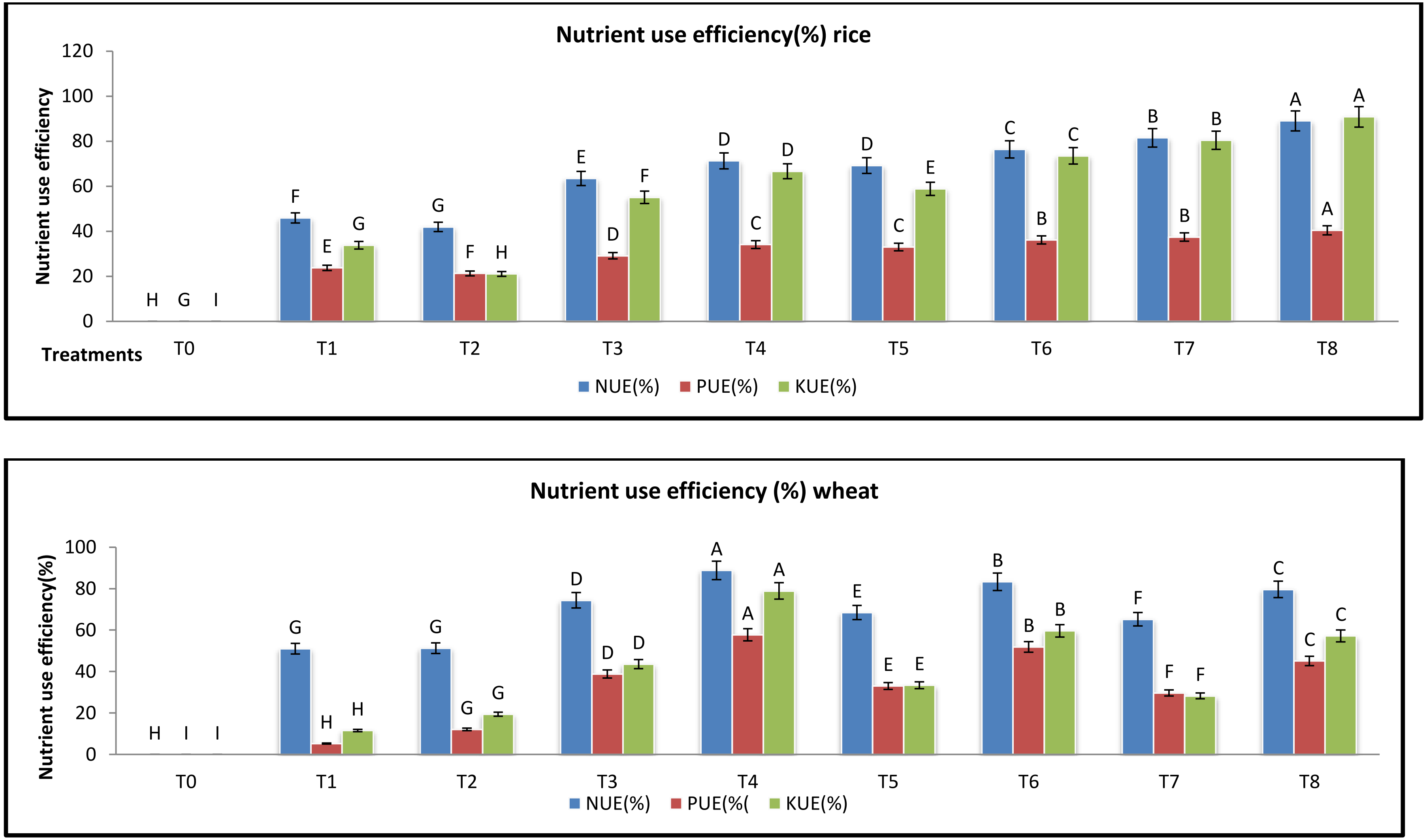


Fig. 4.6.4(a,b) represent nutrient use efficiency (%) of rice & wheat crop of pot experiment.Values with same alphabet are not significantly different from each other according to DMRT($p<0.05$)

Table 4.6.4 Effect of biochar on nutrient use efficiency(%) of rice wheat pot crop.

	Rice			**Wheat**		
Treatments	NUE (%)	PUE (%)	KUE (%)	NUE (%)	PUE (%)	KUE (%)
T0- Control (no fertilizer)	0±0.0 H	0±0G	0.0±0.0I	0.00±0.00H	0.00±0.00I	0.00±0.00I
T1-100%RDF	45.9±1.1F	23.8±1.03E	33.8±1.32G	51.02±0.22G	5.27±0.97H	11.56±0.04H
T2- 50%RDF + Biochar	41.9±1.2G	21.3±0.56F	21.1±0.42H	51.28±0.61G	12.12±1.07H	19.41±0.08H
T3-50%RDF+25%FYM+Biochar	63.4±1.6E	29.1±0.82D	55.1±0.26F	74.37±0.31D	38.80±0.85D	43.61±0.59D
T4-50%RDF+50%FYM+Biochar	71.3±1.4D	34.1±0.52C	66.6±0.92D	88.82±0.97A	57.7±0.15A	78.89±0.57A
T5-50%RDF+ 25%Vermi-compost + Biochar	69.2±0.8D	33.0±0.94C	58.8±2.4E	68.47±1.15E	33.08±1.77E	33.42±0.38E
T6-50%RDF+ 50%Vermi compost+ Biochar	76.4±1.6C	36.1±0.65B	73.5±1.9C	83.31±0.36B	51.90±1.95B	59.67±0.25B
T7-50%RDF+ 25%poultry manure+ Biochar	81.5±1.2B	37.4±0.35B	80.4±1.7B	65.22±1.23F	29.69±2.03F	28.26±0.45F
T8-50%RDF+50% poultry manure+ Biochar	89.0±1.3A	40.5±0.64A	90.8±0.36A	79.60±1.63C	45.12±1.19C	57.22±0.70C

4.6.5: Soil characteristics: Soil nutrient contents were higher when manures, fertilizers and Biochar were added to soil than in the control and fertilizers treatments. In rice crop and wheat crop the soil organic carbon recorded per pot. The SOC ranged from 9.50g to 33.37 g /pot in rice and 9.15 to 33.8 g/pot in wheat crop. The maximum (33.3 and 33.8 g/pot).SOC recorded under T8-50%RDF+50% poultry manure+ Biochar in rice and under T450%RDF+50%FYM+Biochar in wheat. The second highest SOC (32.05g and 32.48 g) recorded under T6-50%RDF+ 50%Vermi compost+ Biochar in rice and wheat crop. The lowest SOC per pot (9.50,9.15 g) recorded under T0 followed by T1-100%RDF(24.85,25.2 g). The data of soil nutrient status presented in table 4.6.5 and OC data presented in Fig. 4.6.5(a). After harvesting of crop the soil Available N and P per pot analysed. The available N and P content was significantly affected by different treatments. The maximum N and P content (2.40g and 109.2 mg /pot) observed with the application of 50%RDF+50% poultry manure+ Biochar-T8 in rice crop followed by T6-50%RDF+ 50%Vermi compost+ Biochar (2.25 g,99 mg/pot) and T4-50%RDF+50%FYM+Biochar(1.97g and 96mg) respectively . The lowest N and P available content (0.85 g and 30 mg) in pot noted under T0. The highest N and P content (2.540 and 102.33mg /pot) observed with the application of50%RDF+50%FYM+Biochar-T4 and T6-50%RDF+ 50%Vermi compost+ Biochar. The next highest (2.33g, 77.93 mg) recorded under T6 and T4. The lowest N and P content (0.87 g and 29 mg) in wheat crop recorded under T0.The data of Available N and available P presented in Fig. 4.6.5(b) and 4.6.5(c).

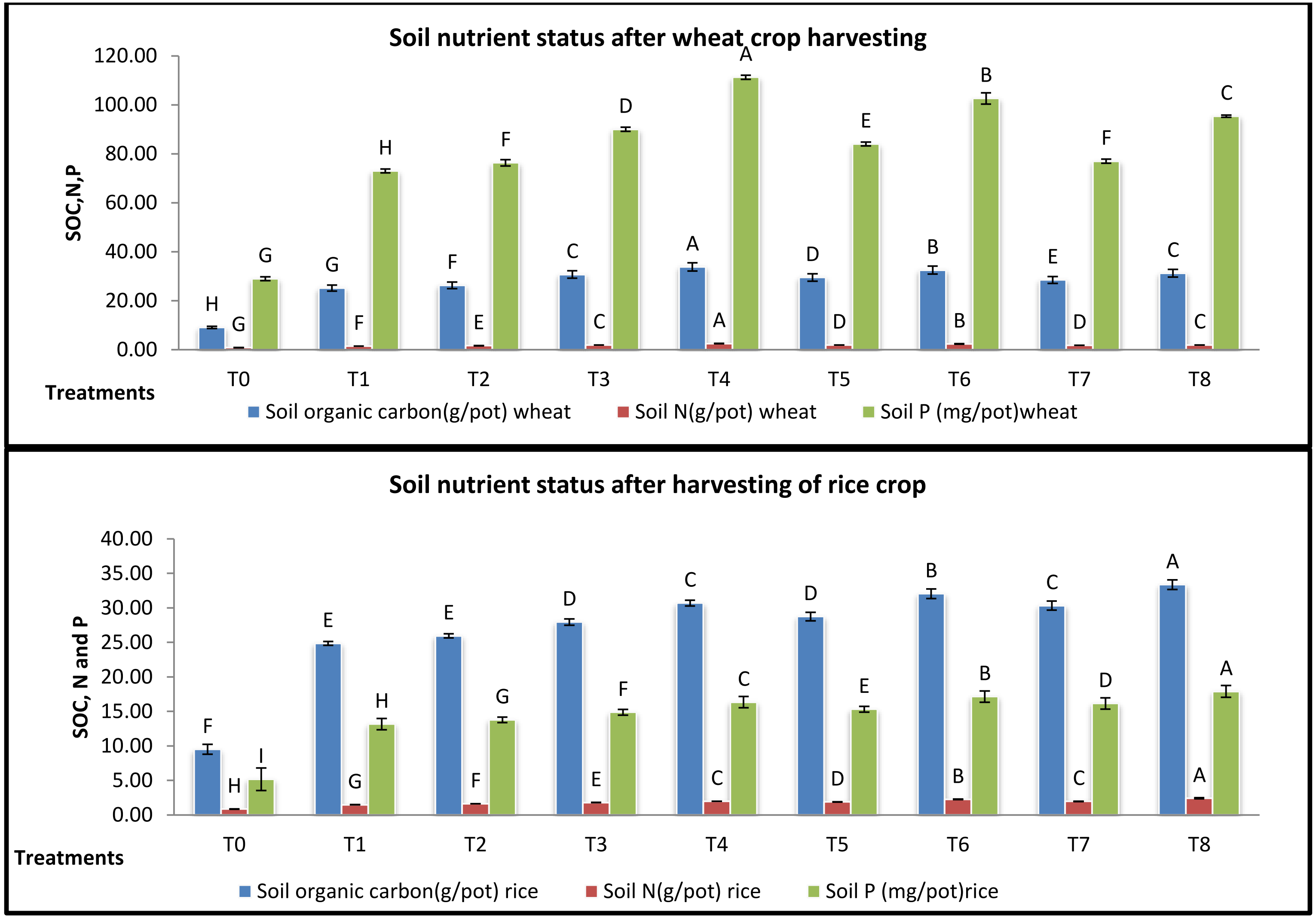


Fig. 4.6.5 represent soil nutrient status of rice wheat crop of pot experiment. Same letters above the error bars indicate that treatments are non significant among themselves.

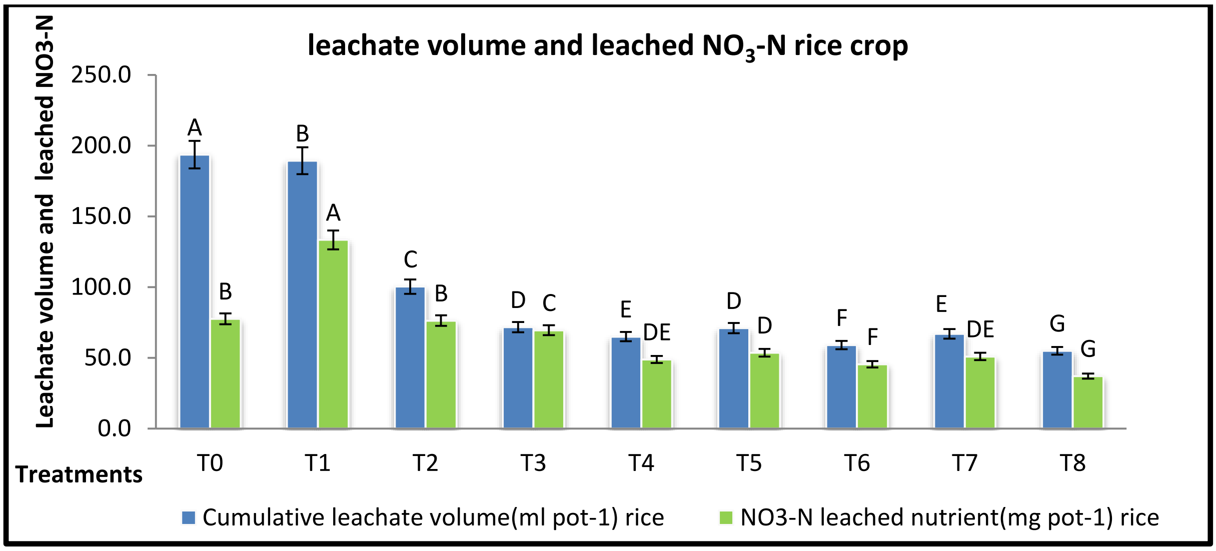
Table 4.6.5 Effect of biochar application on soil nutrient status of pot experiment(mean± S.E) of rice- wheat crop.

