EFFECT OF BIO-CHAR BASED ORGANIC AMENDMENTS ON SOIL BIOLOGICAL & BIOCHEMICAL INDICATORS IN RELATION TO INCREASE SOIL NUTRIENT RELEASE POTENTIAL & YIELD OF POTATO

Thesis submitted for the award of the degree of

DOCTOR OF PHILOSOPHY

in (Agronomy)

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DECLARATION

I, hereby declare that the presented work in the thesis entitled "**Effect of Bio-char based organic amendments on soil biological & biochemical indicators in relation to increase soil nutrient release potential & yield of Potato**" in fulfillment of degree of **Doctor of Philosophy (Ph.D.)** is the outcome of research work carried out by me under the supervision Dr. Anaytullah Siddique, working as Associate Professor, in the Department of Agronomy of School of Agriculture, Lovely Professional University, Punjab, India. In keeping with the general practice of reporting scientific observations, due acknowledgments have been made whenever the work described here has been based on the findings of other investigators. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE I

This is to certify that Jagmohan Singh (Registration No: 41500090) has personally completed the thesis entitled, '**Effect of bio-char based organic amendments on soil biological & biochemical indicators in relation to increase soil nutrient release potential & yield of potato**'under my guidance and supervision. To the best of my knowledge and belief, the present work is the result of his original investigation and study. No part of the dissertation has ever been submitted for any purpose at any university. The project report is appropriate for the submission and partial fulfillment of the condition for the evaluation leading to the award of the degree of **Doctor of Philosophy** in **Agronomy (Part-time).**

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CERTIFICATE II

This is to certify that the thesis entitled, '**Effect of bio-char based organic amendments on soil biological & biochemical indicators in relation to increase soil nutrient release potential & yield of potato**' submitted in partial fulfillment of the requirement for the award of degree **Doctor of Philosophy** in **Agronomy (Part-time)** to Lovely Professional University, Phagwara (Punjab) is a bonafide research work conducted by Jagmohan Singh (Registration No: 41500090) under our guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

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Effect of bio-char based organic amendments on soil biological & biochemical indicators in relation to increase soil nutrient release potential & yield of potato

ABSTRACT

The goal of this study was to determine how an organic amendment based on bio-char would affect the entire phase of growth and yield of the potato. The research was carried out in the village of Kalloh, Mansa (Punjab), during the two Rabi seasons of 2017–18 and 2018–19. The investigation was based on field assessment while conducted in randomized block design by considering thirteen combinations of farm yard manure, fertilizer doses, bio-char, bone meal, vermicompost, and poultry manure. bio-char used in the experiment was produced from locally available raw material rice straw at a temperature above 600 ^{0}C under oxygen-limited conditions. The field trials were laid out on sandy loam soil and conducted with three replications to reduce the error. The impact of treatment combinations (farm yard manure, fertilizer doses, bio-char, bone meal, vermicompost, and poultry manure) was compared with the control (i.e. recommended dose of fertilizers, 187, 62, and 62 kg of nitrogen, phosphorous, and potassium ha^{-1}). Soil samples were gathered from the experimental plots both before and after the completion of the experiments, and analyzed for soil parameters to determine the soil status while recording entire parameters decided for the present piece of work i.e. growth and development, yield and yield attributes, and quality parameters. The results from the experiment indicate that there was an improvement in the pH of the soil, availability of nutrients, organic carbon (OC), particulate organic carbon (POC), labile carbon, and microbial biomass carbon (MBC). It showed positive influences on soil fertility, enzymatic activities, carbon fractions, and nutrient uptake while also revealing that entire morpho-physiological growth, and yield contributing parameters were influenced by treatments. Treatment T_4, among the various combinations of bio-char-based organic resources i.e. [25% or 50% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%] demonstrated the highest percentages of emergence, plant height (cm), leaf area index (LAI), days to maturity, number of haulms plant^{-1}, weight of tubers plant^{-1}, and tuber yield ha^{-1}. In contrast, the lowest values were observed under T_1 [control]. The data pertaining to percentage increase or decrease revealed that the emergence percentage exhibited rapid growth under T_4, with an increase of 0.86%.

Hence, it is advisable to recommend a treatment combination of the bio-char-based organic amendment, which comprises either 25% or 50% of the recommended dose of fertilizers, along with 75% composed of bone meal, vermicompost, and poultry manure, supplemented with 40% bio-char. This approach is suggested for optimal results in terms of promoting potato growth and enhancing production for farmers.

Keywords: Bio-char, Bone meal, Poultry manure, RDF and Vermicompost

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Date: 06/04/2024

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviations	**Meaning**
ANOVA	Analysis of variances
B:C	Benefit-cost ratio
cm	Centimeter
%	Percent
DAS	Days after sowing
e.g.	Example gratia (for example)
Fig.	Figure
FYM	Farmyard manure
g	Gram
et al.	Etalii (and others)
ha	Hectare
i.e.	id est (that is)
kg	Kilogram
@	At the rate
FAO	Food and Agriculture Organization
m	Metre
mg	Milligram
RDF	Recommended dose of fertilizer
m^{-2}	Per meter square
no.	Number
p.	Page
pp.	Pages
Max.	Maximum
Min.	Minimum
etc.	et cetra (and other things)
mm	Millimeters

T	Tonne
viz.,	Namely
q ha^{-1}	Quintal per hectare
kg ha^{-1}	Kilogram per hectare
-1	Per
0C	Degree Celsius
Rs.	Rupees
µg g^{-1}	Microgram per gram
m ha.	Million hectares
MT	Metric tonne
mg	Milli gram
Q	Quintal
L	Litre
cv.	Cultivated variety
mM	Millimolar
ppm	Part per million
Mmol g^{-1}	Millimole per gram
nm	Nanometer

CHAPTER-I

INTRODUCTION

As a result of the green revolution, India has seen tremendous growth in its agricultural sector after 1966. According to the report published by the Public Sector Investment Board (PIB) of India, the percentage share of gross value added (GVA) of the Agriculture and Allied sector to the real economy for the year 2018-19 was 17.6%, for the year 2019-20 (18.4%), and for the year 2020-21 (20.2%), respectively (Sharma, 2023 and Chand, 2022). Despite this, human ingenuity has enabled us to overcome many agricultural obstacles, and our agricultural system, which generates an abundant supply of food, fodder, and fiber, is one of the modern wonders of this world. Food and nutritional security have been made possible thanks to the adoption of improved crop types, fertilizers, and pest control techniques, as well as irrigation techniques that have resulted in high yields. Even though production levels have increased, farmers have noticed different issues associated with our modern agricultural systems (Jama and Pizarro, 2008 Pretty and Bharucha, 2014). Being the most popular crop in the world, the potato holds a prestigious 3rd standing behind the cereals rice and wheat on account of its status as one of the staple food crops for more than one billion people all around the world (Birch *et al.*,2012). Concerning the worldwide production of potatoes, from 2009 to 2019, the annual output of potatoes varied to a great extent as far as the global production of potatoes is concerned. In contrast, the highest value 373.85 million metric tonnes (MMT) was recorded in 2017, while the lowest was recorded in 2010 i.e. 328.62 million metric tonnes when 17.62 and 18.17 million hectares of cultivated land were used respectively (FAO, 2021). There is no doubt that China will be the most important country to produce potatoes in 2020 (Figures 1.1, 1.2, and 1.3). It is followed by India (51.3 million metric tonnes) and Ukraine (20.84 million metric tonnes) as the major producers of potatoes.

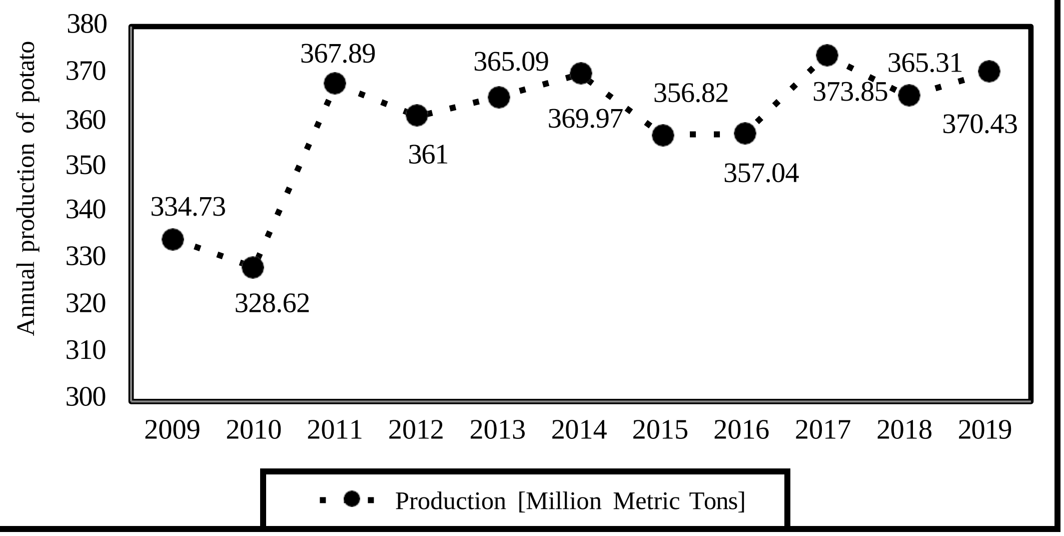
There are a lot of issues affecting industrialized nations continuously, but soil degradation caused by overcropping or the misuse of mineral fertilizers should be given special attention, as it leads to the degradation of a non-renewable resource that is becoming increasingly scarce (Blanco and Lal, 2008 and Bhattacharyya *et al.,* 2015). Although this issue may not be solved by the appropriate use of the various forms of organic leftovers that are generated daily by human activity, and which are otherwise difficult to deal with in an ecologically acceptable manner, there is a way to deal with it. Moreover, the microbial population in the soil is influenced by various factors, such as the structure of the soil, the rate at which organic matter is broken down, and the microbial diversity when there are sufficient levels of organic residues in the soil. It is important to consider these factors, but they are not limited to: The influence of organic additions on soil biology has become a highly intriguing research topic because they may affect soil function and structure and may be indicators of soil pollution (Sadhu *et al.,* 2018; Stott *et al.,* 2018 and Nair and Ngouajio, 2012). Many organic residues can contain multiple pollutants, and it is essential to know how these residues will affect the natural biology of the soil. Some of the management techniques that can help maintain soil health include implementing an integrated plant nutrition system (IPNS), recommending fertilizers based on soil tests, delivering micronutrients, and controlling industrial wastes and low- quality agricultural water. To achieve long-term sustainability and high fertilizer utilization efficiency, soil, plant, and climatic aspects must be considered (Schmidt, *et al.,* 2011; Ye *et al.,* 2017 and Tamene *et al.,* 2017).

Research has shown that greenhouse gas concentrations in the atmosphere are constantly rising as a result of scientific research. As a result of these shifts in greenhouse gas emissions, humans are primarily responsible for the cause of these changes. There is an increase in greenhouse gases in the atmosphere, and that is a cause for concern because they can cause drastic changes to the air, the temperature, and the severity of the weather patterns as a result. Carbon dioxide storage by agricultural land has recently been the subject of international attention due to its ability to store gas. It has been suggested that soil carbon storage can be enhanced by utilizing agricultural conservation measures such as crop rotation, residue management, and organic farming (Rasul and Ahmad, 2012; Janssens-Maenhout *et al.,* 2017; Basche and DeLonge, 2019).

The practice of using bio-char to increase the yield of crops has been employed by farmers for thousands of years; therefore, it is not a new practice. There is a good example of this in the practice of slash-and-burn farming that is common in North East India, which is still practiced today. The storage of carbon in the soil requires something that can endure prolonged periods of oxidation to CO_2 or methane decomposition to be effective. The scientific community has recommended the use of bio-char as a soil amendment, which can be beneficial since it protects the biomass from further oxidation, which may prove to be beneficial for farmers. The fact that these partially burned products, also known as pyrogenic carbons or black carbons, can decompose and undergo chemical transformation at a slow rate makes them an essential long-term carbon sink as a result of their slow rate of microbial decomposition and chemical transformation (Vista and Khadka, 2017; Thakur, 2022 and Kamali, *et al.*, 2022). Although the burning and biological decomposition retains only 3% and 10% of the original carbon (C), respectively, the transformation of biomass into bio-char results in the forfeiture of the original Carbon up to 50%. The result is also that, as a matter of fact, it provides a more stable carbon source than burning or applying biomass directly to the soil (Singh *et al.*, 2015). There is little effect of the temperature at which biomass C is converted to bio-char which typically ranges between 350 to 500 ^{0}C (Zhang *et al.*, 2017).