Treatments	**RICE**			**WHEAT**		
	Soil organic carbon(g /pot)	Soil N(g/pot)	Soil P(mg/pot)	Soil organic carbon(g /pot)	Soil N(g/pot)	Soil P(mg/pot)
T0- Control (no fertilizer)	9.50±0.73F	0.85±0.02H	30.00±1.6I	9.15±0.53H	0.87a±0.01G	29.00±0.8H
T1-100%RDF	24.85±0.29E	1.47±0.01G	71.00±0.8H	25.20±0.00G	1.45b±0.02F	73.00±0.8G
T2- 50%RDF + Biochar	25.95±0.29E	1.61±0.01F	74.50±0.4G	26.30±0.00F	1.64c±0.02E	76.33±1.2F
T3-50%RDF+25%FYM+Biochar	27.95±0.45D	1.79±0.01E	76.50±0.4F	30.70±0.41C	1.95e±0.02C	90.00±0.8D
T4-50%RDF+50%FYM+Biochar	30.70±0.41C	1.97±0.01C	96.00±0.8C	33.80±0.33A	2.54g±0.03A	77.93±47.2A
T5-50%RDF+ 25%Vermi-compost + Biochar	28.75±0.61D	1.88±0.01D	83.50±0.4E	29.50±0.00D	1.90de±0.01D	84.00±0.8E
T6-50%RDF+ 50%Vermi compost+ Biochar	32.05±0.69B	2.25±0.04B	99.00±0.8B	32.48±0.35B	2.33f±0.12B	102.63±2.3B
T7-50%RDF+ 25%poultry manure+ Biochar	30.33±0.66C	1.96±0.02C	90.00±0.8D	28.50±0.00E	1.82d±0.01D	77.00±0.8F
T8-50%RDF+50% poultry manure+ Biochar	33.37±0.69A	2.40±0.08A	109.25±0.9A	31.20±0.00C	1.95e±0.01C	95.33±0.5C

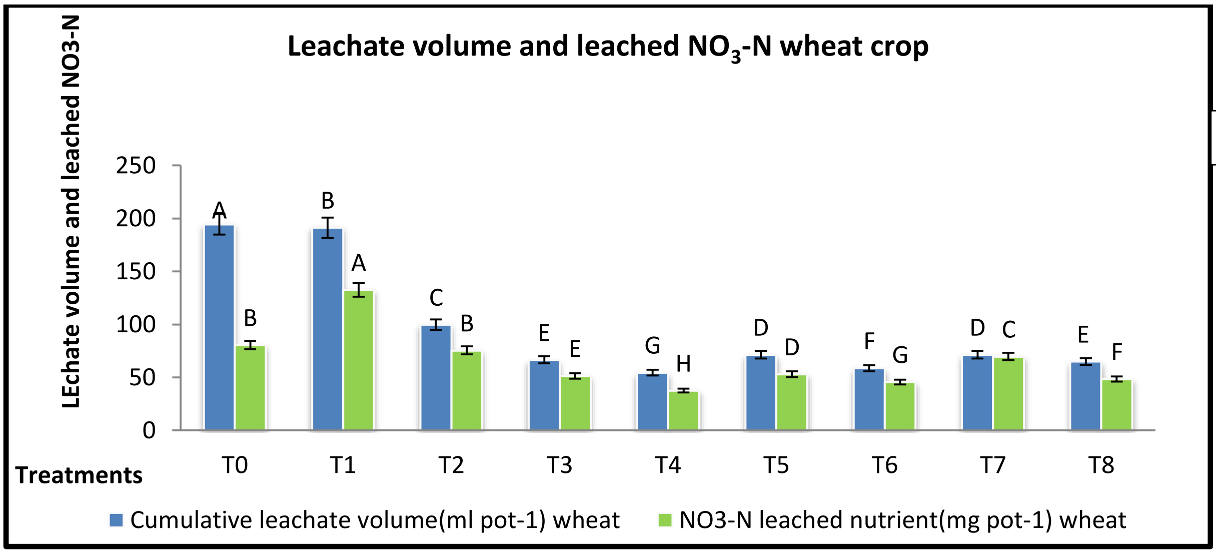
4.6.6 Leachate volume and leached nutrients: The treatments with organic components (Biochar and manures) significantly decreased leachate volume (Table 4.6.6). Differences in leachate volume among treatments increased during the growing period, because the demand for water by plants depended on treatments. Therefore, the cumulative leachate volume was inversely related with the above- and belowground biomass. The leachate volume recorded minimum in Biochar amended plots. The minimum leachate volume in rice crop (55 ml/pot) and in wheat crop (37.6 ml/ pot) recorded under T4 in wheat and T8 in rice followed by T6-50%RDF+ 50%Vermi compost+ Biochar with leachate volume (59, 58.7 ml). All the treatments showed superiority in leachate volume as compared to control and fertilizers. The data of leachate volume presented in Fig.4.6.6 (a)

Most of the native available NO_3-N was leached from the control during the crop-establishment period. As the growth of plants progressed, the leaching of nutrients was markedly reduced because of higher nutrient uptake by the plants, and hence smaller amounts left to leach.NO_3-N concentration measured from leachate volume. The minimum NO_3-N concentration in rice crop (37.2 mg/pot) recorded under T8 followed byT6-50%RDF+ 50%Vermi compost+ Biochar(45.2 mg/pot) and T4-50%RDF+50%FYM+Biochar(48.9 mg/pot). The highest NO_3-N recorded in T1-100% RDF (133.4 mg/pot) followed by T0(77.7 mg /pot. In wheat crop the least NO_3-N (37.6 mg/pot) recorded under T4-50%RDF+50%FYM+Biochar followed by byT6-50%RDF+ 50%Vermi compost+ Biochar(45.7 mg/pot) and T8-50%RDF+50%PM+Biochar(48mg/pot). The highest NO_3-N recorded in T0-100% RDF (132.7 mg/pot) followed by T0 (80.5 mg /pot). The data of NO_3-N presented in Fig. 4.6.6(b).

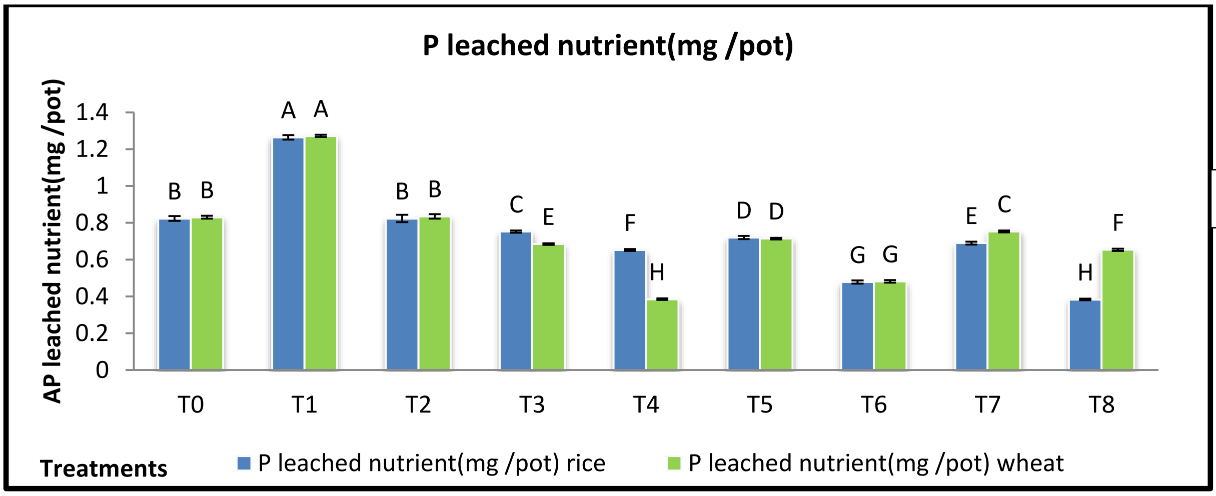
The minimum Leached P(0.38 mg/pot) recorded in T8-50%RDF+50% poultry manure+ Biochar followed by T6-50%RDF+ 50%Vermi compost+ Biochar(0.48 mg) in rice crop and in wheat crop minimum leached P(0.39mg/pot) observed in T4-50%RDF+50%FYM+Biochar followed by T6-50%RDF+ 50%Vermi compost+ Biochar(0.48 mg). All the Biochar amended treatments recorded minimum leached P as compare to alone fertilizer and control. The highest leached P (1.26 mg and 1.27 mg/pot) observed under T1-100%RDF.The data of leached P presented in Fig. 4.6.6(c).



4.6.6a



4.6.6 b



4.6.6c

Fig. 4.6.6(a,b,c) depicted the leachate volume, NO_3-N and leached P(mg/pot) in pot experiment. Siimilar letters above standard error bars reflect that treatments are non significant

Table 4.6.6 Effect of biochar based amendents on leached nutrients and leachate volume in pot (mean± S.E)

	Rice			**Wheat**		
Treatments	Leachate volume (ml/pot)	NO_3-N (mg/pot)	Leached P(mg/pot)	Leachate volume(ml/pot)	NO_3-N (mg/pot)	Leached P(mg/pot)
T0- Control (no fertilizer)	193.7±2.1A	77.7±4.0B	0.82±0.01 B	194.5±0.4A	80.5±0.4B	0.83±0.83B
T1-100%RDF	189.3±1.6B	133.4±1.2 A	1.26±0.01 A	191.3±1.9B	132.7±0.5 A	1.27±1.27A
T2- 50%RDF + Biochar	100.3±1.2C	76.3±1.2B	0.82±0.02 B	99.8±0.6C	75.5±0.4B	0.835±0.84 B
T3-50%RDF+25%FYM +Biochar	71.7±0.8D	69.5±0.5C	0.75±0.01 C	66.5±0.4E	51.5±0.4E	0.69±0.69E
T4-50%RDF+50%FYM +Biochar	65.0±1.2E	48.9±0.4E F	0.65±0.01F	54.7±0.5G	37.6±0.7H	0.39±0.39H
T5-50%RDF+ 25%Vermi-compost + Biochar	71.0±0.8D	53.7±1.2D	0.72±0.01 D	71.5±0.4D	53.0±0.8D	0.71±0.71D
T6-50%RDF+ 50%Vermi compost + Biochar	59.0±1.6F	45.5±0.4bF	0.48±0.01 G	58.7±0.5F	45.7±0.3G	0.48±0.48G
T7-50%RDF+ 25%poultry manure + Biochar	67.0±1.2E	51.0±0.8D E	0.69±0.01 E	71.5±1.2D	69.7±0.4E	0.75±0.75C
T8-50%RDF+50% poultry manure+ Biochar	55.0±1.6G	37.2±0.9G	0.38±0.00 H	65.0±1.6E	48±0.65D	0.65±0.01F

s

4.7 Economics: Cost of cultivation, gross returns, net returns and B: C ratio categorised under economics as presented in table 4.7.1(a) and 4.7.1(b).

4.7.1 Cost of cultivation: In case of rice Rs. 32000 was common cost of cultivation for all treatments. Cost of cultivation change due to different sources of manures and fertilizers. The lowest expenditure among all treatments Rs.32000 was computed under T0 (control) as compared to other treatments. However the maximum expenditure 93479 computed under T6 (50%RDF+50% VC+ Biochar) followed by T5 (Rs. 92729) and T4 (Rs. 92629) in rice crop. In wheat crop, the common cost of cultivation for all treatments was 29991. The lowest expenditure was computed (Rs. 29991) under T0 and maximum Rs. (97069) computed under T8.followed by T6- (Rs. 96319) among all treatments.

4.7.2 Gross returns: In rice crop, the maximum gross return of Rs. 303195 computed under T8 followed by T7 (Rs. 295542).The lowest gross returns (Rs. 70082) computed under T0 control. In wheat crop maximum gross return (Rs. 185491) under T4 followed by T8 (Rs. 179642). Lowest gross return (Rs. 50910) computed under T0.