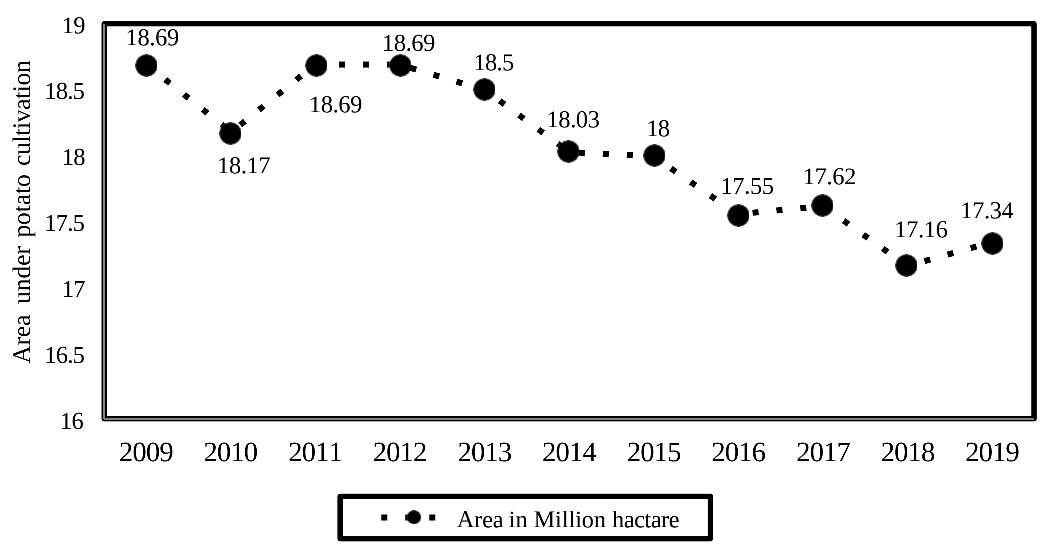
Over the recent years, the government, academia, and the scientific community have given bio-char a great deal of attention. Several studies have shown that bio-char has the ability to trap carbon in the soil, therefore reducing global warming to an extent. In recent years, the incorporation of organic base-bio-char that is rich in carbon, such as black carbon and bio-char, has been pushed as a method to increase soil fertility and minimize agricultural and environmental consequences. Under a limited supply of oxygen, biomass is pyrolyzed under a controlled temperature to produce bio-char, which is a form of carbon. In the past few years, it has been extensively advocated as a relatively new strategy for enhancing the quality and yield of soils and crops. Due to its unique physico-chemical characteristics, bio-char is a very effective soil supplement due to its distinct properties. Agricultural soil amendments may improve crop growth, quality, and yield by enhancing the soil, optimizing microbial growth, physical structure, and reproductions (Schmidt *et al.*, 2019; Arif *et al.*, 2020, Aoulad *et al.*, 2022; Zhang *et al.*, 2020). Optimizing the physical and chemical characteristics of the soil, together with enhancing its structure and microbial population richness, can help minimize nutrient loss. It uses bio-char to increase crop roots' growth, development, and functioning ability (Alkharabsheh *et al.*, 2021 and Atkinson *et al.*, 2010). In bio-char- enriched soil, plants that produced secondary and tertiary roots had longer and thicker roots than those grown in unamended soil and greater root mass and length density. Researchers found that adding corn straw bio-char to sandy loam soil stimulated rice root development, increased root volume, increased total and active absorption area, and maintained strong root TTC (2,3,5-triphenyl tetrazolium chloride) lowering capability, as reported (Mitchell, 2015). In a study by Zhang *et al.*, (2020), the primary nutrients derived from bio-char are biological solids, which have a slow biomineralization process that affects the supply of nutrients. It has been shown that bio-char indirectly improves soil fertility by altering the soil environment, and the effectiveness of nutrients varies depending on the method of biomineralization used. It is also important to note that the adsorption properties of bio-char make it an excellent tool for removing toxins and heavy metals from organic fertilizers (Bandara *et al.*, 2020). This is because bio-char creates a habitat for microorganisms to grow and reproduce in, thereby improving the composition and quantity of the bacterial populations that exist in the soil. Moreover, it also helps to release more nutrients constantly into the soil (Siedt *et al.*, 2021). Krishnakumar *et al.* (2014) predict that by using bio-char as a carbon sequestration medium, it will be able to sequester over 400 billion tonnes of carbon by the year 2100, lowering the concentration of CO_2 in the atmosphere by 37 parts per million at that time. There is some evidence that the increased nutrient retention capacity in soil may reduce the environmental harm associated with fertilizers, such as nitrous oxide emissions and nitrogen leaching into groundwater (Shukla *et al.*, 2020). At present, the only carbon-negative renewable energy source that we have is bio-char, which is one of the few instruments that we have that can remove carbon from the atmosphere (Lehmann, 2007). This is essential to realize the importance that soil organic carbon (SOC) plays in soil fertility as well as the global carbon cycle. By releasing dissolved organic matter produced by the use of bio-char itself, or by conserving the naturally occurring organic matter in the atmosphere, bio-char may increase the SOC in two ways. Increased soil water retention capacity, distribution of pore size, adsorption ability, porosity, liming effects in acidic soils, soil composition, and stability, a rapid pace of nutrient alterations and consumption efficacy, and activation of bacteria and enzymatic processes have all been attributed to the beneficial effects of bio-char on the production of crops (Lorenz and Lal, 2014 and Das *et al.*, 2020). As a result of further research, it will be possible to figure out how much of an effect bio-char has, how the frequency of application affects the effect, and how crops respond to a bio-char application rate in the future. In the experimental setting, it has not yet been established whether adding bio-char to soils over a long period will affect soil characteristics. This research was aimed at testing the hypothesis that the addition of bio-char, when combined with different percentages of organic and inorganic amendments (e.g. recommended dose of fertilizer, bone meal, vermicompost, and poultry manures) provided significant yield increases. According to Filiberto and Gaunt (2013), bio-char-based organic amendments boost soil productivity depending on the amount and frequency of application as well as fertilizers. The plants that were treated with bio-char grew more prominently, produced a significant amount of food, and were of higher quality. Additionally, when bio-char was applied to potato fields, it showed a positive association between the amount of plant growth and the production of tubers (Jay *et al.*, 2015; Adekiya *et al.*, 2020 and Singh *et al.*, 2019). A study conducted by (Nair *et al.*, 2017) showed that potato yield increased gradually in the same proportion as the amount of bio-char increased in the soil over time. Potatoes serve as a rich source of water, carbohydrates, starch, and proteins, with a notably low level of fat.

Fig- 1.1: Annual potato production [million metric tonnes] from 2009 to 2019



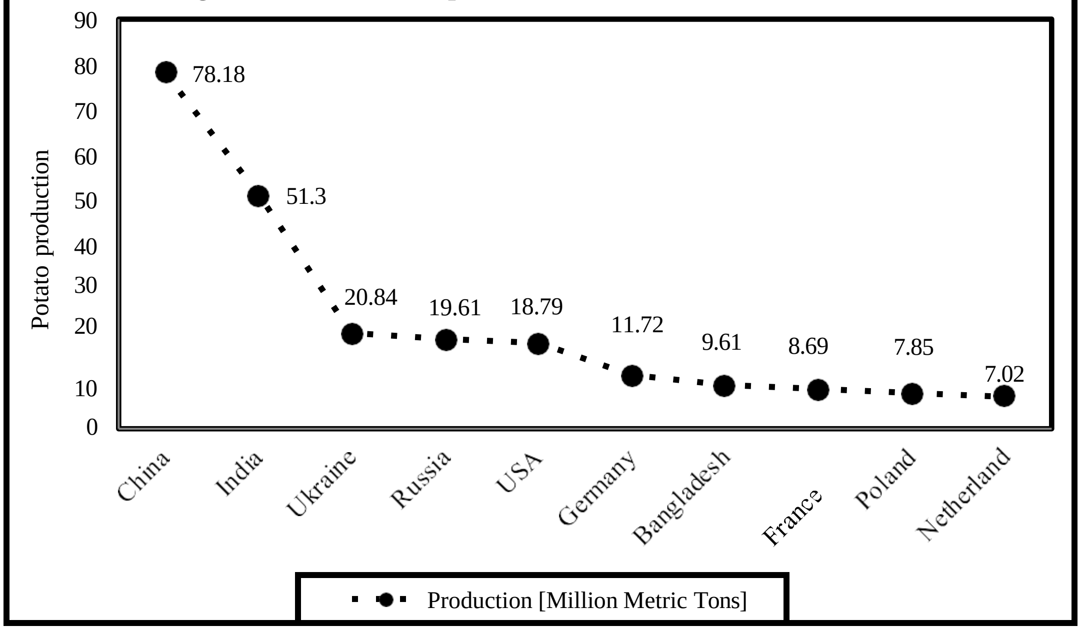
Source: FAO (2021) Potato area harvested worldwide from 2002 to 2019

Fig-1.2: Area under potato cultivation [million hactare] from 2009 to 2019



Source: FAO (2021) Potato area harvested worldwide from 2009 to 2019

Fig-1.3: Production of potato [million metric tonnes] in 2020



Source: FAO, (2022) Potato production worldwide in 2020, by leading country

There are many qualities of potatoes, including the dependency of humanity on this crop around the world, which make it more demanding; therefore, the present study aims at boosting the output of potatoes by balancing the source of nutrients (Organic and Inorganic). As a result, to achieve the goals, the following objectives have been decided upon.

1- To study the potential of bio-char-based organic amendment in relation to increase soil nutrient release potential.

2- To identify the combination of organic amendment to be mixed in different proportions with bio-char.

3- To study the impact of organic amendment on soil biological and biochemical indicators.

4- To evaluate the carbon and nitrogen sequestration of soil amended with different proportions of organic amendments.

5- To correlate the soil enzymes, soil nutrient status and soil physical status with the growth parameters.

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CHAPTER-II

REVIEW OF LITERATURE

It has been shown that the uninterrupted burning of crop residues creates many problems by reducing the nutrients in the residue as well as reducing the carbon in the soil, thereby deteriorating the soil quality, water holding capacity, and the way crops are produced. It is thought to be one of the best options to preserve the merits of soil and maintain the production efficiency of agricultural output by using bio-char as an organic amendment, which is derived from the plant material and produced by incineration at low temperatures under anaerobic conditions (Rawat and Saxena, 2019). Due to its extensive surface area and porosity, it enhances the physical and chemical characteristics of the soil, influencing factors such as pH, cation exchange capacity (CEC), organic content, and electrical conductivity (EC). Additionally, it contributes to the reduction of nitrogen loss from the soil (Dume *et al.,* 2015). Several contrasts were reported for some of the soil and growth parameters, which may be due both to the soil type and the type of bio-char used. Under the appropriate headings, we have referred to the following literature as support for the proposed work entitled "Effect of bio-char based organic amendments on soil biological and biochemical indicators with increasing soil nutrient release potential and yield of potatoes".

2.1 The historical approach of bio-char

Agriculture has been using bio-char for the cultivation of crops since ancient times, but scientific attention has started to focus on the "Terra Preta", a dark soil in the Amazon rainforest that has been used for centuries for the cultivation of crops. It has been suggested by researchers that these soils were formed by the presence of a high level of bio-char and organic matter in the soil, which is also considered anthrosols (Verheijen *et al.,* 2010). Depending on the purpose of the char, there are different types of chars today, such as charcoal and mineral-char unlike bio-char, which is produced from organic materials by incinerating them under anaerobic conditions, mineral char is produced from combustible sedimentary rocks that are extracted from underground by incinerating them under anaerobic conditions. On the other hand, it has been a long tradition for people to use charcoal to capture atmospheric carbon, even though they also use charcoal to increase the fertility of the soil. Alternatively, bio-char is emerging as an emerging technique for improving soil fertility and sequestering carbon at the same time (Lehman and Joseph, 2009). The value and credibility of bio-char for enhancing soil fertility, water-holding capacity, and carbon sequestration have grown in recent years. The earth renewal and restoration alliance, the carbon zero project, and the International bio-char initiative are bringing bio-char to the attention of the general population and scientific community.

2.2 Effect of bio-char

Worldwide, people are becoming increasingly concerned about the soaring world population, dwindling food supplies, and the destruction of the environment (carbon abatement) (Lehmann and Joseph, 2009). It is expected that temperature increases and droughts in semi-arid regions will significantly reduce agricultural yields of staple commodities such as corn (maize), rice, and wheat during the next two decades as a consequence of a changing climate (Brown and Funk, 2008). There are also regular occurrences in the agricultural sector such as the degradation of agricultural land and infertility (Chan and Xu, 2009). The application of bio-char to soils has been proposed as a long-term solution to this problem of low nutritional soils (Laird, 2008). When organic compounds are incinerated in the absence of air, they are converted into a carbon-rich char that is extremely difficult to decompose as a result (Thies and Rillig, 2009). As bio-char can remain in soils for many generations, when used as a soil amendment, it can increase agricultural production when utilized to amend soil (Downie, 2011).

The agricultural potential of bio-char has been demonstrated using poor soils from moist tropical locations in prior studies (Verheijen *et al.*, 2009). In a study by Chan and Xu (2009), adding bio-char to soils with low cation exchange capacity (CEC) and depleting organic carbon enhanced the physicochemical characteristics of the soils, including water-holding capacity, CEC, and organic carbon (Novak *et al.*, 2009). As a result of adding bio-char to the soil, several benefits have been observed in agriculture. Moreover, not only does the soil's ability to adsorb nutrients, but it also has the capability of slowing the release of nutrients for the growth of plants, which contributes to maintaining a healthy ecosystem

(Laird, 2008).

2.3 Influence of bio-char on soil chemistry

Brandstaka *et al.,* (2010) demonstrate, bio-char is capable of greatly increasing soil chelating agent capacity with a variety of benefits, which include improved coarse aggregate stability, an increase in microbial activity, a greater water-holding capacity, a reduction in pollution problems, and a reduction in fertilization requirements. The ability of bio-char to hold water, boost buffering capacity, improve nutrient retention and decrease bulk density has been linked to a higher level of agricultural production. A study by Mohammed *et al.,* (2017) found that adding bio-char to soil improves the soil's physicochemical qualities because it has a large surface area and is porous; it also enhances the soil's capability to retain water and absorb nutrients. In addition, the researchers speculate that if bio-char is applied to the soil at an appropriate rate, it may be able to boost soil fertility and agricultural production in the future.

In Belgium, Ameloot *et al.,* (2015) conducted research and found that the addition of pine chips and chicken litter bio-char to soils boosted net nitrogen decomposition, as opposed to the samples that had not been treated. As a result of replacing rice husk pyrolysis with granular soils and acid sulfate soils, Manickam *et al.,* (2015) have achieved improved soil physicochemical parameters and increased yields of corn and rice in Malaysia. When bio-char was applied at the level of both 2 and 5 percent, there was a dramatic yield enhancement was observed in the maize. The rice mill bio-char produced higher yields than the belonio-based bio-char. During their research work in China, Lashari *et al.,* (2013) discovered that by adding bio-char to salt-stressed soil, agricultural productivity increased while soil salinity decreased, which increased agricultural productivity. Increasing the long-term soil carbon pool through the use of bio-char has increased the importance of this technology. (Namgay *et al.,* 2010) suggest that soils contaminated with trace minerals may benefit from the application of bio-char, according to their study. The use of bio-char significantly reduces the possibility of nutrient loss through leaching has also been reported by (Major *et al.,* 2012). There was a study performed by Doan *et al.,* (2015) determined the influence of compost and vermicomposting on plant production in conjunction with bio-char (used alone or in combination with vermicompost). In their view, this could be a viable substrate for increasing the water stress tolerance of agricultural systems. By amending the soil with organic materials, it was possible to reduce runoff, soil erosion, and the transmission of ammonia and nitrate to water. The beneficial effects of vermicomposting on plant growth and yield were not the only ones identified in this study; vermicomposting also showed the ability to significantly reduce the harmful effects of organic fertilizers on water quality. As a result of the introduction of bio-char, these positive benefits are further enhanced. As a result of the low pH, weak neutralizing properties, and low CECs (which can vary from 2 to 8 mol kg^{-1}) present in sandy soils that have been generated, there is the possibility that these soils may contain Al toxicity as well as low CECs (Novak *et al.,* 2009).

It has been recently shown that bio-char may substantially boost crop yields, especially in areas where minerals are scarce when applied to badly leachable, deficient soils (Liang *et al.,* 2006 and Lehmann and Rondon, 2006). Synthetic fertilizers remain readily available for a long period due to the permanence of organic compounds and the restrictions on plant material recycling nutrients (Glaser *et al.*, 2001; Lehmann and Rondon, 2006). In contrast to the use of fresh biomass in soils with identical soil parameters, it has been shown that bio-char can remain in soils for thousands of years rather than just a few years (Steiner *et al.,* 2008 and Zimmerman, 2010). A study including regular administrations of fresh fabrication shop biomass waste on sandy soil over an extended period could not demonstrate the long-term development of soil's Carbon (Curnoe *et al.,* 2006). There was a study done by Van Zwieten and colleagues (2010a) in which it was found that bio-char made from paper mill waste significantly boosted soil carbon in the range of 0.5 to 1.0 percent. In addition, bio-char has been demonstrated to be more efficient than fresh biomass in carbon sequestration, enhancing soil fertility, and enhancing the liming capability of acidic soils (Vaccari *et al.,* 2011 Yuan *et al.,* 2011). Additionally, Chan and Xu (2009) studied the effects of bio-char on soil health and discovered that it contains a high concentration of carbonic acid; therefore its liming properties could help to reduce soil acidity by reducing the amount of carbonic acid in the soil as a means of reducing the negative impacts of acidic soils. In their study, Van Zwieten *et al.,* (2010b) discovered that the calcium carbonate present in bio-char facilitated the growth of wheat. In pores, nanocrystals of bio-char, acid, and alkalinity of the water can reside within micrometers of each other. This study shows that the pH of the solution has a significant impact on the surface charge of oxide surfaces, especially amphoteric surfaces. The result of this phenomenon is that the surfaces have a positive and a negative charge in both acidic and alkaline environments. On the basal regions of layer silicates, there is a persistent negatively charged site along with the amphoteric edge sites, which are also present. As a result of the carbonate anion's existence of O, carbonate mineral interfaces are comparable to oxide surfaces **(**Amonette and Joseph, 2009).

According to Bruun *et al.,* (2012), when bio-char is applied in conjunction with other fertilizers, not only does the soil nutrient status improve but also the plant growth and development improve. Although slow pyrolysis bio-char could improve the mineralization of nitrogen, slow pyrolysis bio-char can also increase the soil nutrient status. Yao *et al.,* (2012) soils react differently to bio-char in terms of nutrient leaching and nutrient sorption. Based on a three-year experiment, it has been reported that there is no discrepancy between soil with bio-char and soil without bio-char. After three years, however, phosphorus was much more readily available after the second application of bio-char while the interchangeable potassium and calcium, Organic matter, and electrical conductivity of the soil after 3 years (Quilliam *et al.*, 2012). It is common for bio-char to be referred to as "black carbon" because it can be compared with biomass-derived black carbon (Liang *et al.,* 2006). As a result of partial combustion, plants, fossil fuels, and other sedimentary deposits produce black carbon as a by-product of their combustion. As a result of the creation of black carbon, two compounds are formed. When a soot-BC has a high concentration of graphite, it is formed by the condensation of volatiles, while bio-char is produced by the condensation of solids. In the black carbon spectrum, all organic compounds that have been charred, such as charcoal, soot, and graphite, are classified under the C forms of a wide range of aromatic compounds (Schmidt and Noack, 2000). Based on the findings of Lehmann (2007a), it can be said that bio-char is a suitable alternative-to-alternative energy source since it is carbon negative rather than carbon neutral. Since bio-char is a carbon-negative substance, it may be possible to use it as a long-term carbon sink due to its carbon-negative properties. In the first place, the feedstock parent material for bio-char is carbon negative since it removes organic carbon from the photosynthetic and breakdown pathways in the plant (Lehmann, 2007b). Organic carbon is eventually accumulated in the soil, where it can be stored, as a result of this process (Glaser, 2007).

A major advantage of bio-char is that it allows a delayed release of CO_2 into the atmosphere, which is far superior to simply storing CO_2 with original content since it will break down over time (Gaunt and Lehmann, 2008). By absorbing CO_2 from the atmosphere and storing it as carbon dioxide, bio-char can help to reduce global warming by reducing CO_2 emissions from the atmosphere (Lehmann 2007a). It is important to note that ideal carbon capture and storage have no negative impacts on soils because of the increased carbon intake. As a result of using bio-char instead of pesticides and fertilizers, there would be no damaging pests and diseases in crops (Vaccari *et al.*, 2011). There is evidence that bio-char made from non-activated pecan shells can greatly enhance the soil's physical properties (Busscher *et al.*, 2010). For this aim, switch grass (*Panicum virgatum*) was added. Even though switch grass boosted soil carbon, the consequences are likely to be short- lived due to the soils' and climate's high oxidation rates.

2.4 Impact of bio-char on vegetative and reproductive growth of plant

Based on the findings of Akhtar *et al.*, (2015), adding bio-char to salt-affected soils can result in a significant increase in agricultural productivity. Uzoma *et al.*, (2011) found that grain yields improved by 150 and 98%, respectively, when bio-char was combined with maize grain. There is also evidence that charcoal treatment improves maize WUE and nutrient uptake in a significant manner. It was discovered that adding bio-char to productive soil in a moderate climate improved topsoil nitrogen absorption by fertilizer, but not crop growth or nitrogen usage efficiency moreover, it is not recommended to use charcoal as fertilizer (Lehmann and Joseph, 2009). It was noted that the application of both bio-char and nitrogen fertilizer together increased the amount of dry matter (DM) in radish. The difference between the soils that had no bio-char application and the soils that had received the most nitrogen fertilizer (100 tonnes ha^{-1}) ranged between 95 to 266 %. In the context of nitrogen fertilizer application, it has been demonstrated that the use of bio-char has a major benefit in increasing the yield proportionate of fertilizer used (Chan and Xu, 2009). As a result of a field trial by Major *et al.*, (2010), a corrosive and unproductive oxisol was treated with dolomitic lime and wood bio-char, and the results showed that the treatment increased crop yields as well as nutrient uptake. Throughout several growing seasons, crop rotations of soybeans and maize were studied concerning their growth patterns. Moreover, the soils that were enriched with bio-char and the soils that were not enriched with bio-char received the same amount of inorganic fertilizer. Over four years, the trial was conducted. In the first year of use, no noticeable effects were observed as a result of the use of the product. By increasing the rate at which bio-char was applied, on the other hand, the yield of maize gradually increased over the following years as a result of increased bio-char application. To achieve these gains in yield, improvements in pH and nutrient retention have played a major role. Following the fourth year of treatment, there was a noteworthy reduction in the soil's calcium and magnesium supply.

2.5 Effect of bio-char on the accessibility of plant nutrients and other non-essential components in the soil

As an outcome of a study conducted by Sukartono (2011), it was found that the application of bio-char improved nutritional absorption and maize yield as well as soil fertility status in terms of SOC and cation exchange capability. The fact that the organic matter content of soil amended with bio-char was significantly greater and more stable than that of soil amended with cattle manure implies that bio-char has a greater ability to sequester carbon from the atmosphere than cattle manure-treated soils. Abrishamkesh *et al.,* (2015) found similar outcomes.

The application of bio-char to alkaline soils has been shown to provide further benefits for plant development and quality. Because of using litter and bio-char, pH, cation exchange capacity, interchangeable calcium, and total phosphorus were all reduced. The combined effect of litter and bio-char on soil phosphorous availability was not substantial when litter and bio-char were combined. Although trash and charcoal have been used, maize phosphorous absorption has increased (Satriawan and Handayanto, 2015). Plant nutrient consumption and availability of constituents like P, K, and Ca are commonly improved in soils that are supplemented with bio-char, while free aluminum concentrations are typically decreased in soils that are supplemented with bio-char. As a result of the high porosity of bio-char's basic compounds, the soil pH becomes acidic as a result (Chan *et al.,* 2007).