4.73 Net returns: In rice crop among nine treatments the maximum net monetary returns (Rs. 211216.8) recorded under T8 followed by T7 (Rs. 203934) lowest net monetary returns (Rs. 38082) exhibited under control. In wheat crop the application of 50% RDF+50% FYM+ Biochar recorded highest net returns (Rs. 91422) followed by T7 (Rs. 83016.7). The lowest net returns (Rs. 20919) computed under T0.

4.7.4 B: C ratio: In rice crop the highest B:C ratio (2.29) was recorded with T8 followed by T7(2.26). The lowest B: C ratio (1.19) obtained in control. In wheat crop, the maximum ratio (1.5) obtained under T1 followed by T4 (0.97). The lowest B: C ratio (0.69) obtained under control.

Table 4.7(a)Avg. Cost of cultivation , gross returns,net returns and B:C ratio of rice crop .

Treatments	**Cost of cultivation Rs. ha^{-1}**	**Gross returns Rs. ha^{-1}**	**Net returns Rs. ha^{-1}**	**B:C ratio**
T0- Control (no fertilizer)	32000.0	70082.92	38082.9	1.190091
T1-100%RDF	35000.0	150875	115875.0	2.080714
T2- 50%RDF + Biochar	91229.0	260586.3	169357.3	1.856397
T3-50%RDF+25%FYM+Biochar	91929.0	274985.8	183056.8	1.991285
T4-50%RDF+50%FYM+Biochar	92629.0	279585	186956.0	2.018331
T5-50%RDF+ 25%Vermi-compost + Biochar	92729.0	281106.3	188377.3	2.031482
T6-50%RDF+ 50%Vermi compost+ Biochar	93479.0	287342.9	193863.9	2.073877
T7-50%RDF+ 25%poultry manure+ Biochar	91608.0	295542.5	203934.5	2.226165
T8-50%RDF+50% poultry manure+ Biochar	91979.0	303195.8	211216.8	2.296359

Table 4.7(b) Average Cost of cultivation, gross returns, net returns and B:C ratio of wheat crop.

Treatments	**Cost of cultivation Rs. ha-^{1}**	**Gross returns Rs. ha-^{1}**	**Net returns Rs. ha-^{1}**	**B:C ratio**
T0- Control (no fertilizer)	29991	50910.42	20919.42	0.697523
T1-100%RDF	40000	100168.6	65020.58	1.504215
T2- 50%RDF + Biochar	92569	150242.4	57673.42	0.623032
T3-50%RDF+25%FYM+Biochar	93319	176725.9	83406.92	0.893783
T4-50%RDF+50%FYM+Biochar	94069	185491.4	91422.42	0.971866
T5-50%RDF+ 25%Vermi-compost + Biochar	94444	171645.3	77201.25	0.817429
T6-50%RDF+ 50%Vermi compost+ Biochar	96319	174624.8	78305.83	0.812984
T7-50%RDF+ 25%poultry manure+ Biochar	94819	177835.2	83016.17	0.875522
T8-50%RDF+50% poultry manure+ Biochar	97069	179642.2	82573.17	0.850665

4.8 Discussion: The investigation entitled" Probing the impact of Biochar combined fertilizers on soil nutrient status in relation to growth and yield of rice –wheat cropping system was carried out during two consecutive years 2018-2019 and 2019-2020 at Lovely Professional University, Phagwara, and Punjab. On the basis of finding, an attempt has been made in this chapter to explain the possible reasons of variation in the observation recorded due to different treatments. The results have been discussed in light of literature available for the different characters under study. In general, the weather conditions prevailed during 2018-2019 and 2019-2020 were favourable for growth and development of rice-wheat crop. Variation in growth and yield of crop was mainly due to effect of the treatment tested. The findings presented in preceding chapter provided a detailed account of the performance in terms of growth, development, yield and yield contributing characters of rice- wheat influenced by different biochar based amendments. Attempts have been made to evaluate and explain the important observations recorded in the course of present investigation in terms of cause and effect relationship as far as possible in light of reasoning and to find out the information of practical value. However, the results on all aspects given in the preceding chapters are being discussed as under following heads.

4.8.1 Effect of biochar based amendments on soil physicochemical properties

4.8.2 Impact of biochar combined fertilizers on soil carbon fractions

4.8.3 Impact of biochar based amendments on soil biological indicators

4.8.4 Effect of biochar application on growth and yield of crops

4.8.5 Effect of biochar on yield components and yield

4.8.66 Effect of biochar on nutrient uptake and nutrient use efficiency

4.8..7 Effect of biochar on nutrient leaching

4.8.1 General discussion on effect of biochar based amendments on soil physicochemical properties:

4.8..1.1Bulk density and porosity: Bulk density is an important index of soil structure, compactness and quality. It affects the interaction of plant- soil processes like rooting depth, oxygen and gas exchange, water infiltration dynamics which influenced soil functioning (Herath et al., (2019). Biochar amendments reduced bulk density due to interaction between soil particles and biochar (Burrel et al., 2016) which improved aggregate stability and porosity due to inverse relationship between them (Omnodi et al., 2018). The increase in porosity has positive effects on air, water and gases transport in soil (Paneque et al., 2016). The high porosity, large surface area and more number of micro pores of biochar improved soil physical properties to create better environment for the plant root growth and nutrient uptake. Biochar can support the building process of soil structure such as providing habitat for soil micro -organisms and enzyme activities. Biochar amendment to soil has the capacity to decrease bulk density (Gundale and DeLuca, 2006) and bulk density directly correlated to porosity (Joseph et al., 2019). When physical properties of soil in all treated plots were compared, rice husk biochar applied plots recorded lowest bulk density and high porosity. It might be due to the particle size, surface area and porosity of biochar which attributed to change in bulk density of soil (Downie et al., 2009). The maximum reduction in bulk density recorded by T8 (50% RDF+50% PM+ biochar) in rice crop. In both years when considered as alone factor application of poultry manure affect soil physical properties, significantly lowered bulk density and enhance porosity as compared to control. On the other hand, biochar alone also improved soil physical properties as compared to control. The interaction of biochar and poultry manure was significant during both years in rice crop for soil bulk density and porosity. Poultry manure increased the soil organic matter by the manure and improved soil structure by lowering bulk density and enhancing porosity. Similar effect of poultry manure has been reported by (Abel et al., 2013 and Githinji 2014). The enhancement in porosity of biochar applied plots might be due to the more porous nature of biochar which reduced the bulk density by increasing the pore volume (Suliman et al., 2017). The control plots have high bulk density as compared to biochar treated plots could be reduced the spaces where water could be retained (Laird et al., 2010). Biochar increased porosity due to internal porous structure and enhanced soil porosity which increased the surface area of soil and penetration (Oguntude et al., 2008). In case of wheat crop, the reduction in bulk density was due to continuous application of organic material in form of FYM and vermicompost.

Integrated application of biochar along with 50% RDF+50% FYM significantly reduced bulk density might be due to high soil organic carbon, available N, P, K. The interaction of FYM, RDF and biochar exerted positive effect on the accumulation of soil organic matter. As the soil organic matter increased porosity increased and bulk density reduced. This result is in confirmity with the findings of Lehman J.2007, Naseem khan (2018). Biochar contain recalcitrant aromatic compounds which were responsible to maintain the stability of C in soil and air (Hammond et al., 2007). Wolf, 2008 observed that the improvement in soil physical properties of soil was due the presence of an organic acid which formed organominerals .These organominerals resulted soil aggregation and added functional components of organic matter to soil. According to Mukherjee et al., 2013 the application of biochar reduces bulk density by improving pore volume. The biochar application decreased the bulk density more porous nature of biochar significantly (Leonard Githinji, 2013). By the application of biochar, the overall porosity of soil increased (Hert et al., 2013) might be due to more porous nature of biochar.

4.8.1.2 pH: Soil pH was observed to change the treatments and crop season. Increase in pH value with the application of biochar was also found by Laird et al., 2010. This result is also in confirmity with the findings of Matsubra *et al,* 2002 and Lehmann et al., 2003. The increase in pH of soil with the application of biochar might be due to enhancement in concentration of alkaline metal (Ca^{2+}, Mg^{2+} and K^{+}) oxides in soil due to their presence in biochar (Shenbagavalli and Mahimairaja 2012). Low pH in control might be due to secretion of organic acids which caused reduction in pH. Nitrogen cycling is considered the mechanism for the change in pH by transforming organic N to NH_4^+ containing H^+ and side by convert to NO_3^- releasing $2H^+$ (Cheng et al., 2008). Soil pH is an important property of soil in case of nutrient availability and plant growth. Most of the crops have suitable pH range where maximum growth and productivity can be maintained (Fageria and Baligar, 2008).It is common practice to amend acidic soils by addition of lime to raise pH which permits the plants to grow at their maximum capacity when other requirements such as water and nutrient availability are met. Increase in pH of soil convert the form of available nutrients and facilitate adsorption of ions to plant roots for uptake (Gul et al., 2015). By the biochar amendment soil pH increased it might be due to the proton consumption by functional groups which are present on surface of biochar (Van Zwieten et al., 2010). Similar findings were reported by Mete et al., 2015 and Christopher et al.,2012 as this change in pH with biochar will enhance bioavailability of precipitated nutrients on colloidal sites such as P, Ca^{2+}, Mg^{2+}

and K^+). Previous studies have showed that the biochar having more pH which increased the pH of soil by enhancing calcium levels and decrease aluminium toxicity (Steiner et al., 2007). The pH of biochar used in experiment was 8.1. A smaller increase in pH was observed when biochar added to soil might be due to more initial CEC and high buffering capacity (Suliman et al., 2017). The integrated application of biochar with poultry manure and synthetic fertilizers reduces the salinity of soil by 3.6 gkg^{-1} by increase in soil pH 0.3 and increased CEC of soil (Lasari et al., 2013). If soil having high CEC than it converts the soil into soil having high buffering capacity which had little effect on soil pH also (Granatstein et al., 2009). This result is also in confirmity with the findings of Li et al., 2015, Jaafar et al., 2015b, Hardie et al., 2014. In case of wheat crop, the combination of FYM+ RDF+ biochar resulted increment in pH of soil. It might be due to addition of organic matter which increased CEC and organic fractions of soil. The organic matter present in soil contains colloids which bind up the cations and increase in pH of soil (Novak et al., 2019, Liang et al., 2006). The potential of manures to increase soil pH might be due to presence of basic cations present in poultry manure. The other mechanism responsible for enhancement in soil pH due to manures especially poultry manure was due to the ion exchange reactions. This reaction happens when terminal OH^- of Al^{3+} or Fe^{2+} hydroxyl oxides are replaced by organic anions which are decomposed products of poultry manure i.e. malate, citrate and tartarate (Natscher and Schwertmann 1991, Rodriguezz et al., 2009). Rice straw contains nutrients like Ca, Mg, K, and Na. In case of pyrolysis, accumulation of alkaline substances on biochar surfaces which enhances soil pH (Dias et al., 2010).

4.8.1.3 EC: Electrical conductivity is a measure of soil salinity and ability of soil solution to carry charges (Kumari et al., 2014). EC can be used as an indicator of ionic strength (olowoboko et al., 2018) by estimating the amount of dissolved salts in soil solution. Release of nutrient from organic material and mineralization processes responsible for increase in salt content of soil (Hossain et al., 2011). Electrical conductivity of soil indirectly shows the mineralization of SOM and acts as measure of soluble nutrients (Yuan et al., 2011). Findings from the study revealed that during first year of experiment, high EC recorded and it reduced during second year. That could be due to biochar amendment which initially increase soil EC due to release of weekly bound nutrients (Cations, anions) into soil solution for plant uptake (Abujabhah et al., 2016) reported slight decrease in EC of soil during subsequent year of study due to continuous cultivation of crop suggesting increase in uptake of cations and anions from soil solution by main crop with positive effect on plant growth and yield(Borchard et al.,2014)Biochar application has significant effect on electrical conductivity of soil. The biochar amended plots recorded more EC as compared to control. This result is supported by Masto et al., 2013. Increase in EC by application of biochar might be due to the presence of high concentration of alkaline metal oxide (Ca^{2+}, Mg^{2+} and K^{+}) in biochar (Kumar et al., 2013). Belyaeva and Haynes (2012) stated that biochar is responsible for salinity in soil which limits plant growth and establishment. But under field conditions the salts which are soluble leach out of surface soil layers due to rainfall/ irrigation. All the biochar amended plots showed more EC over control. Presence of more amount of alkaline metal i.e. Ca^{2+}, Mg^{2+} and K^{+}) in poultry manure and FYM responsible for increase in soil EC of soil.

4.8.1.4: Soil Nitrogen: In current research synthetic fertilizers, manures were applied with biochar which increased the availability of N in soil. In rice crop available N recorded highest with 50% RDF+50% PM + biochar over control and other treatments might be due to effect of surface properties of biochar which retain N contained in manure and fertilizers(Pietikainen et al.,2000, Deluca et al., 2009). As the poultry manure organic matter components starts to decompose nutrients were released to soil and increase the availabilty of N. When biochar co-composted with PM, it increased nutrient retention capacity of soil. Revell et al., 2012, Hansen et al., 2016 and Yao et al., 2017 reported that combined application of rice husk biochar and N fertilizer induced significant increase in NPK. Biochar is a black C in which carboxylate groups present which provide CEC ,improve O/C ratio and increase in nutrient retention capacity (Oya and Iu, 2002) Biochar has ability to absorb NH_3(Iyobe et al., 2004) and in soil it acts as a buffer . So, it has capacity to reduce voltalization of ammonia in agricultural soils (Lehmann and Rondon, 2006). Along with that biochar has ability to absorb dissolved soluble nutrients like ammonium nitrate (Lehmann et al., 2002, Mizute et al., 2004) Phosphate and other ionic solutes (Radovic et al., 2001) The interaction of biochar and poultry manure in enhancing soil available N could be due to addition of poultry manure to biochar increase surface oxidation of biochar by raising temperature and change the properties of biochar (Kuzyakov et al., 2009). Biochar absorbed the leachate which increased moisture content. Along with that, biochar also absorbs organic matter and nutrients which increased the availability of nutrients in soil (Jia et al., 2015).The available N found in biochar applied soils was higher than that non biochar applied plots because of optimum nitrogen storage in soils during whole cropping systems. High amount of available N in 50% RDF +50% FYM+ biochar application mixtures in wheat crop due to the combined effect of manures and fertilizers and biochar. Available C and a terminal electron acceptor (NO_3^-) required for the denitrification (Deluc et al.,2009) Addition of biochar and manure increased the available C in soil solution(Steiner et al., 2017) which increases the denitrification capability in mineral soil under anaerobic condition. It increased the nutrient use efficiency. In unamended plots the low level of available N found that could be lost by immobilisation and voltalization (Xie et al., 2013). During both years of experimentation an increase in soil inorganic N with integrated use of biochar, manures and fertilizers was observed which could be due to decrease in leaching of N with increase in available N. The reason behind this is that biochar application accelerates an enhancement in net mineralization of soil organic N (M. Prosdocimi et al., 2016, Q. Liu et al., 2016).This result is in confirmity with the findings of Atkinson et al., (2010) and Borchard et al., 2014 who reported that increase in available N content in biochar amended soils as compared to control. Accumulation of organic N in SOC pools and slow conversion of inorganic N responsible for increased in available N in soil (Prommer et al., 2014). This conversion increase organic N storage and C sink in agricultural fields. The availability of N in soil was increased that might be due to the improvement in physical conditions of soil microbial biomass and contribution of N by added quantity of FYM. This result is in confirmity with the findings of Newa and Yadav (1994). Biochar combine with vermicompost also showed significant effect on soil available N it might be due to the vermicompost as it contains organic acids, hormones and microorganisms which stimulate microbial activity in soil. Co-composting of poultry manure and FYM with biochar reduce losses of nitrogen (Dias et al., 2010, Pros et al., 2013)

4.8.1.5 Soil available Phosphorous: Availability of soil P plays vital role in increasing the crop yield. Soil P content was significantly improved by the biochar application. Addition of biochar to soil can improve nutrient retention capacity of soil and availabilty to plants such as P might be due to its high CEC (Krull et al., 2003).Biochar improved soil fertility and production capacity while maintaining high levels of soil nutrients like P. Biochar has the capacity to improve P availability by increasing mycorrhizal association in which P available by fungi (Major et al., 2009). In phosphorous availability mycorrhizal fungi plays vital role and biochar used as a habitat by mycorrhizal fungi. The fine parts of mycelium are more vulnerable to fungal grazers and these elements protected within biochar particles and increased soil P content (Matsubara et al., 2002). Biochar absorbed ionic compounds of mycorrhizal fungi. Wallstedit et al., 2002 reported that reduction in water soluble phenols by the application of biochar to soil which increased fungal capacity for P availability in soil.

This result is also in confirmity with the findings of Laird et al., 2010. The P availability increased with increase in pH of soil. Application of biochar alone or in combination with manures significantly increased soil available P. Sasmita at al., (2009) found out synergistic effect of biochar with organic manures in enhancing soil P availability. The increment in pH of soil would reduce sorption of available P. This result in consent with the findings of Deluca (2010) who reported more available P in biochar amended soils as compared to unamended soils and improve biochar capacity to retain and exchange phosphate ions due to its positively charged surface sites. P concentration in soil was improved by absorption of orthophosphate in soil solution within biochar pores. Due to this leaching and runoff losses are less but nutrient remain available for uptake by plant roots. Decrease in leaching of P and increased availability n biochar amended soils could be attained to endothermic absorption of P in meso pore surfaces of biochar. Increase Ca bound P, decrease Al and Fe bound P and improve aggregate stability and P concentration (H. Rave, 2014), X. Peng (2012), G. Xu (2014). Interaction of FYM with biochar and synthetic fertilizers was found significant. It increased the availability of P in soil might be due to the production of organic acids in soils by FYM which release more P from SSP. All the treated plots enhance soil available P concentration as compared to control. The integrated application of manures with biochar induced higher amounts of available P concentration. Once they incorporated into soil they add P to soil. This result is in confirmity with the reported study of Ghosh, Ow and Wilson (2015) which stated that co-application of biochar with manures increase soil P concentration. The more availabilty of P in biochar treated plots might be due to liming effects of biochar which favours desorption and solubilisation of the nutrients ions (Randolph et al., 2017). The similar findings found by Novak et al., (2009) and Verheijen et al., 2010)

4.8.1.6 Available Potassium: Similar to N and P available K increased with the co-application of biochar with the fertilizers and manures. Biochar has the capacity to increase the nutrient retention capacity of soil due to its high surface area (Lehmann and Joseph, 2009), Kloss et al., 2014 and Lashari et al., 2015 reported that application of fresh biochar which comprised with soluble P&K. It contributed to plant available pool upon incorporation in soil. In this study, the increase in available K concentration in experimental soils could be due to release of natural soluble potassium of biochar. On the other hand, increase in pH and CEC of soil reduced the activity of Fe, Al which might be contributed towards improving availabilty of K (Niggusie et al., 2012). This result is also in agreement with the findings of (Lentz et al., 2019, Tammeorg et al., 2012). Increased K availabilty by the biochar application might be due to the considerable amounts of K which were added along with biochar (Brunn et al., 2011). Similar results of K was obtained by major et al.,2010, Lehmann et al., 2003.The integrated application of biochar and manures increased the K availability in soil might be due to more amount of K concentration in rice straw biochar. Available K in biochar applied soils resulted significant difference in both years as compared to control. That might be due to high level of exchangeable K content in rice straw biochar. In rice straw 90% of total K present in water soluble form. During pyrolysis, temperature above 600^0C K was found in exchangeable and extractable form (Yu et al., 2005, Chan and Xu, 2009).Application of FYM with biochar along with inorganic fertilizers increased the available K in soil which might be due to more capacity of organic colloids to hold K^+ ion exchange sites (Wakene et al., 2001), Nasser and Hussain (2001), Bonde et al., 2004 and Singh et al., 2008 also reported similar findings. Available K content was significantly affected by the addition of organic matter in soil. It could be due to higher mineralization of potassium at more levels of organic matter. This result is also supported by Rathod et al., 2013, Kumar et al., 2012, Pawar et al., 2012.

4.8.2 General discussion on impact of biochar combined fertilizers on soil carbon fractions:

4.8.2.1 Soil Carbon: Soil carbon is the driving agent of soil organic matter content and soil quality. SOC is a heterogeneous mixture of organic substances. The various fractions of SOC have different effect on soil quality. Along with that soil C has nutrient holding capacity and contributes to the structural properties like aggregate stability (He et al., 2008).Soil carbon and organic matter content increased under all treated plots of biochar. In both years, total soil organic carbon changed significantly due to biochar. The highest SOC was detected in biochar applied plots along with manures and fertilizers. Increased SOC of soils after the application of biochar were already stated in previous biochar research both in field and incubation (Schulz et al., 2013, Ghoneim and Ebid 2013,Zhang et al.,2012) Total soil organic C is one of the key indicator of soil quality (Laird et al.,2010). The used biochar along with manures and fertilizers during both years in rice-wheat cropping system increased soil organic carbon. Increase in SOC with biochar have been reported by Zhang et al., 2012 a. The soil organic C content is an index of soil fertility which was affected by the cropping system and organic nutrient source. In case of rice crop 50% RDF+50% PM+ biochar recorded highest OC%. That could be due to interactive effect of biochar and PM. Poultry manure addition with biochar increased surface oxidation of biochar which changed properties of biochar by high microbial activity during degradation of available C source (Kuzyakov et al., 2009). The leachates and organic matter absorbed by the biochar increased nutrient retention capacity and nutrient content which leads to increase the organic C content in soil (Jia et al., 2015).In case of wheat, biochar+50%RDF+50%FYM significantly recorded highest organic carbon . SOC is an important parameter of soil organic matter which aerates soil and helps in retaining water and nutrients. Soil organic matter provides substrate for soil microbial biomass which makes nutrients available to plants (Sukartono et al., 2011). Previous studies showed that FYM addition enhanced the quantity and quality of SOM (Fischer and Glaser 2012). Rivero et al., 2004 found that coconut shell biochar increased SOC. Biochar application to soil stimulate C pools due to its stability and inherent capacity (Liu et al., 2016). Results of study revealed that SOC increased in biochar amended plots as compared to control. The enhancement in SOC could be due to the conversion that takes place during pyrolysis process. C formed in rice husk was converted from aliphatic C to aromatic C which was responsible for increase in percentage of recalcitrant C in rice straw biochar (Laird et al., 2010). The other reason behind increase in SOC might be due to addition of labile C into native C pools of experimental soils and protect the native SOC from decomposition by the interaction of biochar- soil organo mineral complex (Dong et al., 2016).This result is in consent with the findings of Aller et al., 2017, Lehmann et al., 2012, Butnan et al., 2015). Dong et al., (2016) found increased levels of water soluble organic C in biochar amended plots over control in rice –wheat cropping system. Biochar undergo physical and chemical disintegration into colloidal and fine particles (Lian and Xiang, 2017). The disintegrated particles absorb and fix inorganic and organic carbon pools in soil and gradually released to soil over time (Darby et al., 2016 and Nguyen 2018).

4.8.2.2 Labile Carbon (POXC): POXC shows relatively younger and less recalcitrant organic compounds like labile humic materials and polysaccharides. More labile C content recorded in biochar amended plots during two years of crop cycle over control. The C input through 50%RDF+50% PM+ biochar in rice and 50%RDF+50% FYM+ biochar in wheat recorded significantly more labile C to soil (Bhattacharya et al., 2012). This result corroborates with the findings of Thorburn et al., 2012 who found that the soils treated with biochar recorded higher POXC concentration in soil. Tian et al., 2013 found the increase in concentration of POXC with the integrated application of biochar with manures and fertilizers might be due to more organic matter input through this. Higher content of labile C by rice straw biochar also reported by Bhattacharya et al., 2012, Leite et al., 2007 found that soils with the application of biochar with manures had higher labile C stocks than sole application of inorganic fertilizers and biochar. The thermal oxidation of OC is more in wheat as compared to rice due to stagnation of water on the surface (Bhattacharya et al., 2004). The increase in SOC storage based on crop mediated C input, exogenous supply of OM and initial OC in soil (Benbi and Snapati, 2010). This result is in confirmity with the findings of Neider and Benbi, 2008). FYM, vermicompost and poultry manure acted as a source of OM and when they returned to soil they enhance OC in soil (Banger et al., 2010) for which the treatments with biochar+ manures resulted high labile C.

4.8.2.3 Particulate organic carbon (POC): POC is biologically available and source of C and energy for soil microorganisms (Gregorich et al., 2005). POC is considered an intermediate fraction of SOC between active and passive fractions which change quickly over time due to change in management practices (Haynes, 2005). POC is a clear pool of organic matter between fresh residues and humified organic matter. Application of rice straw biochar along with poultry manure and fertilizer increased POC in soil. All treatments except control and RDF recorded significantly more POC during two crop cycles. More POC content in soil due to biochar along with manures significantly in present study due to fast conversion of applied C to humified C (Chan et al., 2007).Prabha et al., 2013 revealed that in biochar treated plots contributed more POC to SOC which has potential to stabilize and retain C in lower fractions of soil. Seasonal variation i.e. reduction in POC from rice to wheat might be due to seasonality of organic matter input to soil which was the main factors affecting the amount of POC in soil (Tian et al., 2013). This result is also in confirmity with the findings of Russel et al., 2004 who reported that plant species significantly varied in their effects on POC concentration in soil. This result also supported by SK Jemstad et al., 2006. Active C pools in soil basically contribute to C mineralization which is susceptible to microbial attack. But by the addition of C rich amendment like biochar made balance between active and passive pools. Previous studies reported the immediate release of CO_2 flush by biochar addition to soil (A.R Zimmerman, 2011, W. W. Lu, 2014). The stable part of biochar remains in soil for long time due to temporary flush of mineralization (S. Munda, 2016). After biochar addition, the short term stimulated C mineralization which was in consent with the recent study (Amand 2017). RHB application recorded more C mineralization that could be due to the interaction of soil and RHB which resulted positive and negative priming effects. Th negative priming increased storage of biochar C and soil C which showed positive effect on mitigating climate change (H.M.S.K et al., 2015). POC commonly represents large portion of light fractions of SOC (Bayer et al., 2002). POC is composed of more proportion of labile materials like root biomass, leaves, manures and biochar.