The long-term impacts of bio-char on nutrient density may be caused by both an increase in the overall oxidation and the CEC, as Liang *et al.,* (2006) have suggested. In a variety of studies, charcoal has been shown to play a significant role in improving the fertility of the soil after ADE. According to Glaser *et al.,* (2001), the amino acids, amines, and amino sugars that are found in plant-based bio-char are some of the molecules that contain nitrogen. There is a possibility that plants due to the development of heterocyclic N aromatic amines could not use some of these chemicals during catalytic pyrolysis (Cao and Harris, 2010 and Gaskin *et al.,* 2010). It is found that the bio-char's remaining nitrogen. contains heterocyclic nitrogen rather than bio-available amine nitrogen. Cao and Harris (2010) and Novak *et al.,* (2009), Co-administering bio-char with mineral N fertilizer has been demonstrated to enhance the functionality of the fertilizer, thus indicating that bio-char can offset the possibly unavailable bio-char N (Steiner *et al.*, 2008). In addition, bio-char has a lower cost than traditional mineral fertilizers, which makes it an attractive option for producers (Steiner *et al.,* 2008).

There is some evidence that bio-char influences soil N dynamics, however, the effects of bio-char have not been fully understood through scientific investigations (Lehmann, 2007a). bio-char degradation has been found to result in soil N sequestration as a result of the high C content of infiltrating sources (Laird *et al.,* 2010). It is possible to reduce NH_4^+ leaching in antagonistic soil types by applying high volumes of bio-char 10% to 20% by weight (Lehmann *et al.,* 2003). It has also been found that the intake of nitrogen increases as the number of bio-char increases, according to Chan *et al.,* (2007) since nitrates (NO_3^-) are the primary form of nitrogen taken up by plants, the intake of basic cations is necessary to maintain electronic weighing balances in plants. There is, therefore, a considerable increase in K uptake, while there is a minor increase in calcium uptake as a result of this. To determine whether a soil amendment is suitable for a particular application, the soluble NH_4^-N content of the amendment is routinely measured. It is because of this that CaO and Harris (2010) conducted a study that concluded that carbonizing dairy manure-derived bio-char at temperatures below 200 ^{0}C is preferable to carbonizing it at higher temperatures. To ensure that the NH_4^-N content of the bio-char could be effectively utilized as a soil supplement to feed the crop, the following procedure was followed.

The use of X-ray photoelectron spectroscopy (XPS) has revealed that pyrrolic and pyridinic amines are the most common N functional groups in low-temperature bio-char (Amonette and Joseph, 2009). In bio-char, nitrogen is present in the nitrate form of nitrogen (NO_3^-N) and ammonical form of nitrogen (NH_4^-N). When applied externally, organic N through bio-char begins to decompose, suggesting that this material could be applied as a liberation of nitrogen (Chan and Xu, 2009). Chan *et al.,* (2007) assessed the agronomic benefits of green waste bio-char by using bio-char as a soil amendment in glasshouse pot trials. To determine how much dry matter an onion can produce in acidic, low-carbon soil, the plant was grown in acidic, low-carbon soil. Researchers looked at the potential for green waste and ammonium nitrate to produce DM in radishes by excluding nitrogen fertilizer and examining their availability. A bio-char treatment did not increase crop yields in the absence of fertilizer, according to the results of this study. It should be noted; however, that when there is a supply of nitrogen (N) fertilizer equivalent to 100 kg ha^{-1}, increased bio-char utilization (10-100 tonnes ha^{-1}) results in substantial improvements in production. When applied to the soil, bio-char did not add any additional nitrogen to the crop because of its low nitrogen contents (1-2 g kg^{-1}) and high carbon-to-nitrogen ratio but it can effectively enhance the efficacy of N fertilization by as much as two times (Chan *et al.,* 2007; Ding *et al.,* 2010 and Gaskin *et al.,* 2008) as compared to organic fertilizers (Chan *et al.,* 2007). Researchers Steiner *et al.,* (2008) conducted a study of the effect of nitrogen retention on a charcoal-compost mixture in a humid tropical soil with high permeability. There is some evidence that soil charcoal additives are more effective at increasing the efficacy of mineral N fertilizers than composting. As a result of the use of soil bio-char, the total nitrogen recovery of the soils was increased by 7.2% as compared with the reference soils, which is a considerable improvement.

This study led to an increase in the quantity of N, P, and K fertilizer applied to the soil. There is a common problem of phosphorous deficiency in tropical locations due to the low levels of plant-available phosphorus in the soils of the region. A large amount of phosphorus is absorbed by corrosion products in the soil, acting as a sink on the plants' ability to access inorganic phosphorus (Turner *et al.*, 2006 and Oberson *et al.,* 2006). Bio-char can reduce the leaching of phosphorus from sandy soils; hence it is envisaged that P levels will rise with increased bio-char applications (Novak *et al.,* 2009). In a study on the responsiveness of radish dry matter (DM) generation using green wastes, the bio-char amendment increased P concentrations. It was only when the charcoal treatment rate exceeded 50 tonnes ha^{-1} and no N fertilizer was used that substantial yield gains were seen. Because of the high levels of readily available phosphorus in bio-char, this increase was because P was not a significant constraint to the growth of bio-char (Chan *et al.*, 2007). A study conducted on the adaptability of radish DM production using green waste found that the treatment with bio-char increased the concentration of potassium (K) in radish DM. That was when bio-char treatment rates exceeded 50 tonnes ha^{-1} and no nitrogen fertilizer was used for the first time that significant improvements were achieved. This increase was in part caused by the high levels of exchangeable potassium in bio-char (Chan *et al.*, 2007).

In one investigation of radish dry matter (DM) synthesis using green waste materials, it was found that bio-char increased Ca concentrations in the DM. A substantial improvement in yield was reported only when charcoal treatment rates exceeded 50 tonnes ha^{-1} and no nitrogen fertilizer was used in the experiment (Chan *et al.*, 2007). Based on the results of a four-year field trial in which bio-char infiltration rates of 0, 8, and 20 tonnes ha^{-1} were used, it was found that overall Ca availability was improved. Over time, there was an increase in the concentration of Ca from 101 percent to 320 percent, as well as a depth of up to 30 centimeters. These improvements led to a very low amount of calcium leaching from bio-char as a result of these improvements (Major *et al.*, 2010). In a six-week pot trial on DM production of radishes from greener waste, bio-char moisture content was equivalent. According to our understanding, only 10 tonnes ha^{-1} of decreases were observed in the produced-fertilized regimen and 50 tonnes ha^{-1} of decreases were observed in the unfertilized-fertilized regimen, respectively (Chan *et al.*, 2007). It was found by Major and co-workers (2010) that when bio-char was applied at a rate of 0-20 tonnes ha^{-1} over four years, the accessible magnesium (Mg) content increased from 64% to 217 %. In a study by Yilangai *et al.*, (2014), found that tomato fruit production was significantly higher in mattresses with charcoal than in mattresses without charcoal. In comparison to farmer's techniques, bio-char amendments have been shown to increase vegetable yields by 4.7-25.5 percent in comparison with farmer's techniques (Vinh *et al.*, 2014). In a different study, however, the raw material to finished product ratio of winter wheat and summer maize over four seasonal changes was greatly increased in a calcareous soil even though the yearly yield was not (Liang *et al.*, 2014). When the bio-char of maple was tested at increasing concentrations on pea and wheat roots, there was no noteworthy variance in root length between the two plant varieties., possibly due to the short-term effects of bio-char on plants (Borsari, 2011).

It has been shown that bio-char has a significant influence on the development and output of french beans, according to (Saxena *et al.*,2013). When rice husk bio-char was used in the lettuce, there was an increase in end biomass, vegetative growth, plant height (PH), and the number of branches (NB), with experiments in which no bio-char was used. Hottle (2013) found that slow pyrolysis-derived oak bio-char was tested for four years in alfisol soil with 100 and 50% N fertilizer on a maize-soybean rotational, with a clear development path for yield, developed over this period. It has been reported that Wang *et al.,* (2013) have used bio-char as part of their pot culture experiments, using four different proportions of bio-char in five distinct saline-alkali soil conditions. When the fraction of bio-char increases, with the same saline-alkali level soil, the pH of the soil rises, while the EC of the soil decreases as the fraction of bio-char increases. Seeds of wheat germinate at different rates depending on the saline-alkali content of the soil in which they are planted. As a result of the significant saline-alkali soil without the addition of bio-char, the germination percentage of wheat seeds is 0%, whereas the vegetative growth of wheat plants in the soil with 45 percent bio-char is 48.9%. In both mild saline-alkali soil and regular soil, wheat seedlings benefit from the growth-improving properties of bio-char. There was no discernible influence on the development of wheat seedlings when bio-char was applied to them.

The influence of rice straw-based bio-char (BC) on the sequestration of Cd in soil and its subsequent absorption by wheat in soil contaminated with industrial pollutants was investigated. Four distinct phases of rice straw-based bio-char were incorporated into the soil and cultivated for two weeks. These stages comprised 0 percent, 1.5 percent, 3.0 percent, and 5 percent W/W. It followed that the wheat seedlings were harvested in the altered soil until they reached maturity, after which they were harvested. As a result of the data presented above, it can be concluded that BC treatments enhanced pH and silicon concentrations in groundwater, as well as in organic matter while decreasing bioavailable cadmium status in the experimental soil as a consequence of these treatments. Moreover, the application of biochar (BC) spray demonstrated a dose-dependent enhancement in plant height, spike length, shoot length, dry mass, and grain yield as compared to the control treatment. It was found that the polyphenol content and the gas exchange characteristics of the leaves treated with BC were higher than those of the control group. In comparison to the normal initial level of oxidative stress, bio-char specifically targets oxidative stress while increasing the antioxidant capacity.

2.6 Effect of organic manures

The conclusion drawn asserts that soil degradation, attributed to human activities (Leita *et al.,* 1999), has a profound impact on soil physical, biochemical, and physicochemical characteristics. This impact leads to a decline in soil productivity and alterations in soil ecological processes (Granadstein and Bezdicek, 1992). The degree of soil usage is intricately linked to soil quality, and various metrics are employed to gauge this quality. Notably, there is compelling evidence indicating the effectiveness of organic soil additives, such as Farm Yard Manure (FYM), organic manure, bone meal, and neem cake, in enhancing agricultural production when introduced into the soil (Melero *et al.,* 2007). This underscores the potential role of organic amendments in mitigating soil degradation and fostering sustainable agricultural practices.

Despite this, a significant amount of research has shown that organic fertilizers are more effective when used together rather than separately during the initial stages of crop growth, to meet the crop's needs rather than using them separately to meet the needs of the crop. Therefore, it can be concluded that to improve crop yield in tropical soils, it is necessary to use both organic and inorganic fertilizers at the same time (Ghosh *et al.,* 2004). Agegnehu *et al.,* (2016) concluded that all organic additions increased grain yield by between 10% and 29% in their study. In this study, they examined total ground biomass and maize yield and concluded that organic additions increased grain yield by between 10% and 29%. The organic treatments greatly increased the levels of some plant characteristics, such as the amount of chlorophyll in the leaves. This study found that total biomass, photosynthetic pigment, nitrogen and phosphorus content, soil organic carbon, and soil moisture all had a positive effect on maize grain production. Brennan *et al.,* (2014) also found the same thing to be true.

The durability of soil aggregates and the availability of water in China were studied over three years using organic supplements. As a result of three years of soil improvement, the bulk density of improved soil was considerably lower than that of control soil after three years. Besides the increase in soil organic carbon concentration, the relative soil macroaggregate proportion, and the mean soil weight diameter, it was also found that excessive water availability to plants improved, as well as the increase in soil organic carbon concentration. The evidence suggests that organic matter (OM) is both a source and sink for plant nutrients in the soil and that organic matter (OM) is an integral part of the soil structure that allows air and water to penetrate deeply into the soil. Mallory and Porter (2007) found that by adding organic supplements to potato yields each year, the yields of potatoes increased significantly because of the addition of organic supplements to potato yields. The availability of OM in soil plays an important role in determining the physical, biochemical, and biological characteristics of soil while the presence of soil organic matter is determined by (Larson and Pierce, 1991). A general rule of two soil organic matter (SOM) properties are identical (i.e., modifying one property will usually result in similar changes being made to the others as well). If degradation does not exceed soil formation, then biotic and abiotic qualities of soil are generally regarded as the most important factors in determining soil quality when degradation does not exceed soil formation.