4.8.2.4 Microbial biomass C: The C of microbial biomass (MBC) is one of the most vital variables which show differences between organic and conventional areas (Zhang et al., 2010).Microbial biomass is one of the labile pools of organic matter. Soil MBC is the index of the response of microbial biomass to the changes in soil management which influences the conversion of organic matter (Baath and Anderson, 2003). After the application of biochar there was increase in MBC is in agreement with the findings of Linag*e al*., 2010, Paz – Ferreiro et al., 2012. Masto et al.,2013 reported that increase in MBC with biochar application might be due to increased decomposition and availability of substrate C. Biochar act as habitable pore area for the bacteria which provide greater microbial habitation(Atkinson et al.,2010). Other mechanism might be increase in the colonisable surfaces by biochar which enhanced microbial biomass. Biochar treated soils increased the surface area of soil which promotes the microbial activity (Atkinson et al., 2010) and Lehmann et al., 2011. It might be due to the improvement in soil physical and chemical properties. This result is in confirmity with the findings of Chan et al., 2008, Steiner et al., 2008a, Dempster et al., 2012. Sushmita Munda et al., 2018 recorded significant effect of rice straw application on MBC. D. Bhadur et al., 2016 found enhancement in MBC content with the application of peanut shell biochar. The MBC content directly reflect the changes in total C of soil (Z. Costanzo et al., 2011).An enhancement in MBC showed changes in supplying of nutrient capacity of organic matter(Sharma, Bali and Gupta,2001). These results supported by Albiach, Canet, Pomares, Ingelmo, 2000) where they observed that organic manures along with biochar increased microbial population, soil microbial biomass and their activities. It has been found that organic sources like FYM, VC and PM decomposed slowly resulted inorganic C assimilation in soil (Singh, Singh, Meelu and Khind, 2000). FYM along with fertilizers and biochar improved microbial biomass Banerjee, Aggarwal, Pathak, Singh and Chaudhary, 2006). That could be due to antagonism among the micro flora contains in FYM and biochar. An enhancement in MBC is related to the changes in the potential of nutrient supplying of organic matter (Karmegam and Rajasekar 2012). Soil MBC shows the response of nutrient management on microbial biomass. In case of wheat crop MBC highest value recorded with the application of 50%RDF+50%FYM+biochar among all treatments might be due to catalytic effect of FYM in inducing microbial growth, resulting in high MBC(Basak et al.,). Vineela et al., 2008 also recorded significant increment in soil microbial biomass C by application of FYM, NPK and biochar. In case of control low MBC recorded that could be due to inadequate and imbalanced supply of nutrients for microbial utilization in soil (Bhatt et al., 2016).MBC increased in RSB (rice straw biochar) applied plots which reduce C use efficiency and increase total C of soil (B. Keith, 2011). During both years MBC recorded significant variation in rice crop 50%RDF+50%PM+biochar recorded more MBC whereas 50%RDF+50%FYM+biochar recorded more MBC. That could be due to lower C: N ratio and more labile N in labile pools of RHB which stimulate microbial growth (Singh et al., 2007). In case of control the slow decomposition leads towards less build up MBC (Singh et al., 2007).

4.8.2.5 Microbial quotient (q_{mic}): The actual amount of biomass at any time cannot judge the SOM quality is increasing or decreasing. To answer this question, the other soil related parameters were compared to MBC; ratio of MBC to TOC gives a measure of OM dynamics (Leite et al., 2007). The q_{mic} ratio may be the measure of efficiency of organic C transformation into microbial C and the losses of soil C during decomposition. Q_{mic} is a soil quality parameter which allows comparison in soils with different organic matter content (Jiang et al., 2006). Microbial quotient is an indicator of microbial C use efficiency. The plots with lower SOC however have high q mic ratio and soil biological activity might be due to the fast decomposition of soil organic matter which will be harmful to soil quality (B. Keith2011, Y. Lin et al., 2012). The reduced values of q_{mic} could be due to shift in bio available substrates from labile C pool to passive C pools and decrease C use efficiency (M. Farrel et al., 2013). D. Bhaduri et al., 2016 reported that in short term experiments the increase in these ratios cannot confirms the accumulation of organic matter. Since our experiment is of 2 years, the conversion in organic matter equilibrium observes very carefully and long term study will be required to draw any conclusion.

4.8.3 General discussion on impact of biochar based amendments on soil biological indicators: The measurement of enzymatic activities give information on soil chemical processes, nutrient mineralization rate and organic C accumulation.

4.8.3.1 Urease: Urease enzyme in soil is essentially a microbial extracellular enzyme assimilated through release of urease from living and disintegrated microbial cells. Urease producing micro-organisms present in soil which helps in enhancing urease activity .Addition of organic manures in soil increased microbial population. Addition of organic manures with biochar increased urease activity in soil reported by X.T Jug et al., 2009. After two years study and biochar application along with manures and fertilizers significantly increased enzymatic activities in surface soil (0-15 cm) than subsurface soil (15-30 cm). Change in enzymatic activities of soil has been found in this study which also affects nutrient cycling, decomposition of litter and N2O emission (S.O. Oladele, 2019). Increase in enzymatic activities could have been stimulated by increase OC, MBC and nitrogen pools which provide organic substrate to enzymes (M.S. Awopegba, 2017). Urease enzyme converts the applied urea into NH3 and CO2. The urease enzymatic activities reduced with the soil depth might be due to decrease in OC and microbial population with the depth (C. Lammirata et al., 2011). The biochar amendment showed positive effect on urease enzyme activity because it involved in N cycling and N availability from agricultural fields (S. Kumar et al., 2013). The urease activity increased by combined application of biochar with manures and fertilizers might be due to hydrolysis of urea by biochar (V.L. Bailey, 2011). In rice crop urease enzyme activities increased with 50% RDF+50% PM+ Biochar could be due to high microbial biomass which involved in releasing urease enzyme which is a constitutive enzyme (Geisseler et al., 2010). This result is also in confirmity with the findings of Khare and Goyal, 2013) and Knicker et al., 2008).The other mechanism behind this is that the decomposition of OM is affected by enzymes mainly urease and activity of urease in soil mainly result of its release from plant cells and decaying microbes (Wu et al., 2013). In case of wheat crop, the highest urease enzyme activity was recorded with 50% RDF+50% FYM+ Biochar that might be due to the synergistic interaction of biochar with FYM and synthetic fertilizers which increased microbial population as well as release nitrogenous fertilizers in large proportion in root exudates which stimulate urease enzyme activity(Garg and Bahl ,2008). The increased activity with 50% RDF+50% FYM+ biochar may be due to the fact that OM added to soil increases microbial fermentation of organic compounds which decreases reduction and oxidation. Ethanol, acetate, lactate are the fermentation products which are rich source of energy for microorganisms and microorganisms release enzymes into soil (Vajantha et al., 2010). The results of study showed that highest urease activity in both crops recorded at heading stage. This result is corroborates with the findings of Nayak and Manjappa 2010 and Rama Lakshmi et al., 2012.There was a positive correlation of vermicompost and FYM with available N and P. So, the activity of urease was also increased with them.

4.8.3.2 Dehydrogenase (DHA): Dehydrogenase activity shows the total range of oxidative activity of micro flora and good indicator of soil quality (Saha et al., 2008).DHA is a combination of intercellular enzymes found in microorganisms in soil. DHA was observed highest in all treatments except control. The significant increase in dehydrogenase activity in wheat by 50% RDF+50% FYM+ Biochar and in rice by 50% RDF+50% PM+ Biochar might be due to the addition of organic matter through FYM, PM which enhanced microbial activity and microbial biomass. The same results found by (Prakash et al., 2002, Sheng et al., 2005), Tejda and Gonzalez, 2009. The lowest dehydrogenase activity was recorded in control followed by 100% RDF that could be due to imbalanced fertilization inhibitory effect in making the non -availability of C. By this the retention capacity of C increased and osmotic potential of soil solution increased due to fertilizer salts these conditions reduced the activity of dehydrogenase(Ramalakshmi et al.,2012, Kaur and Brar,2015) The decreased activity of DHA with 100% RDF is related with the redox potential of soil. Redox potential of soil might be increased due to deposition of nitrate which reduced DHA activity. These results are in corroborate with the findings of Bhatt et al., 2016, Mandal et al., 2007 .The dehydrogenase activity was improved with the integrated application of biochar with manures and fertilizers . This result confirms that combination of biochar with manures and fertilizers maintained active pools of C and N in soil surface due to plant biomass addition. The organic pools of C and N related with the nutrients mainly N could be maintained in rhizosphere zone for improving SOM and enzyme activities (Reddy Ru, 2012).Similar findings were reported by Bharati et al., 2011, Bhavan et al., 2017.The increase in DHA due to PM and VC due to availability of higher C substrates and energy for heterotrophs. Similarly enhancement in DHA with the application of chicken manure biochar reported by Park et al., 2011 and Paz-Ferreiro et al., 2012).

4.8.3.3 Acid and alkaline phosphatase: Phosphates are important because they provide P for plant uptake by releasing PO4 from immobile organic P. In the current study acid phosphatase activity was found to be much higher than the alkaline phosphatase which might be due to acidic reaction of soil. Phosphates are group of enzymes which catalyse the hydrolysis of organic compounds t phosphate. Plants and soil micro-organisms demand of P may be responsible for stimulation of phosphate enzymes (Turner and wright, 2014). Increase in the phosphatase activity shows variation in the quantity and quality of soil phosphorylates substrates. Plant roots contributed the acid phosphatase and the condition which supports plant root growth may also increase the secretion of enzymes (Nottingham et al., 2015). The phosphatase activity was directly correlated with extractable P. The acid phosphatase activity was increased in wheat crop with 50% RDF+50% FYM+ Biochar. It could be due to the organic matter addition which increased OC and N (Reddy and Reddy 2012); the organic acids produced during decomposition of FYM might be responsible for enhancing enzymes activities (Kadlag et al., 2008). Similar results were found by Benitez et al., 2000, Bhattacharya et al., 2005. Higher activity of phosphatase enzyme in FYM, VC, PM +biochar applied treatments over control and 100% RDF could be due to the extra supply of C and n substrates through applied manures which supports microbial activity(Bhatt et al.,2016). This result also supported by Mishra et al., 2008 and Elayara and Singarvel, 2011. The activities of both acid and alkaline phosphatase were decreased with depth. Garg and Bahl (2008) reported that increase in alkaline phosphatase activity with combined application of biochar with manures and fertilizers. Biochar contain substantial amount of P which increased acid and alkaline phosphatase activity in soil (Zamuner et al., 2008). Increased activity of alkaline phosphatase have been reported by Jin (2010) that could be due to uptake of N and P by plant s and growth of fine roots and root hairs into biochar pores which induced the production of organic N and P by plants and growth of fine roots and root hairs into biochar pores which induced the production of organic N and P mineralization enzymes. Enhancement in alkaline phosphatase by biochar is also observed by Paz-Ferreiro et al., (2012) and Masto et al., (2013). Increased activities of phosphates with biochar also reported by Wang et al., 2011.Reduction in alkaline and acid phosphatase with soil depth is in agreement with the findings of Kumar et al., 2013, Ni et al., 2011 which could be due to low levels of microbial activities and OC content. Increased phosphatase activity in soil indicates more availability of P to crops and soil microbes (S.M. Shahzad, 2014). The obsevations corroborates the findings of J. Chen et al., 2013).

4.8.3.4 Nitrate reductase: Higher Nitrate activity occurred with increasing pH due to high NR Activity. The availability of nitrate can positively correlated with NR enzyme activity.

4.8.4 General discussion on effect of biochar application on growth and yield of crops: The growth in terms of plant height, tillers, leaf area, Chlorophyll index, fresh weight, dry weight of plant, flag leaf length, CGR, RGR and NAR presented in tables in result sections shows that the growth was slightly more as crop growth starts towards development during crop season. The more growth rate could be due to the favourable weather conditions like temperature, rainfall and sunshine presented in graph. The effect of different treatments was negligible at early vegetative stages and increased at later stages of crop development. Among different treatments during year of study these variations in growth parameters were because of cumulative effect of biochar with manures and fertilizers. Rice straw biochar has positive response on growth and yield of rice –wheat crop. The findings of the study showed that the growth parameters like plant height, tillers, leaf area, Chlorophyll index, fresh weight, dry weight of plant, flag leaf length of rice-wheat plants improved in biochar amended plots as compared to control. These growth parameters were significantly better in biochar combined manures and fertilizers treatments. This show that some inorganic fertilizer can speed up growth and yield when added with rice straw biochar. The same result recorded by Gebermedhin et al., 2015.The increase in plant height by use of rice straw biochar along with manures and fertilizers. The plant height increased with the increase in number of days after sowing. Di Lanardo et al., 2013 observed that greater elongation of plant grown on soils containing biochar as compared to those grown on soils containing biochar as compared to those grown on soils without biochar. Zheng et al., 2013 revealed that wheat shoot biomass increased by 21% due to biochar amendment. The enhancement in the plant height might be due to the potential of biochar to reduce accumulation of Cd, Zn and lead in shoots of wheat which improved growth. It appears that increase in plant growth might be due to uptake of macro and micro elements by plants. The manures add organic matter to soil which increased the nutrient retention capacity of soil and availability of nutrients to plant throughout life cycle. The increase in growth of plants by rice straw biochar might be due to Silicon deposition in rice plants which showed positive impact on growth of plant by suppressing the excessive transpiration which increased the light interception structure of rice plants and reduce lodging(Koyama et al.,2016).The increase in plant height during developmental stages in T8 and T4 in rice wheat crop because of more moisture and nutrient availability to crop plants may be the reason of recording high values of plant height . The more moisture content kept the high turgor potential which is responsible for more photosynthesis due to more opening of stomata for long time. This also increased the cell enlargement and division which leads to high growth rate .Similar findings were observed by Naresh et al., 2012, Phogat et al., (2001). The lowest plant height recorded in control (T0) because of low availability of nutrients as no fertilizer was applied in this treatment. Application of FYM, PM, VC and biochar, solely or combined with fertilizers increased leaf chlorophyll content and productive tillers over inorganic fertilizers alone. This also showed that increased availability of nutrients, vigorous plant growth and healthy plants contributed in increasing yield. Previous studies had shown that the nutrient supplying capacity of manures was higher when applied together with biochar as applied together with biochar as compared to alone biochar (Fischer and Glaser et al.,2012, Schulz and Glaser 2012. Liu et al., 2012 found a positive synergistic effect of biochar with manures and fertilizers which enhance soil organic matter content and nutrient concentration which improved plant growth characters. Plant growth parameters were improved by use of organic matter with biochar could be due to additional supply of nutrients and addition of these improved physical, chemical and biological aspects of soil (Agegnehu et al., 2015a, Bolan et al., 2012, Chan et al., 2013, Dil and Oelbermann 2044, Domen et al., 2014). The nutrient present in manures and biochar might be increased soil nutrient concentration and become available to crops. With the availability of nutrients the shoot biomass increased. According to Prendergast-Miller et al., 2014 reported that biochar amended plots have longer rhizosphere zone as compared to unamended plots. The enhancement in growth of rice-wheat plants could be due to considerable effect of biochar on the suppression of weeds due to the inhibitory effect on weed seed germination. Arif et al., 2012 observed that application of biochar @25 tha^{-1} and 5t ha^{-1} FYM recorded low weed density in maize crop. They concluded that application of biochar decrease the emergence of seedlings (Quilliam et al., 2012). In this study, increase in yield contributing parameters was more pronounced when organic amendments, fertilizers and biochar were applied together. Application of organic manures combined with fertilizers induced crop growth parameters which is in agreement with the fertilizers induced crop growth parameters which is in agreement with the findings of (Doan et al., 2015, Albuquerque et al., 2013).Biochar and N had positive synergistic effect on crop growth parameters. This may be due to the fact that manures and N fertilizer partially substitute for one other in case of supply of N (Kaur et al., 2008). Other studies have shown that addition of mineral fertilizer with manure and biochar improve yield attributing parameters of rice-wheat (Meade et al., 2011, Blackwell et al., 2015). Biochar amendment to soil increased plant growth and enhance nutrient use efficiency (Barrow ,2012).The significant improvement in biomass of plant and crop growth has been observed by application of biochar to soil (Abiven et al.,2015, Agegnehu et al., 2015b). Some of the previous studies showed that biochar influenced the crop at early stages (Solaimen et al., 2012, Van Zweiten et al., 2010). The combined application of biochar, mineral fertilizers and manures signifies organic matter status (Fischer and Glaser 2012) which is related to release of nutrients such as N. The change in soil status affects germination and growth of seedlings (Schulz et al., 2013). Plant growth parameters improved with biochar additions that could be due to optimization of the availability of plant nutrients (Agegnehu et al., 2016) enhancement in microbial biomass and activity an decrease of exchangeable Al3+(Vaccari et al.,2013). Similarly addition of biochar improved N uptake & FUE (fertilizer use efficiency in wheat which increased the plant biomass as compared to control. Biochar and biochar-manure –fertilizers improved yield attributing parameters by a number of mechanisms i.e. direct supply of nutrients, improving pH of soil, increasing pH of soil and nutrient uptake by enhancing soil CEC and increasing soil water holding capacity(Sigua et al.,2016, Biederman and Harpole ,2013). Enhancement in plant growth in biochar+ FYM+RDF may be due to nutrient availability and uptake compared to biochar alone(Agegnehu et al., 2016b).Lehmann et al.,2003 reported that biochar act as a direct source of nutrients for uptake by plant and increased growth parameters . Same result was found by Vaccari et al., 2011, Schulz et al., 2013. In case of rice crop the combination of 50% RDF+50% PM +biochar respond better in case of all plant growth parameters that could be due to the potential of biochar to improve the efficiency of utilization of nutrients in the PM. The addition of biochar in such mixed treatments application has capacity to reduce nutrient leaching and increased nutrient retention capacity of nutrients. The inculsion of biochar with PM increased NUE (Adekiya et al., 2018). The plant growth is better when roots of plant interact with biochar. Rhizosphere is a primary point of interaction between any materials and growing plants. The mechanism behind biochar-crop interaction include by changing soil physico-chemical properties(Jones et al., 2012) by changing microbial biodiversity and by reducing residual effects of herbicides and allelochemicals and absorption on surface(Miller et al.,2014). The synergistic effect of biochar and synthetic fertilizer is the result of increased plant nutrient uptake, less nutrient losses and improved availability of cationic elements (Fiscer and Glaser, 2012). It is also possible that direct release of nutrients (P, K, Ca, and Mg) for rice plants is the possible reason for increase plant growth. Lai et al., 2017 revealed that rice plants when treated with biochar and N fertilizer in pot experiment performed better in case of leaf area, plant height, SPAD value and number of tillers as compared to control. This result is in confirmity with the findings of Kamara et al., 2015 who found that plant height of rice, tiller number and plant biomass were increased by rice straw biochar application. The chlorophyll content of leaf increased with advanced crop growth stages which plays vital role in performance of crop that could be due to improved uptake of N by cultivated crop by supply from organic amendments. Chlorophyll content of leaves is an index of photosynthetic productivity and vigour of plant. Chlorophyll index related to N concentration in green plants and act as indicator to measure N response to fertilizers (Liu et al., 2013). In this study, chlorophyll content was considerably high in organic amendments and inorganic fertilized plots as compared to alone fertilizers. All organic amendments with fertilizers and biochar significantly improved chlorophyll content of leaves that could be due to increased soil available N and plant N and contribute towards improvement in growth and yield. Our study conclude that 50%RDF+50%FYM+Biochar in wheat increased chlorophyll index of both crops (Hue et al.,2012) as compared to 100%RDF and biochar alone. Our findings reflect that organic amendments enhance growth and productivity of rice wheat crop. Plant biomass and leaf area was significantly affected by organic amendments along with mineral fertilizers. These results are corroborates with the findings of Major et al., 2010, Mekura et al., 2014,Uzoma et al., 2011 and Zhang et al., 2016 and might be due to the availability of nutrients and soil moisture. Solaimen et al., 2012 have been reported that the germination of wheat seed increased from 93-98% with the application of biochar. Cornelissen et al., 2013, Doan et al., 2015 reported that manure+ fertilizer+ biochar improved the overall plant growth. The availabilty of essential nutrients in right amount is a key point for balanced nutrient uptake, healthy plant and optimum yield (Inalet et al., 2015). The improvement in soil physicochemical properties due to the biochar application was indicated in growth and biomass production of rice-wheat crop. The tiller number, fresh weight, dry weight indicated remarkable difference .The number of tillers in rice-wheat crop indicated a clear difference in biochar amended plots as compared to control. The mechanisms behind increase in the number of tillers with biochar addition due to the decomposition of OC which increased OM and WHC and reduce silt which enhancing tillering in crop. This result is supported by Fagbenro et al., 2013 who reported that synergistic effect of biochar with mineral fertilizer in case of tillers. Increase in the number of tillers with biochar+ FYM+RDF attributed to the release of nutrients from the decomposition of FYM. The minimum tillers in control plots probably might be due to exhaustive effects of crop in terms of nutrient absorption which led to nutrient deficiency and crop performance (Uzoma et al., 2011)

Co-application of FYM, N and biochar stimulate growth of leaf, assimilation capacity due to more photosynthesis leaf area increased. Leaf area was significantly affected influenced by different biochar based amendments. The change was progressively increasing up to 90 days. The increase in leaf area by biochar addition might be due to increment in cell expansion. This result is supported by Burke et al., 2012, Njoku et al., 2015 showed that biochar applied plots had more leaf area as compared to control. The increase in leaf area and leaf area index of maize by biochar application reported by Lashari et al., 2015and Ahmad et al., 2015. Incorporation of manures increases soil N status and affect chlorophyll content in crop through better N absorption and improved leaf area of wheat (khan et al., 2008). The plant growth in case of dry matter accumulation was increased significantly and maximum in T4 and T8 in rice-wheat crop respectively. This shows that organic sources along with mineral fertilizer and biochar supplied the N to crop plants and N is the main constituents of chlorophyll, protein, cellulose, photosynthesis and tissue build up for proper growth. So, the integrated application provides N slowly to crop but for long time. These results are in confirmity with the findings of Yadav, 2006. Application of 100% RDF+ FYM+ biochar was the best integrated nutrient management treatment reported by Bhaduriya et al., 2016 and Prabhakar et al., 2003. Application of PM @1.5 tha-1+100%RDF in combined form increased leaf area, LAI, total dry matter and grain yield as compared to other treatments. Same result observed by Choudhari and Channappagouda, 2015.

Crop growth rate, relative growth rate and net assimilation rate were significantly influenced by different combinations. Biochar amendment increased CGR through its nutrient availability. The results supported by Agegnehu et al., 2016n findings who observed that increase in crop growth rate and biomass production of maize crop with biochar based amendments. Van Zwieten et al., 2010 revealed that the positive interaction of biochar with fertilizers in case of biomass production in wheat. Rondon et al., 2007 observed that there was 3% increase in biomass production in pot experiment by use of 60g /kg biochar. Edmunds (2012) and Schulz et al., 2013 showed that above ground biomass production increased in switch grass and sorghum by biochar + compost application. This was supported by Brennan et al., 2014. NAR is the useful measure of photosynthetic efficiency of plants which is significantly affected by biochar based amendments. NAR was decreased due to progressive mutual shading by increase of leaf area. NAR was significantly influenced by biochar application.