There are many types of soil organic matter (SOM), and each of these types has its unique characteristics, It is crucial to recognize that there exists a variety of SOM types. As an example, total soil organic matter, light fraction, and micro-organic matter (particles) are all types of SOM. There is no doubt that organic matter (SOM) in the soil is one of the most important factors in determining the fertility of the soil. It is also important to note that SOM is a source of nutrients, but it is an important part of the transportation of nutrients between the soil and the plants. The amount of carbon in SOM, compared to that of the atmosphere and terrestrial plants, is three times greater than that of the former. While it is clear that soil organic matter has some effect on soil fertility, the exact mechanism through which it does so is not well understood.

Bacterial activity plays a significant role in determining the complete mineralization of soil organic matter it plays a vital role in breaking down organic matter (OM) into simpler, inorganic compounds through a process known as mineralization. In terms of soil fertility, the amount of organic carbon present in the soil significantly influences its chemical composition. The concept that soil organic carbon (SOC) has the potential to serve as an atmospheric carbon dioxide (CO_2) sink has recently attracted the attention of researchers (Post and Kwon, 2000). This idea suggests that the soil, through the sequestration of organic carbon, may contribute to mitigating the concentration of carbon dioxide in the atmosphere. Indeed, there is a significant improvement of organic carbon (OC) in soil microorganisms, and this, in turn, influences nutrient cycling and breakdown processes. The presence of organic carbon in the soil serves as a substrate for various microorganisms. Microorganisms, such as bacteria and fungi, play a crucial role in decomposing organic matter and cycling nutrients through processes like mineralization (Pankhurst *et al.,* 1997). Currently, we do not have a comprehensive understanding of soil biology, which is one of the driving factors behind nutrient conversions.

To assess soil health, one can measure the diversity and activity level of bacteria in the soil, which responds rapidly to environmental factors (Kennedy *et al.,* 1995 and Pankhurst *et al.,* 1995). Kumar *et al.,* (2018) observed in a field study on maize that the application of organic fertilizer resulted in the highest plant height in T_6 (50 percent recommended dose of fertilizer of NPK+ bone meal), while the shortest plant height was observed in T_1. This data was collected at various times (30, and 60 days after seeding, and at harvest time). The organic additions in T_6 (45.46, 72.86, 170.37cm) enhanced drainage and aeration, which in turn allowed the plants to develop to their full potential and achieve their record-breaking height. The control plot had the shortest plant height (30.1, 57.93, 133.17 cm) since no organic or inorganic fertilizer sources were used. Bharvand *et al.,* (2014). All treatments raised the height of the maize plants over time, reaching a maximum altitude of 48.8 centimeters. Maize plants grew at a rapid pace during the vegetative period. The physicochemical qualities of the soil were renovated as a consequence of the addition of inorganic and organic supplements.

Further research revealed that the growth rate of maize plants increased over time during the growing season up to the eighth week following planting (50-55 days). The reproduction phase started after 50-55 days of growth is slowing. Most likely, this was due to carbohydrate underlying assumptions regarding occurring when the cob/ear was being filled, as this is how maize plants normally develop over time. This contradicts the conclusions of Palta *et al.,* (1994) and Riccardi and Sttelluti (1994). Organic inputs and inorganic mineral fertilizers tend to have a good influence on the growth of plants, especially when applied in combination with high rates of soil improvements. Bending *et al.,* (2004) found that the results were inconsistent. They also discovered that the intervention had a considerable impact on the soil's properties. A wide range of soil physiochemical characteristics was affected by the addition of natural and synthetic materials to the stain's soil physiochemical characteristics. subsequently concluded that every organic manure has an impact on the soil's physical, chemical, and biological features. The best results were obtained with the (50 percent RDF of NPK Plus 50 percent BM). It is hard to sustain the productivity of the soil using only organic and inorganic sources. The results of this research unmistakably demonstrate that the use of organic manures positively influences soil properties, crop yield, and the overall growth of crops. As a result, the application of both inorganic fertilizers is suggested in terms of maintaining the soil's fertility and performance throughout time. Organic additions showed a considerable influence on soil OM. Management and tillage regulate the microbial decomposition of both plant substances and native organic matter, which controls agricultural soil carbon sequestration (Rickman *et al.,* 2001). Singh (2001) studied soil quality metrics and carbon capture and storage in a rice-wheat maize-wheat farming system and found that management approaches had a significant impact. Three water regimens and twelve different degrees of nutrient application were used in the experiment. When organic manure (especially FYM), green manure, and biofertilizers were used alongside nitrogen fertilizer, the results showed that both organic matter content and biomass production carbon levels rose.

2.7 Effect of organic manure on pH and EC

According to Marschner (1995), adding organic manure to soils did not change the soil's pH or electrical conductivity in any way. Several studies have found that poultry manure treatment increases soil pH and conductance, according to Gupta and Charles (1999). According to Walker *et al.,* (2004), when organic manure was added to soil, neither the pH value nor the electrical conductance of the soil changed as a result of the addition. Despite the application of both natural and synthetic sources of nutrients in rice and wheat farming systems for twenty years, no substantial enhancement was observed in soil pH.

In a study conducted by Dhonde and Bhakare (2008), it was found that alternative management strategies for the supply of nutrients had no substantial progress on pH or electrical conductivity (EC). It has been reported that increasing the administration of partially decomposing FYM at 5 to 10 tonnes ha^{-1}, together with the sources and methods reported for fertilizers, resulted in a reduction in pH and EC of the experimental field. It was found that after four weeks of adding poultry manure to the soil, Heidi *et al.,* (2011) found that the pH of the soil had risen from 4.9 to 5.7. Despite the presence of both inorganic pollutants and manure, there is no significant change in pH when the two are intermingled (Kannan *et al.,* 2013). It was reported by Yaduvanshi *et al.,* (2013) that soil pH reduced from 8.7 to 8.4 when synthetic fertilizers were used separately and to 8.17 when synthetic fertilizers were used in combination with natural animal waste.

2.8 Effect of manure on organic carbon

As a result, this is comparable to 50% micronutrients + 50% RDF when it comes to the amount of carbon in the soil that was gained by including all the micronutrients via FYM, 4.11 g kg^{-1} soil and 3.79 g kg^{-1} soil (Mathur, 1997). There is evidence to suggest that when organic material, especially FYM, nitrogen, and phosphorus are used together, clay-loam soils can be improved by increasing organic carbon and CEC (Rautaray *et al.*, 2003). According to Selvi *et al.,* (2003), compared to the control plot, it was the organic carbon (7.0 g kg^{-1}) was found to be the highest, while the lowest (4.2 g kg^{-1}) was found to be the lowest. The study undertaken by Liu *et al.,* (2006) discovered that organic matter content increased substantially when the integrated nutrient management (INM) was applied in a 50:50 ratio in place of inorganic fertilizers. The organic matter content in soil increased from 8.8 to 8.5 g kg^{-1} when cereal crops were grown with the addition of plant fertilizers, although the amount was significantly smaller than the interaction package of 50% ammonia through compost and 50% ammonia through FYM (9.2 g kg^{-1}) (Varalakshmi and colleagues, 2005).

There has been a substantial improvement in the organic material of the soil as a result of adding 50 percent RDF + 50 percent FYM to the soil, which increased from 0.40 percent to 0.74 percent (Dhonde and Bhakare, 2008). Using 50 percent exogenous nitrogen and 50 percent FYM and poultry manure nitrogen, Kumar and Reddy (2010) found that the organic carbon concentration in the soil increased from 0.32 to 0.50 percentage, respectively.

The study conducted by Kameswari and Narayanamma (2011) showed that when using RDF, the soil's organic matter content was exceptionally low (100-50-50 kg ha^{-1}) when compared to 100% FYM or when the cumulative effect was applied with RDF. This was followed by treating the sandy loam soils of Rajendranagar and Hyderabad Agricultural Research Station with animal manure in 2007 and 2008. As a result of the simultaneous use of synthetic fertilizers as well as organic fertilizers, the organic carbon content of the plants increased by 31.7%, when compared to the average plant biomass that is obtained in the case of organic fertilizers alone.

2.9 Effect of organic manure on soil nutrient availability

When organic resurce is administered at elevated levels, Olsen (1954) observed a rise in the concentration of available phosphorus in the soil ranging from 34 to 159 ppm due to the application of organic manure. As recorded by Sharma and Saxena (1985) in their investigation, the application of poultry manure and FYM led to a noteworthy increase in phosphorus levels compared to the control throughout the entire growth and development of the plant. As outlined by Diacono and Montemurro (2010), the recurrent addition of farm compost resulted in an augmentation of soil organic matter content and the overall nitrogen content in the soil. This, in turn, enhanced the availability of essential plant nutrients for plant growth. According to a study by Eekeren *et al.,* (2010), the soil biota is positively affected by farm composting, according to results from the study. Using FYM or chicken litter in combination with NPK fertilizer, Bharadwaj *et al.*, (1994) found a reduction in the amount of NO_3^-N in the soil after the addition of FYM or chicken litter. The amalgamation of NPK fertilizer at 100% of the recommended dosage, coupled with FYM fertilizer, elevated the soil's phosphorus availability beyond the initial level, as reported by Masto *et al.*, (2008). It was found in a study conducted by Kaur *et al.,* (2005) that under a pearl millet and wheat agricultural sequence, the soil received FYM, poultry manure, and sorghum filter cake alone and in conjunction with chemical fertilizer during the seven-year study period. It was found that all treatments except the application of commercial fertilizers enhanced the organic soil material, and total N, P, and K levels in the soil.

According to Subbaiah *et al.,* (2013), the integrated nutrient management (INM) interventions improved nitrogen supply for the subsequent crop, by converting NH_4^+N into NO_3^-N, as a result of the nitrogen conversion process. Following an experiment conducted by Akbasova *et al.,* (2015), it was determined that the use of 8 tonnes of organic manure ha^{-1} on gray soils led to a 1.2-1.5 times increase in root crop yields. Vermicompost is richer in nutrients (NPK) and organic humic acids (OHA) compared to regular compost, making it a more advantageous fertilizer due to its higher nutrient and organic humic acid content. In addition to encouraging root growth, vermicompost also reduces the negative effects of contaminants on plants. In this investigation, Shirzadi (2015) examined the impact of utilizing vermicompost and chicken excrement on the growth parameters, as well as the quantity and size of micro tubers in Marfona potato cultivars (with a diameter of 25 to 35mm). The study involved two variables of vermicompost at four levels (0, 3, 6, and 9 tonnes ha^{-1}) and chicken excrement at four levels (0, 10, 12, and 14 tonnes ha^{-1}). As the quantity of vermicompost applied to the plant increased, there was a corresponding reduction in the height of the plant. Among the 12 tonnes of chicken manure that were treated without organic manure, the tubers with a diameter of 25-35mm and the highest weight were produced.

According to Mujtaba *et al.,* (2013), urea nitrogen fertilizers in three concentrations (50, 100, and 150 kg ha^{-1}) and organic manure in four concentrations (0 (control), 4.5, 9, and 12 tonnes ha^{-1}) were used in their studies. It was found that applying 150 kg N ha^{-1} led to the greatest increase in plant height, physiological development dry weight, and Leaf Area Index (LAI), as well as a significant increase in the amount of dry matter accumulated in the tuber and the total mass of the tuber's muscles, all of which resulted in a greater increase in plant growth. Despite this, the application of vermicompost at 12 tonnes ha^{-1} did not affect the height of the plants, according to the findings. It has been observed that the amount of N.P.K. present in the tuber was considerably higher as a result of these relationships compared to experiments that used only nitrogen or vermicompost alone. For optimum yields and little impact on the environment, it is recommended that 12 tonnes of vermicompost be applied ha^{-1} and 150 kg of nitrogen fertilizer be applied ha^{-1}.