4.8.5 General discussion on effect of biochar on yield components and yield: The significant improvement in grain and straw yield with biochar based amendments. The more growth finally resulted into significant increase in grain yield components namely-productive tillers, number of panicles/spikelets per plant, panicle length and test weight. Grain yield is the most important economical part in production system. The data regarding individual and integrated influence of biochar, FYM, PM, VC and fertilizers presented in tables and graphs in result section. Application of 50% RDF+50%PM+biochar in rice and 50% RDF+50%FYM+biochar in wheat produced more number of effective tillers (Panicles/spikelets). The combination of biochar with vermicompost and fertilizers also increased the number of spikes/panicles per plant. Overall, all the treatment combination resulted in more spikes m-2 as compared to control .The number of filled grains per panicle /spikelet, panicle length and test weight was improved by application of biochar with manures and organic amendments. That is because of more supply of N through organic amendments and N availability promotes vigorous growth. N application also enhanced photosynthates which were transport to grain due to this the grain filing percentage, length of spikelet and weight of grains increased. The same result recorded by Akmal et al., 2010, Hussain and Shah (2002). The more number of effective tillers, lengthy spikes and more filled grains and high test weight were recorded with biochar +Nitrogen (Maqsood and Shehbzad, 2013). Yield attributing parameters in wheat crop increased with biochar+ FYM+RDF combination may be due to quick mineralization and timely release of nutrients to soil (Atkinson et al., 2010). FYM in combination with synthetic fertilizers and biochar increase grain yield and straw yield because of slow and timely release of nutrients and reduce N losses. Increase in yield of crops attributed to nutritional value of biochar which increased soil fertility and productivity and increase FUE mainly N fertilizer by reducing leaching of N (Chan et al., 2007). Biochar act as buffer and having some essential plant nutrients which significantly increase crop yield. Blackwell et al., 2009 recorded progressive increase in the crop yield by biochar addition by improving soil properties. Biochar acts as a binder for NH3 and absorbs ammonia in soil and have capacity to decrease voltalization from soil surface and improve NUE which improve straw yield and biomass (Iqbal et al., 2002). Application of mineral fertilizers, FYM and biochar significantly increased grain yield of wheat over control because of N fertilization and mineralization of organic sources like biochar and FYM throughout life cycle of crop which retain nutrients and kept the plant safe from nutrients stress at any stage of life cycle (Atkinson et al., 2010). In rice crop better crop growth and more yield resulted from 50% RDF+50%PM+biochar as compared to other treatments. Slight differences of rice yield between different treatments could be due to the difference in the number of spikelets /panicles per plant. Panicle number is affected by the number of tillers which developed during vegetative stage but spikelet number and filled grains per panicle determined reproductive stage. The yield of rice-wheat crop related to spikelet fertility, 1000 grain weight and harvest index (Walker, 2006). Highest HI was recorded with T4 in wheat and T8 in rice .Lowest HI recorded in some of biochar applied plots might be due to more number of panicles and straw yield. It could be due to the availability of more nutrients to crop. The availability of nutrients influenced by enhancing CEC, improving soil pH and direct contribution of nutrients which increased crop growth and yield(Lehmann et al.,2003). FYM+ fertilizers+ biochar had more exchangeable cations. The other mechanism which provides nutrients to crop is the retention of nutrients in pores of biochar and crop received nutrients without suffering nutrient deficiency. In present research, crop growth and yields from biochar treated plots were higher than yields of control and NPK fertilizer application. Zhang et al., 2012 revealed from their study that biochar + manure treated plots had more yield as compared to unamended plots and yield was not affected by biochar rates. This result corroborates with the findings of Jones et al., 2012 and Glaser et al., 2012.Ghoneim and Ebid (2013) studied effect of rice straw biochar on rice yield as compared to RDF application. Two rates of biochar 15 g kg-1 and 30g kg-1 soil used to observe effect of biochar application on rice yield. They observed that increase in rice yield by 12.7% with biochar over NPK fertilizer. The study suggested that optimum combination of biochar and fertilizers should be adjusted. In the farming aim was economic profitability and getting more production then organic and inorganic fertilizers should be adjusted based on availability of organic amendments and affordability of farmers for chemical fertilizers. In case of rice high yield obtained with 50% RDF+50%PM+biochar that could be due to interactive effect of biochar and PM in both years. Steiner et al., 2007 found increase in yield of rice and sorghum when 11 tha-1 biochar was applied over 2 years. Kimetu et al., 2008 reported double increase in maize yield by use of 7 tha^{-1} biochar over two years. Vaccari et al., 2011 found that grain yield increased by 28-39% by biochar application. They found significant residual effect of biochar on second year crop cycle. Increased crop yield by added biochar because of fertilizer effect and supplying important plant nutrients i.e. K, N, Ca and P (Lehman et al., 2009). Improvement in crop yield by biochar application because of increased nutrient retention in soil (Asai et al., 2009, Chan et al., 2008 and Steiner et al., 2008).The other mechanism for the retention of nutrients is the slow oxidation in soils which produced carboxylic groups and can enhance CEC and O: C ratio and enhanced capacity to retain nutrients (Steiner et al., 2008). Biochar and manures are found to enhance HI in both rice and wheat crop during both years. Increase in HI due to biochar application over control was reported by Shaleh et al., 2011. This result also supported by Major et al., 2010. Biochar may be acted as slow release fertilizer which led to increase NUE and grain yield. Increase in grain yield and straw yield by biochar combined fertilizers because of partitioning and migration of available photosynthates to economic yield (Ahmed et al., 2011). More HI with biochar combined fertilizers over control might be attributed to optimum vigour of plant which favoured the partitioning of photosynthates to reproductive part which increased grain to straw ratio. The production of most of cereal crops based on the source (photosynthesis) and sink (grain) relationship. The potential of system to transport the photosynthates and division of assimilation between their sites of utilization are major determinants of crop yield (Evans and Wardlaw, 1976). Rice straw biochar was more effective and co-application of biochar with manures increased grain yield. The Si content of RSB could be possible reason for high grain yield (Liu et al., 2012 and Zhang et al., 2012). The co application of biochar manures and fertilizers boosted availability of elements in soil which leads to increase grain yield. The combination of biochar with vermicompost also recorded second highest yield parameters in both crops. Vermicompost is more stable and resistant to degradation than FYM (Ngo et al., 2013, 2014) so because of this it had more water holding capacity and hydraulic conductivity (Jouquet et al., 2010). The increase in straw yield with biochar amended plots as compared to control could be attributed to better crop growth rate, Leaf area index and accumulation of photo assimilates by crop which produced more straw yield.

4.8.6 General discussion on the effect of biochar on nutrient uptake and nutrient use efficiency:

4.8.6.1 Nutrient uptake by grain and straw: In the present study biochar application increased nutrient uptake in grain and straw over control which might be due to the fact that biochar contain more exchange cations due to its high porosity and surface area which improved plant nutrients uptake and P, Ca, K availabilty in soil(Yamato et al.,2006). More N uptake could be due to higher N availability under biochar application. The N and P uptake was more through grain and potassium more through straw. The higher N, P uptake in grain could be attributed to its chemical composition due to higher amino acids and protein content in grain needs more N and P but K content in straw might be its higher content is required for providing strength to stem by forming cellulose, lignin and protein. The higher uptake recorded in T4 in wheat and T8 in rice because of high grain and straw yield during experimentation. Similar result was found by Rani et al., 2009. The maximum N content in rice was observed from treatment 50% RDF+50%PM+biochar-T8 and in Wheat with 50% RDF+50%FYM+biochar-T4 during both years which was significantly higher as compared to other treatments. That could be due to addition of FYM, PM along with biochar which improved concentration of N in both crops. The application of organic amendments increased root system and absorbing capacity and availability of N. FYM also contain N and decomposition of FYM produced organic acids which increased N availability. The improvement in N content could be attributed to increase in bacterial activity in presence of organic matter which increased N availability to plants. This result corroborates with the findings of Abedi et al., 2011.The N uptake was increased due to co-application of mineral fertilizers with biochar and manures. The enhancement of N uptake by grain and straw under INM treatments could be attributed to increase in microbial activity which favoured N mineralization. The organic amendments multiply soil microbes which increased transformation of organically bound N into inorganic forms and quick mineralization which is responsible for high N content in plant biomass (Chesti et al., 2015 and Bhadur et al., 2012 found same result. Van Zweiten et al., 2010 recorded significant increase in N content in grain and straw by application of 50tha-1 biochar over control. This enhancement in N uptake in grain under biochar amended plots attributed the useful effects of biochar which enhance FUE, reduce leaching and denitrification. Our results are in confirmity with the findings of Silva et al., 2006 who observed that increased concentration of N in wheat grain and straw when FM in combination with mineral fertilizers and biochar was used as compared to sole biochar and sole NPK. Other possible mechanism could be the vigorous growth of plant components in response to optimum nutrient availability in plots incorporated with FYM, PM, biochar and RDF (Gibson et al., 2007, Shah et al., 2009)

Biochar appears to respond a significant source of available P for crops (Asai et al., 2009). Atkinson et al., 2010 observed several reasons which can increase availability and P uptake after addition of biochar application to soil. Biochar serves as source of soluble P salts and exchangeable P forms prevent P precipitation by modifying soil pH and increasing microbial activity which is responsible for changes in P availability. The favourable effect of organic matter on P availability to plants is due to solubilisation effect on fixed forms of P in soil. The application of 50% RDF+50%PM+biochar and 50% RDF+50%FYM+biochar recorded significantly higher P uptake in rice-wheat grain and straw that could be attributed to their solubllization effect on native insoluble P fraction through release of organic acids and recorded ssignificant improvement in P content. The organic amendments make the soil porous and friable which increased root growth and development. This might be improved nutrient uptake by plant (Abedi et al., 2011).

The K uptake by grain and straw significantly influenced by biochar combined fertilizers during both years of experimentation. The application of 50% RDF+50%PM+biochar and 50% RDF+50%FYM+biochar in rice-wheat crop could be attributed to the synergistic effect of biochar, N and manures (Shilpa et al., 2017).

The application of PM with biochar improved soil physical and chemical properties and improved nutrient availability leading to increased uptake by plants. Application of FYM with biochar increased K uptake in grain and straw might be due to favourable effect of PM on K uptake by wheat crop. These results are in close confirmity with the findings of Pandey,2000.The integrated application of FYM+RDF+Biochar increase K uptake could be attributed to addition of OM and microbes which reduced K fixation and release K due to interaction of OM with clay rather than direct addition to soil. The K content recorded more in straw might be due to the decomposition of OM accompanied by release of more quantities of CO2 which when dissolve in water made carbonic acid which has potential to decompose certain primary minerals and release of nutrients and more absorption resulted higher K uptake in plant biomass .This result supported by Mehdi et al., 2015 and Chesti et al., 2015.

4.8.6.2 General discussion on effect of biochar on Nutrient use efficiency: The data computed for NUE (%) of N, P, K presented in table and Fig. In case of NPK the maximum NUE, PUE and KUE was recorded under application of 50% RDF+50%PM+biochar in rice and 50% RDF+50%FYM+biochar in wheat. Lowest N recovery recorded with control (T0). The nutrient efficiency increases in rice and wheat crop due to the co-application of biochar with manures and fertilizers reported by Yaduvanshi et al., 2013 and Duan et al.,2014. Biochar has more surface area and porosity which retain the nutrients for long time and also increased availability of nutrients. Bhaduri and Gautam 2012 reported that FYM, VC and PM incorporation along with biochar and mineral fertilizers increased crop yield and nutrient uptake and gave highest nutrient recovery and economic return. Co-application of fertilizers with biochar showed positive effect in increasing FUE (Krobel et al., 2012). The same result was recorded by Prasad et al., 2010, Almaliev et al., 2014 and Ying et al., 2014. Biochar and manures mixture improves direct supply of nutrients by improving pH and NUE. The NUE improved due to increase in CEC and improving soil WHC. Biochar addition to soil holds cations for long time and increase FUE.

4.8.7 General discussion on effect of biochar on nutrient leaching: Variations in cumulative percolation of water and amount of nutrient leaching among treatments were caused by uptake variations by plant and efficiency of nutrient retention. Leaching of nutrients was significantly decreased from all biochar amended plots over control and 100% RDF supporting our aim to conduct pot experiment. The treatment 50% RDF+50%PM+biochar and 50% RDF+50%FYM+biochar in wheat crop had more impact in reducing the cumulative leaching of nutrients than other combinations might be due to more pore space and increased sorption capacity of biochar by oxidative reactions on biochar surfaces over time. This result is in confirmity with the findings of Singh et al., 2010 who reported that application of manure and wood biochar reduced the leaching of NH4-N by 53-59%. Meisinger and Delgado, 2002 found that applied N fertilizers led to 0-60% of NO3-N. Remarkable differences were observed among treatments in case of extent of leaching. This result corroborates with the findings of Lehmann et al., 2003 who stated that charcoal application reduced the proportion of leached N and Ca. N and K are very mobile in soil Application of biochar reduced NO3-N and K leaching compared with soils amended with fertilizers only. The N and K retention basically related to slow releasing amendments. When most of ions present in exchangeable form than leaching reduced and uptake of nutrients by plants increased. This result is supported by Sika (2012) who reported that biochar significantly reduced leaching of NO_3-N(26-95%) , NH4-N(12-86%) and P. Increase in N retention or absorption in soil and crop N uptake have been generally hypothesized the main cause of decrease in N leaching after biochar application. The reduced soil NO3-N and NH4-N concentration decreased the inorganic N pool for leaching. The other reason behind reduction in leaching was increase in soil WHC due to reduced bulk density. There was a significant linear correlation between amount of leaching of nutrients and volume of leachates. As the growth of plant advances the leaching of nutrients was significantly reduced because of high nutrient uptake by plants and hence low amount left behind to leach. This result supported by Sukartono et al., 2011, Yao Y et al.,2011 and Van Zwieten et al., .2010.