An investigation by Ramamoorthy *et al.,* (2020) was carried out to find out the influence of vermicompost applied in different doses ranging from 25-100% on the length, and thickness of radish tubers after 30, 60, and 90 days of growing. The maximum tuber length and weight were recorded in 75 percent of the vermicompost were observed at 30, 60, and 90 days respectively, except for the tuber breadth and diameter in 75 percent of the vermicompost concentrations. Within the first 60 days of exposure to vermicompost, 50% of it reached its maximum breadth and diameter, and both of those values decreased as the concentration of vermicompost increased.

Vermicomposting at a rate of 75% affects the radish plant's tuber production, according to the research. There has been an experimental study conducted by Panwar and Wani (2014) that uses organic manure, green manure, organic manure, and neemcake to add nitrogen, potash, and phosphorus to sweet potato crops. When planted under cottonwood trees, (vermicompost) has shown the highest survival rate, length of vine, number of branches per vine, fresh weight of the shoot, and dry matter production of the shoot when planted under cottonwood trees. Ultimately, the firm earned a total of Rs.99204.00 in commissions from the sale of its products. One of the greatest benefits-to-cost ratios that could be found was 1:1.37, which was the highest ratio. The addition of vermicompost to rehabilitative sodic soil has been shown to increase the yield of potatoes, spinach, and turnips in rehabilitative soil, (Ansari, 2008).

During the trial, soil performance and quantity were measured. The vermicompost was applied at a rate of 4, 5, and 6 tonnes ha^{-1} in plots that had previously been rehabilitated by Vermi-technology. At a dosage of 6 tonnes ha^{-1} of vermicompost, it has been observed that soil quality has improved considerably when vermicompost is applied. During the two-year study, vermicompost @ 6 tonnes ha^{-1} treated plots performed better than control plots by a wide margin as compared to the control plots.

It was found that the requirements for vermicomposting for leafy crops such as spinach were lower than those for tuber crops such as potatoes and turnips, which require 4 tonnes ha^{-1} and 6 tonnes ha^{-1} respectively. A research study conducted in Bangladesh by Alam *et al.*, (2007) explored the influence of vermicompost and NPK and S on the growth and yield of potatoes. All of these elements were absent from the soil that was used for the investigation while the pH of the soil was 5.4, which makes it fertile. Control, 2.5 tonnes ha^{-1}, vermicompost (VC) 5 tonnes ha^{-1}, vermicompost 10 tonnes ha^{-1} and vermicompost 2.5 tonnes ha^{-1} + 50% NPK were used as a treatment. Potatoes were treated with 90, 40, 100, and 18 kg ha^{-1} of N-P-K-S-doses. The usage of 10 tonnes of ha^{-1} vermicomposts and NPKS had a significant impact on the growth and productivity of potato crops. There were 25.56 tonnes ha^{-1} of potatoes per acre in the treatments. According to Shweta and Sharma (2011), organic manure and chemical fertilizer applications had a substantial impact on tuber and haulm production. For the highest tuber and haulm yields (both 30.46 tonnes ha^{-1}), 100% NPK + 25 tonnes ha^{-1} organic manure was used, which was much better than using chemical fertilizers alone (both 9.04 t ha^{-1}). Under the minimum NPK dose of 100 percent (21.39 tonnes ha^{-1}) but without organics, potato tuber production was equal to 25 tonnes FYM ha^{-1} or 12.5 tonnes VC ha^{-1} administered along with 75 percent of the acceptable NPK dose, showing a 25 percent savings in NPK.

Sood and Sharma (2001) tested Azotobacter & vermicompost for crop production in Shimla in 2000, they found that "Bacillus cereus (A) and Bacillus subtilis (B) each enhanced the rhizome yield of potato from 115 to 268 q ha^{-1} par with 100 percent NPK treatment," as reported by Sood and Sharma (2001). The tuber production was improved by 34 to 65 q ha^{-1} with vermicompost @ 5 tonnes ha^{-1}. When the recommended NPK fertilizer dosage was used, yields rose even further. In the lack of nitrogen (N), Azotobacter injection of seed tubers boosted tuber yield by 68 q ha^{-1}, but Azotobacter's effect diminished with increasing N dose. For maize grown for grain, Mária and her colleagues conducted experiments with four treatments a control procedure, three treatment options with increasing amounts of organic manure (4.6: 9.2: 11.6 tonnes ha^{-1} respectively), which supplied total nitrogen to the soil at rates of 57, 114, and 142 kg ha^{-1}, respectively. Irrigation was not used in any of the experiments. There was a total of seven different fertilization procedures used in the potato study. Increasing the organic manure dose increased grain yields. Grain weight, carbohydrate content, and magnesium concentration were all lowered by 1,000 metrics as the amount of vermicompost increased. A dose of 4.6 tonnes ha^{-1} of organic manure is recommended based on the characteristics of the 1,000-kernel weights, the starch content, and the magnesium content of the organic manure.

There was an increase in potato tuber development, carbohydrate contents, and dry matter contents when vermicompost was used more frequently. It has been reported that potato tubers lost some of their vitamin C content after being treated with vermicompost. In the study, however, it was found that applying powdered organic manure to potato tubers had a less significant effect on the nitrate levels of the tubers than combining NPK fertilizer with powdery organic manure.

One-third of the nitrogen through FYM + 1/3 nitrogen through vermicompost + 1/3 nitrogen through Neem cake + agronomic techniques treatments had higher plant per meter row length, the height of primary shoots, dry matter (g), and the number of branches $plant^{-1}$

than the other two treatments. Combined therapies (1/3 N-FYM+1/3 N-vermicompost + 1/3 N-Neem cake + agronomic approaches to weed and pest control substantially increased overall tuber output and potato grades (A, B and C).

In a study conducted by Kumar *et al.*, (2012), researchers used subplots to test the efficacy of a variety of manures, including farmyard manure, chicken waste, vermicompost, solubilizing bacteria, and the combination of the three. As a result of

combining organic manures (FYM, PM, or VC) or fertilizers (100 percent recommended dose NPK) with 50 percent of the required dose of chemical fertilizer, nutrient absorption, and soil fertility were found to positively affect the development and yield of the plants, as well as nutrient absorption and soil fertility. In comparison to Azotobactor or PSB treatment alone, Azotobactor + PSB treatment resulted in increased tuber growth and nutrient uptake, compared to Azotobactor or PSB treatment alone. With a three-year integrated solution of 50% of the prescribed NPK through the inorganic and 50% of the RDN through the PM during three years, the highest tuber yield (22.73 tones ha^{-1}) was achieved, with the two treatments outperforming the control by 228 and 223 percent, respectively. The combination of Azotobactor + PSB biofertilizers seed treatment increased tuber yield, and nutrient uptake, and produced a greater return than any other treatment combination investigated. During three years, when 50% of the required dose of NPK was delivered artificially, and the remainder 50% of the RDN was delivered periodically, the soil's available N, P, and K levels reached their maximum levels. During a conducted experiment by Raja and Veerakumari (2013), vermicomposts such as cow dung vermicompost, leaf ash vermicompost, and poultry tassel organic manure were compared with conventional medicinal *Withania somnifera* grown in organic amendments with inorganic fertilizers, as well as plants grown without organic amendments (control). There was a dramatic rise in growth indicators such as shoot and root lengths, dry and wet weights, shoot-to-root ratios, and the alkaloids withaferin A and withanolide D within plants grown in soil treated with poultry feather organic manure.

The research published by Kashem *et al.*, (2015) was conducted to determine the effects of animal manure biodegradable fertilizer on the vegetative growth and fruit production of tomato plants (*Solanum lycopersicum* L.). In addition to this, five different amounts of vermicompost were added to an air-dried sandy loam soil (control, 5, 10, 15, and

20 t ha^{-1}, 100 percent, and 200 percent, respectively). According to the study, vermicompost and NPK fertilizer had a significant (P 0.05) impact on the length of shoots, the number of leaves $plant^{-1}$, the dry matter percentage of shoots and roots, and the volume of fruit and fruit. In comparison to the untreated treatment, the highest use of organic manure (20 t ha^{-1}) resulted in a 52-fold and 115-fold increase in the dry weight of the shoot and root, as well as a 6-fold and 18-fold increase in seed weight (mean), as well as a 200-percent increase in NPK fertilizer (mean) in fruit yield $plant^{-1}$ and fruit length (mean). The plants of tomato plants cultivated in vermicompost-enriched soil performed better than those grown in soil enriched with inorganic fertilizers. The growth, yield, and quality of tomatoes were tested in the field by Meenakumari and Shekhar (2012) to see how vermicompost and other nutrients affected tomato growth, yield, and fruit quality. To test the influences of various nutrients on various tomato plant growth metrics, field trials were carried out using fertilizers with identical nutrient concentrations to test the effects of various nutrients on plant growth. As a control for implementation, one important plant was left untreated, while five others were given multiple kinds of fertilizers (chemical, livestock manure, organic manure, and organic manure mixed with chemical fertilizer) as a way of seeing how different kinds of fertilizers affect the growth of the plants in the various plots. In comparison to control plots, treated plots produced 73% more fruit than control plots that were not treated.

The NPK-treated plots had higher amounts of leaf moisture, dry matter accumulation of foliage, the dry basis of berries, and branches, and a higher number of fruits $plant^{-1}$ than the untreated control with other micronutrients. A variety of fertilizers with similar nutritional contents was fed to tomato plants as part of an experiment conducted. Six experimental fields were used in the study, one of which was unfertilized, while the other five were subjected to a variety of treatments. FYM, Vermicompost, and FYM enriched with artificial fertilizers (and organic manure enriched with chemical fertilizers) are the three types of FYM. Compared to the untreated control plots, the treated plots yielded 73% more fruit when compared to the untreated plots.

The NPK-treated plots had higher leaf moisture content, leaf dry weight, fruit dry weight, network size, and yield $plant^{-1}$ than plots that were not treated with this fertilizer. During a two-year field study conducted by Singh *et al.*, (2014), on tomato development, yield and quality indices. Vermicompost, biological matting, and irrigation level were found to have a substantial influence on the entire growth of tomatoes.

The application of vermicompost to the soil, along with responsible farming practices, led to a substantial improvement in various plant parameters. These included increased plant height, expanded leaf area, greater leaf weight, higher fruit weight, enhanced yield, increased fruit density, prolonged shelf life, and elevated TSS (5.20 Brix). This positive impact was attributed to the combined effects of vermicompost application and responsible farming. Singh *et al.,* (2013) conducted the study to evaluate the impact of vermicompost on tomato crops and as a result of using only vermicompost in the production of the tomato, the shelf life of the fruits was increased by 25-106 percent, as well as the total solids content of the tomato was increased by over 4.5 percent, all of which are desirable properties for summer veggie production and data management. If you want the most effective results from your tomato plants when planted in the field, you need to follow the following procedures: using 5 tonnes of vermicompost per acre, saturating the soil with dried agricultural wastes, applying 80:40:40 kg NPK fertilizer two-thirds of the way through, hydrating 30% of the way through, and applying 80:40:40 kg NPK fertilizer half the way through.

The review study examines the effects of biochar-based organic amendments on soil biological and biochemical indicators, as well as their impact on increased soil nutrient release potential and potato yield, and offers substantial insights into sustainable agricultural practices. The integration of biochar as an organic amendment emerges as a positive contributor to both soil health and crop productivity. The review-based study underscores noteworthy improvements in soil biological indicators, particularly heightened microbial activity and diversity. These findings suggest that biochar creates a more favorable environment for soil microorganisms, consequently positively influencing soil biochemical processes and promoting enhanced nutrient cycling and availability. The observed rise in nutrient release potential in biochar-amended soils contributes to improved nutrient accessibility for plant uptake, ultimately fostering the growth and development of potato plants.

Throughout the review, it becomes evident that specific outcomes are subject to variation based on factors such as bio-char type, application rates, and soil characteristics.

Moreover, the need for long-term studies is emphasized to comprehensively assess the sustained benefits of biochar amendments across multiple growing seasons.

In conclusion, the findings of this review study provide valuable information that contributes to the ongoing endeavors aimed at devising environmentally friendly and economically viable strategies for enhancing soil quality and agricultural productivity. The positive impacts of biochar-based organic amendments outlined in this study underscore their potential significance in the pursuit of sustainable and effective agricultural practices.

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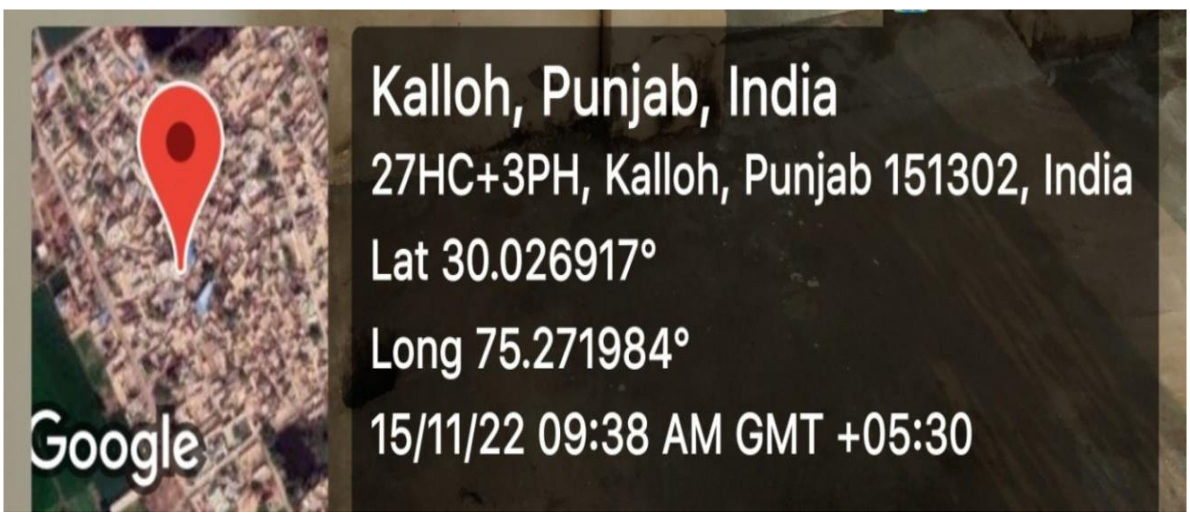
CHAPTER- III

MATERIALS AND METHODS

To ascertain the proposed goals of the entire research work entitled, '**Effect of bio-char based organic amendments on soil biological & biochemical indicators in relation to increase soil nutrient release potential & yield of potato**' An investigation was carried out in the village of Kalloh, Mansa (Punjab), during the Rabi seasons from 2017-19. Detailed information regarding the material and methods used during the course experiment, as well as the field trial and biochemical analysis (soil and plant sample) are presented in brief under the appropriate headings.

3.1 Location of the trial venue:

The experimental trials took place in an area situated between 29° 32' to 30° 12' N latitude and 75° 10' to 75° 46' E longitude, with an elevation of 212 m. above sea level. These trials were carried out throughout the Rabi season spanning from 2017 to 2019.



3.2 Climate and rainfall pattern:

The region experiences typical semi-arid weather, with distinct wet and dry seasons, windy and generally clear skies throughout the year, and a consistent warm temperature. In Punjab City, there is an average of 1150 mm of rainfall annually, and out of a total of 1150 mm, around 88 % of the rains occur during the monsoon season between June and September. Generally speaking, the maximum temperature is recorded in May and June, while the minimum temperature is recorded in December and January. In Tables 3.1a and 3.1b, we provide details about the meteorological observations made during our research from September to April. As a result of reviewing the data, it was noticed that during the experimentation period, the experiment received 76.4 mm of rainfall in 2017-18 and 84.8 mm of rainfall in 2018-19. It is estimated that in 2017-18 the maximum average monthly temperature ranged from 31.2 to 22.8 ^{0}C, while the minimum was 18.7 to 9.1 ^{0}C, whereas in 2018-19 the maximum ranged from 31.3 to 20.2 ^{0}C and the minimum ranged from 17.2 to 6.4 ^{0}C. As for the relative humidity, the average monthly relative humidity (RH) value was recorded both in the morning and in the evening of each month. There was a difference in the relative humidity in the morning and evening for the crop growing period in 2017-18, varying between 88 and 89 % and 38 to 45 %, respectively, and during 2018-19, varying between 89 to 97% and 39 to 47%, respectively.

Figure 3.2a: Agro-meteorological data [average temperature (^{0}C), RH (%) and rainfall (mm)] on monthly basis from September 2017-April 2018

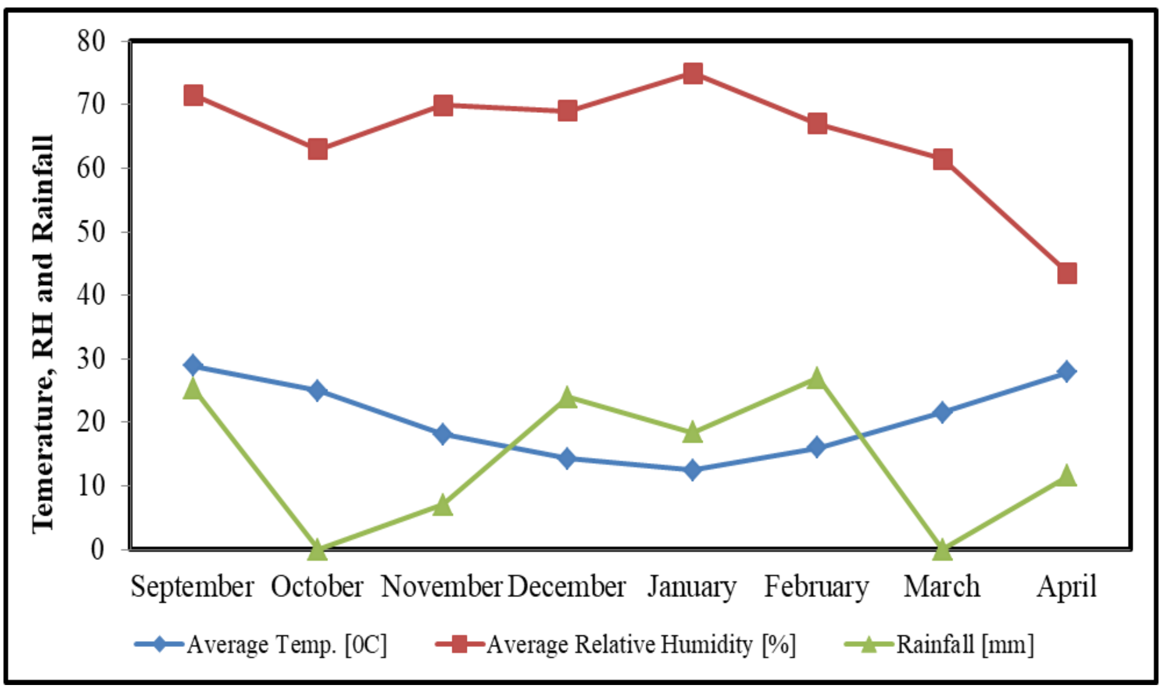
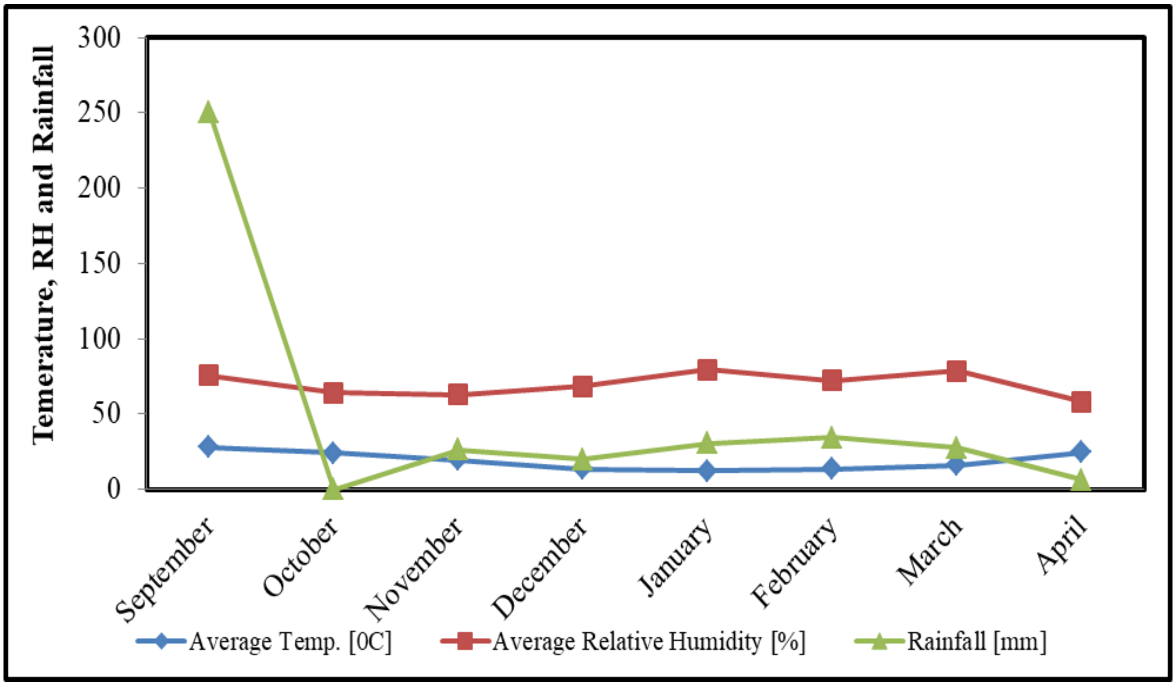


Figure 3.2b: Agro-meteorological data [average temperature (^{0}C), RH (%) and rainfall (mm)] on monthly basis from September 2018- April 2019



3.2 Properties of soil physico-chemistry:

Soil samples were collected from the experimental field utilizing a Soil Auger and Core Sampler to assess the physicochemical attributes of the soil. To determine the physicochemical properties of the soil, samples of soil were mixed thoroughly before they were analyzed. During the analysis of soil properties, a standard protocol was followed by following the samples of soil. Detailed information regarding the soil analysis parameters can be found in the table below (Table 3.1).

Table-3.1: Properties of soil physico-chemistry

Physical parameters	Values	Protocol used
Sand	77.5%	International pipette method Piper (1966)
Silt	15.2%	
Clay	7.1%	
Texture	Loamy sand	
Bulk Density	1.6%	
Particle Density	2.1%	
Chemical properties		
Soil pH	7.4	Jackson (1967)
Soil EC (dSm^{-1})	0.33	Jackson (1967)
Organic Carbon (%)	0.46	Walkley and Black (1934)
Nitrogen content ($kg\ ha^{-1}$)	188	Subbiah and Asija (1956)
P_2O_5 ($kg\ ha^{-1}$)	14.7	Olsen (1954)
K_2O ($kg\ ha^{-1}$)	232	Jackson (1973)
Biological properties		
Activity of dehydrogenase in soil µg TPF 24 h^{-1} g^{-1} soil	1.57	Tatabai (1983)
Activity of acid phosphatase in soil µg PNP h^{-1} g^{-1} soil	67.66	Tatabai & Bremner (1969)
Activity of alkaline phosphatase in soil mg NH_4^+ g^{-1} soil hr^{-1}	18.67	Tatabai & Bremner (1969)

3.3 Details of experiment:

The investigation was carried out employing a randomized block design, comprising three replications and thirteen treatments in the Rabi seasons of 2017–2018 and 2018–2019 while the detailed statements of the treatments are presented (Table 3.3).