Chapter 5

Summary, Conclusion and Recommendations and suggestions for future work

5.1 Summary: Accumulation of crop residues in huge amount throughout world is responsible for the problems of crop management in fields. So, conversion of crop residues to make biochar by pyrolysis process is one viable option which can reduce agricultural waste and convert liability into valuable asset. When biomass of plant is heated at a temperature 350-700 degree C under anaerobic or low oxygen condition then biochar is produced. As biochar is produced through pyrolysis of plant material, it enhances its nutrient recalcitrance as compared to original biomass with average residence time i.e. hundreds to thousands of years. Thus, incorporation of biochar into soils has the capacity to decrease the CO2 release to the atmosphere, stabilize organic matter in the soil and enhance agricultural productivity. Along with that, incorporation of biochar to soil decrease bulk density, increase porosity, improve pH and cationic properties, increases the availability of N, P and K. It is also important to note that all the biochar not behave in same manner and uses of biochar is not universal. Uncertainties about biochar rates, agronomic effects and long term behaviour in different soils required urgent research. Therefore a field and pot experiment was conducted to "Probe the impact of biochar combined fertilizers on soil nutrient status in relation to growth and yield of rice-wheat cropping system during 2018-2019 and 2019-2020 Kharif and rabi season with following objectives:

(a) To determine the impact of biochar combined with organic and inorganic amendments on soil carbon pools.
(b) To analyse the effect of biochar on nitrogen use efficiency.
(c) To correlate soil carbon fractions change with soil nutrient dynamics, plant growth and yield.
(d) To assess the impact of different biochar based amendments on important soil biological indicators

Field experiments were conducted in department of agronomy crop research centre of Lovely Professional University, Phagwara. Field and pot study include nine treatments. The experiment was laid out in RCBD with 3 replications. The total number of plots was 27 and size of unit plot was 5*4m. All treatments except T0 and T1 amended with biochar. The crop was grown as per recommended package and practices during both years. Different intercultural operations such as irrigation, weeding, pest control were done as and when required. The crops were harvested at proper maturity and data on crop growth parameters, yield attributing parameters and yield were recorded. Grain and straw samples were analysed for N, P and K content, nutrient uptake and nutrient use efficiency. Soil samples collected at 0-15 cm depth and analysed for physical, chemical and biological properties. The soil is sandy loam in texture, low in organic C and medium N and P content. Soil samples were collected before and after the experiment. Salient findings from the experiment are summarized below:

1. Rice straw biochar used for experimentation. RSB had more N content, P content and alkaline in nature. It had most labile C.
2. Application of biochar, manures and fertilizers favoured plant growth of rice and wheat crops at different intervals. In rice plant height recorded at 20, 40, 60 and 80 DAT and in wheat at 30, 60, 90 and 120DAS. In rice T8- 50% RDF+50% PM+ biochar and in wheat T4-50% RDF+50% FYM+ biochar registered more plant height during both crop cycles. Minimum plant height recorded in T0 during both years in both crops.
3. The results revealed that number of tillers, fresh weight, dry weight, chlorophyll index, leaf area, CGR, RGR and NAR of rice and wheat crop responded significantly due to application of biochar+ manure+ RDF. Highest number of tillers, fresh weight , dry weight, chlorophyll index, leaf area, CGR, RGR, and NAR recorded under T8-50% RDF+50% PM+ biochar in rice crop and under T4-50% RDF+50% FYM+ biochar in wheat crop during both years. Minimum improvement in crop growth parameters recorded under control.
4. Application of both manures& fertilizers and biochar increased grain yield and straw yield of rice and wheat crops of different seasons. T4-50% RDF+50% FYM+ biochar in wheat and T8-50% RDF+50% PM+ biochar in rice crop recorded significant increment in grain and straw yield of both crops.
5. The trend which recorded in grain yield also observed in yield attributing parameters- number of filled grains, panicle/spikelet length, and 1000 grain weight and harvest index.

6. Different combinations favoured N uptake in rice –wheat grain and straw. The highest N uptake in wheat grain and straw recorded in T8 in rice and T4 in wheat crop and lowest in control (T0).
7. All treatments favoured P and K uptake in grain and straw except control during both years. Highest P,K uptake in grain and straw of rice recorded by application of T8-50% RDF+50% PM+ biochar and in wheat crop highest uptake of P and K recorded by application of T4-50% RDF+50% FYM+ biochar. NPK uptake recorded significantly more over control.
8. All combinations of biochar with manures and fertilizers improve the OC% in soil after harvesting of rice- wheat crop during both years. Poultry manure and FYM combination with biochar and fertilizers registered significantly more OC%.
9. Application of 50% RDF+50% FYM+ biochar in wheat and 50% RDF+50% PM+ biochar in rice recorded significantly more POC in soil than control while all biochar amended plots were comparable to control after two crop cycles.
10. POXC in soil due to different treatments was more than control and 100% RDF after rice and wheat crop during both years. POXC content decreased with the advancement of study. All treatments were statistically significantly better over control in POXC content.
11. Application of RSB significantly improved MBC in soil after harvest of both rice and wheat crop in both years. 50% RDF+50% FYM+ biochar in wheat and 50% RDF+50% PM+ biochar in rice recorded significantly more MBC after harvest of crop than other treatments.
12. Dehydrogenase activity in soil was higher at heading stage and at upper surface of soil. T4 in wheat and T8 in rice recorded significantly more DHA in soil as compared to other treatments.
13. Urease activity in soil was slightly more in wheat than rice crop at heading stage. More activity recorded at surface soil. T8 during both years of rice crop and T4 in wheat recorded more enzyme activities than other treatments.
14. Alkaline and acid phosphatase activities decreased with the advancement of experiment. All treatments except T0, T1 recorded more acid and alkaline phosphatase activities being highest with T8 in rice and T4 in wheat.
15. Nitrate reductase enzyme activities recorded highest at heading stage of rice and wheat crop. All treatments were significantly different from each other. Highest

NR activity in rice crop recorded by application of 50% RDF+50% PM+ biochar and in wheat crop by the application of 50% RDF+50% FYM+ biochar.

16. Q mic consistently highest under T4 in wheat and T8 in rice in both years. There was significant increase in q mic over control was noticed.
17. Different treatments significantly influenced the pH, EC, bulk density and porosity of soil after harvest of rice and wheat crop. There is improvement in pH, EC and porosity observed by different combinations of manures, fertilizers with biochar. There was reduction in bulk density recorded during second year of experimentation.
18. N, P and K availability status in soil improved after the addition of biochar over control. Highest NPK being recorded with T8 in rice and T4 in wheat crop. Minimum availability of NPK recorded under T0.
19. In case of N the maximum nitrogen use efficiency in rice recorded by application of 50% RDF+50% PM+ biochar and in wheat recorded by 50% RDF+50% FYM+ biochar during both years. The lowest N use efficiency recorded with the treatment T0 during both years.
20. Data regarding to PUE and KUE revealed that highest P and K use efficiency in rice crop recorded by application of T8 in rice and T4 in wheat followed by T^ and lowest recorded in T0.
21. The lowest leaching of NO3-N and P recorded in T4 and T8 in wheat and rice crop. The leachate volume recorded lowest in T4 and T8.
22. Cost of cultivation of Rs 32000 in rice and Rs.29991 in wheat was common cost of cultivation for all treatments. Cost of cultivation varied due to different combinations. Among 9 treatments T0 and T1 recorded lowest cost of cultivation as compare to other treatments whereas T6 recorded maximum (93479) cost of cultivation in rice and Rs. 97069 in wheat.
23. Among different treatments in rice crop T8 recorded maximum (303195) gross returns and in wheat T4 recorded maximum (185491) gross returns. The lowest monetary gross returns recorded (70082, 50910) in T0 in rice and wheat crop.
24. The maximum net returns in rice crop (211216.3, 91422) recorded under T8 and in wheat recorded under T4. The lowest net returns (38082, 20919) recorded under T0.
25. The maximum B: C ratio (2.29) in rice and (1.5) in wheat recorded under T8 and T1 in rice, wheat crop. The lowest B: C ratio (1.19, 0.69) recorded in T0.

5.2 Conclusion: From the findings discussed above it could be concluded that Biochar application increased crop yields compared to conventional NPK fertilizer application and non-fertilizer application. According to the results of field experiments, crop yields from biochar-applied plots exceeded the yields of NPK fertilizer applied plots and the control. All biochar tested in the field experiments showed different impacts on crop growths, yields and soil properties compared to NPK fertilizer applications and the control. Among biochar combinations with manures and fertilizers, it was found that 50%RDF+50% poultry manure+ biochar is suitable to apply to rice fields and 50%RDF+50% farm yard manure+ biochar is suitable to apply to wheat fields due to its superiority in retaining nutrients, gas exchange through better ventilation of its pore spaces under submerged condition and, possible direct nitrogen supply to rice –wheat crop. Rice Straw biochar and Rice straw Biochar + FYM + RDF mixture were suitable for wheat upland crop due to their effects on improving soil physical properties such as reducing soil bulk density, increased water holding capacity and nutrient retention. Biochar improved soil quality in alkaline sandy loam soil of Indo Gangetic plain region by reducing soil bulk density, improving soil pH at the level that was not harmful for the cultivated crops, and enhancing water holding capacity after one-year application. .Although there were improvements in both soil physical and chemical properties, some improvements such as bulk density and soil water retention were significantly different from control and NPK fertilizer application in current research findings. The application of biochar proved better in increasing rice and wheat yields and N, P and K uptake. The biochar amended plots recorded more OC%, POXC, POC and MBC over control and 100% RDF. Enzymatic activities also recorded more at surface soils in biochar treated plots. Addition of Fertilizers with manures and biochar had positive impact on crop biomass and measured soil parameters which clearly reflects the capacity of biochar to be used as substitute to synthetic fertilizers. Thus, transforming rice straw to biochar for its application as soil amendment decrease straw burning in open field in Northern India.

5.3 Suggestions

5.3.1 Suitability of Biochar Technology for Indo Gangetic plain region: Impact of biochar on soil quality and crop production cannot be specified, as they are biochar, plant- and site-specific (Lorenz et al., 2014). In current research, impact of rice straw biochar was tested in rice--wheat cropping system on sandy loamy soil. As compared to the control and synthetic fertilizer sole application crop yields showed a positive response to biochar applications. When both of increase in crop production and improvement of soil quality considered then rice straw biochar in combination with 50% farmyard manure and 50% fertilizers will be the most suitable soil amendment for the wheat crop and 50% Poultry manure and 50% RDF with biochar best for rice crop. A mixture of biochar, fertilizer and manure is more suitable as it decreases the chances of the dispersal of biochar by wind during the time of field application. By combining the manure, fertilizers with biochar than manure & fertilizer sole application, crops can benefit the effects of manure and fertilizers more sufficiently because biochar has the properties to control nutrient leaching. Although sudden improvement of soil properties with this amendment will not show, but stable improvement of soil properties can be retained for long time. At last, farmyard manure, poultry manure is easily available for the farmers. Rice straw biochar application +VC+ RDF also showed positive yield responses next to Rice straw Biochar + FYM+RDF mixture and Biochar+ PM+RDF . That might be due to more carbon content and more exchangeable cations of rice straw biochar. Since RS biochar has fine texture, it will easily mix with the soil and will not disturb young seedlings. The major challenges of using RSB are: availability of raw biomass because it is also used as fodder; cost for efficient production technology; and efficient field application method with fewer losses to environment due to its particle size.

5.3.2 Suggestions for Biochar Production and Technology Adoption by Farmers: The black ash of rice husk got from rice mills which use rice husk as fuel is being used as growing media for the nursery of ornamental plants in Punjab. The application of rice husk biochar produced under pyrolysis condition has not yet been widely known up to recent time. Punjab farmers need to be addressed about the benefits of biochar as soil amendment because production and application of biochar from farm wastes is a new technique for them. Therefore, among Punjab farmers for the dissemination and adoption of biochar technology many steps are needed to carry out. This could be accomplished by addressing research results to the farmers' fields, observing biochar field applications for crop production, and the distribution of biochar for farmers. Biochar produced by pyrolysis at temperature (350°C–650°C) have more recalcitrant carbon and a larger surface area. The properties of Biochar will increase soil carbon sequestration and improve crop yields by improving soil physicochemical properties. It will be very effective. If large-scale production is possible, biochar production from the different sources of feed stocks will be possible. Biochar prepared from different feed stocks will have different properties and those biochar can be used for different crop varieties.

5.3.3Suggestion for Future Research: As per the findings of field experiment, pot experiment and laboratory analysis and predicted future impacts on crop yield and soil quality, biochar application with manures and fertilizers showed positive effects on rice-wheat cropping system. Under the specific climatic, crop and soil conditions the long term effect of biochar on crop and soil quality need to be observed. The effect of biochar on drought tolerance, tolerance of insect pest and diseases and nutrient efficiency in field conditions also need to observed. By observing these effects, we can apply the farm wastes in an efficient manner without affecting environment and soil quality. As the positive effect of biochar is not universal, it depends upon source of feedstock and pyrolysis temperature. The method of biochar application, rate of biochar, its impact on soil and crop production vary according to crops. Therefore, further research will be required to study the above-mentioned issues. Related to biochar quantity as applied to 1hectare, different research studies revealed different quantities that might be due to production of biochar from different materials have different properties, it will not be easy to decide the most appropriate biochar dose. It will be better to set the biochar dose based on the crop type, soil type and the purpose of biochar use: whether to improve soil properties or for the improvement of crop yields, etc. For practical field application, not only beneficial effects of biochar on crop production and soil quality considered, but also economics should be considered because farming aims of the most of farmers are food security and profit. Research on type of biochar, method of production, biochar application rates which are economically feasible will therefore be required. Research and observations are also needed to address the farmers about the efficiency of organic soil amendments other than synthetic fertilizers as those organic soil amendments are affordable to smallholder farmers.

CHAPTER 6

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