Table-3.2: Experimental details

Experimental design	Randomized Block Design (RBD)
Treatments	13
Replications	3
Total number of treatments (plots)	39
Individual plot size	7X3 m^2
Total experimental area	819 m^2
Varieties	Kufri Pukhraj
Spacing	60×20 cm

3.4 Details of the treatment applied:

The details about the treatments are presented in **(Table 3.4a and 3.4b)**

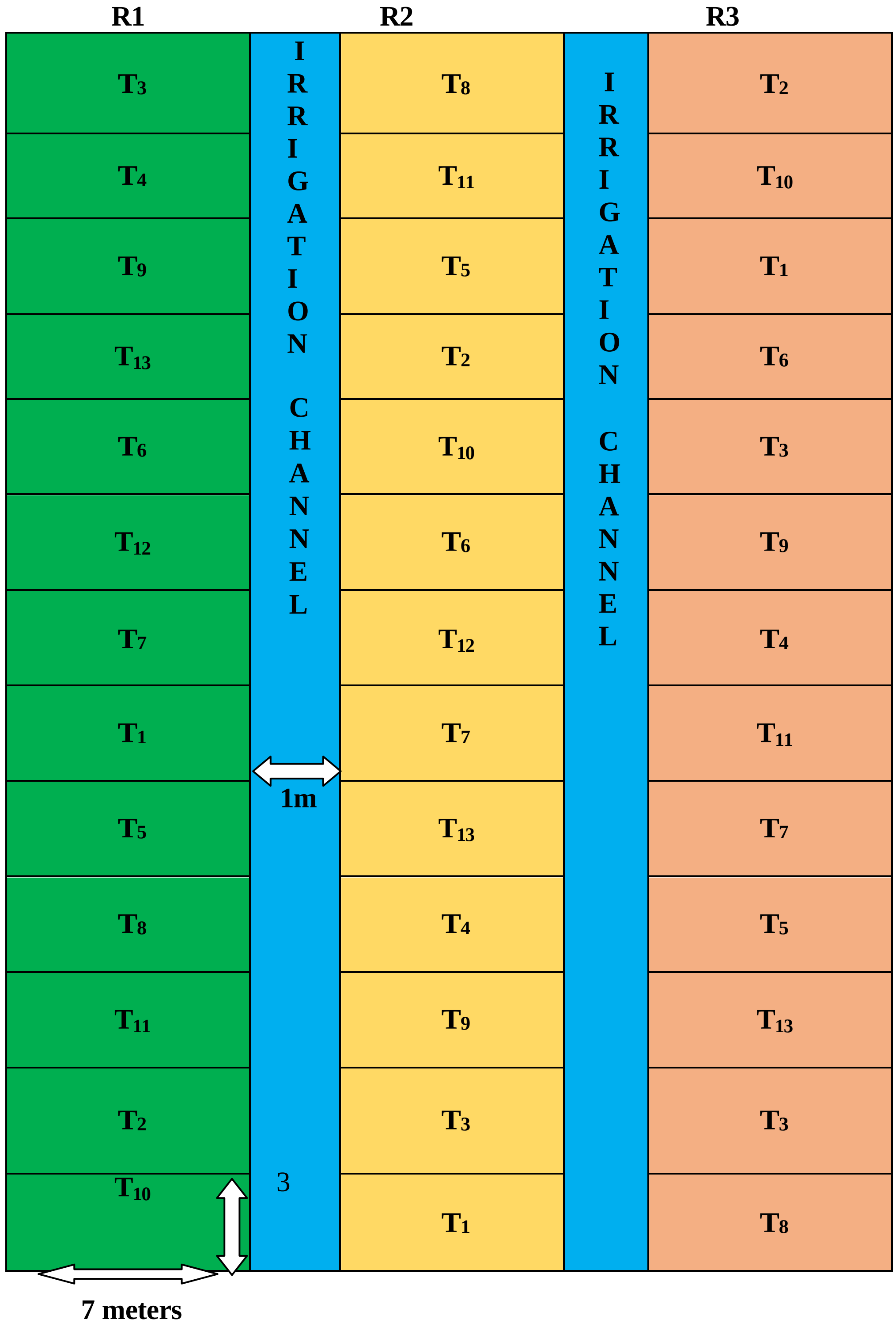
Table-3.3a Treatment details-I

Treatment detail-II	
T1	Control (positive amendments –100% NPK)
T2	[25%] recommended dose of fertilizers + [75%] (bone meal +vermicompost + poultry manure) + bio-char [20%]
T3	[25%] recommended dose of fertilizers + [75%] (bone meal +vermicompost + poultry manure) + bio-char [30%]
T4	[25%] recommended dose of fertilizers + [75%] (bone meal +vermicompost + poultry manure) + bio-char [40%]
T5	[25%] recommended dose of fertilizers + [75%] bone meal + bio-char [20%]
T6	[25%] recommended dose of fertilizers + [75%] vermicompost + bio-char [20%]
T7	[25%] recommended dose of fertilizers + [75%] poultry manure + bio-char [20 %]
T8	[25%] recommended dose of fertilizers + [75%] bone meal + bio-char [30%]
T9	[25%] recommended dose of fertilizers + [75%] vermicompost + bio-char [30 %]
T10	[25%] recommended dose of fertilizers + [75%] poultry manure + bio-char [30 %]
T11	[25%] recommended dose of fertilizers + [75%] bone meal + bio-char [40%]
T12	[25%] recommended dose of fertilizers + [75%] vermicompost + bio-char [40%]
T13	[25%] recommended dose of fertilizers + [75%] poultry manure + bio-char [40%]
BM=Bone meal, VC=Vermicompost, PM=Poultry manure	

Table-3.3b Treatment detail-II

Treatment detail-II	
T1	Control (positive amendments–100%NPK)
T2	[50%] recommended dose of fertilizers + [75%] (bone meal +vermicompost + poultry manure) + bio-char [20%]
T3	[50%] recommended dose of fertilizers + [75%] (bone meal +vermicompost + poultry manure) + bio-char [30%]
T4	[50%] recommended dose of fertilizers + [75%] (bone meal +vermicompost + poultry manure) + bio-char [40%]
T5	[50%] recommended dose of fertilizers + [75%] bone meal + bio-char [20%]
T6	[50%] recommended dose of fertilizers + [75%] vermicompost + bio-char [20%]
T7	[50%] recommended dose of fertilizers + [75%] poultry manure + bio-char [20 %]
T8	[50%] recommended dose of fertilizers + [75%] bone meal + bio-char [30%]
T9	[50%] recommended dose of fertilizers + [75%] vermicompost + bio-char [30 %]
T10	[50%] recommended dose of fertilizers + [75%] poultry manure + bio-char [30 %]
T11	[50%] recommended dose of fertilizers + [75%] bone meal + bio-char [40%]
T12	[50%] recommended dose of fertilizers + [75%] vermicompost + bio-char [40%]
T13	[50%] recommended dose of fertilizers + [75%] poultry manure + bio-char [40%]
BM= Bone meal, VC= Vermicompost, PM= Poultry manure	

Fig 3.3: LAYOUT OF THE TRIAL



3.5 Inputs for the experiment:

3.5.1 Description of potato variety (Kufri Pukhraj)

It is to be noted that the Kufri Pukhraj variety of potatoes was developed by the Central Potato Research Institute in Shimla, Himachal Pradesh. This plant has a vigorous growth habit and grows tall and partially erect to streamline. There are a few thick, green leaves with a bit of curve, straight flaps that are slightly developed. This plant consists of dark green leaves closed with large follicles, ovate to lanceolate leaflets, and each leaflet has a full margin running the length of its smooth, glossy surface. It also has well-developed, high pollen stainability, round stigmas, and white flowers with orange-yellow anthers. As an early maturing variety, it is capable of maturing between 70-90 days and is capable of yielding 40 tonnes ha^{-1} along with the resistant to early blight and moderately for late blight.

3.5.2 Organic manures:

A well-decomposed vermicompost, poultry manure and bone meal were obtained from a standard shop, which is located near Ludhiana in the Punjab province. As per the requirements of the research trial, organic manures were administered in every plot during the process of preparing the field. in a proper manner and mixed well to obtain the best results. As per the recommendation of (Zandian and Farina, 2016), 3 tonnes of ha^{-1} of vermicompost, 10 tonnes of ha^{-1} of poultry manures and 5.5 tonnes of ha^{-1} of the bone meal were applied in the field while the calculation of each organic manure for each treatment was carried out according to recommended done to fulfill the requirements of the entire set of treatments.

3.5.3 Fertilizers:

A recommended dose of nitrogen, P_2O_5, and K_2O (187:62:62 kg ha^{-1}) has been applied in the field through urea, single super phosphate (SSP) and muriate of potash (MOP) as per the requirements of treatments in the present piece of research work. The recommended dose of fertilizers was calculated as per the package and practices recommended by PAU, Ludhiana (187:62:62 kg ha^{-1}).

3.5.4 Bio-char:

Rice straw was used to produce the bio-char utilized in this investigation which was obtained from the Ludhiana-based private organization. The treatment-wise calculation of bio-char was carried out based on 5 tonnes ha^{-1}. The specific properties of bio-char are presented below in tabular form.

Table-3.4: Biochemical compositions of bio-char

Sr. No	Characteristics	Values
1	pH (1:10)	6.13
2	EC (1:10)	1.06 dSm^{-1}
3	Organic carbon	51.02 (%)
4	Organic matter	98.21 (%)
5	Nitrogen (N)	0.59 (%)
6	Phosphorous (P_2O_5)	0.42 (%)
7	Potassium (K_2O)	0.79 (%)
8	Bulk density	0.138 g (cm^{-3})
9	Density of bio-char particles	0.293 g (cm^{-3})
11	Porosity of bio-char	66.47 (%)
12	Ash	10.5 (%)

Observation recorded during the crop growth:

3.6.1 Studies on growth parameters:

a- Emergence (%):

Before the emergence of the crop, a sampling area of one-meter row length was earmarked randomly at two sites in each net plot. The emerging crop plants were counted daily till the constant values were reached. The final values of two sampling sites were averaged and were recorded as emergence count m^{-2} and the emergence percentage was calculated.

b- Plant height (cm):

Five plants selected at random from each plot were used to measure the plant heights at consistent intervals of 30, 60, and at harvest. The measurement of height involved using a meter scale to gauge the distance in centimeters from the plant's base to the topmost leaf. Subsequently, the average plant height was computed and presented as height per individual plant in centimeters.

c- Dry matter accumulation (%):

Plant samples were gathered periodically from each replication to document the accumulation of dry matter. The collected plant samples underwent a thorough cleaning and were subsequently subjected to hot air oven drying at 70 ^{0}C until a constant weight was attained. The dried samples were then converted to grams per square meter.

d- Leaf area index (LAI):

The LAI was calculated by using the formula given by (Watson, 1947) at two intervals i.e. 30 DAS and the harvesting stage. To calculate the LAI, the total leaf area (cm^2) was divided by the total ground area (cm^2). The total leaf area was recorded with the help of a leaf area meter (Model no-211).

$$\text{LAI} = \text{Total leaves area } (cm^2) \,/\, \text{Total ground area } (cm^2)$$

e- Number of haulms plant^{-1}:

From each plot, a random selection of five plants was made, and the total number of haulms for these chosen plants was counted. Subsequently, the average number of haulms plant^{-1} was determined by calculating their mean.

3.6.2 Developmental studies:

a- Days to emergence:

The daily count of days to emergence was documented by observing the ear-marked three-meter row length within each net plot. This recording commenced from the initial seedling emergence and continued until stability was reached. The total number of days taken for emergence was calculated from the sowing date

b- Days to maturity:

The measurement involved determining the the duration from the date of sowing to achieve 95 percent maturity. For potatoes, this assessment was conducted by observing the natural drying of foliage and the subsequent harvesting of skins.

3.6.3 Yield and yield contributing parameters:

a- Number of plants [m^{-1} row length]:

Before harvesting, the total count of plants within a one-meter row length was conducted and documented as the number of plants per meter row length.

b- Tubers [$plant^{-1}$]:

The count of tubers from specified plants in each plot was noted, and the mean value of tubers $plant^{-1}$ was subsequently computed.

c- Weight or mass of tubers [$plant^{-1}$]:

At the harvesting stage, five plants were chosen randomly, and the wt. of tubers from these selected plants was recorded. Ultimately, the mean value of tubers weight $plant^{-1}$ was computed.

d- Yield of potato (q ha^{-1}):

Harvesting of the crop in each plot involved digging the plants from the designated net area using a spade, and subsequently, the potato tubers were separated from the plants. Initially, the potato yield was documented on a net plot basis and expressed in quintals per hectare (q ha^{-1}).

3.5.5 Quality analysis of potato tuber:

a- Starch content (%):

Starch content was obtained by the anthrone method following the procedure outlined by Mc Creedy *et al.,* (1950) and expressed as a percentage.

1- To extract sugars, the sample underwent pre-treatment with alcohol [80%], and subsequently, treatment with perchloric acid was employed to extract starch.

2- Starch undergoes hydrolysis to glucose under hot acidic conditions, followed by dehydration to hydroxyl methyl furfural. When this compound reacts with anthrone reagent, it produces a green colour, and their absorbance were measured at 620 nm using a spectrophotometer.

b- Potato tubers grading:

The yield from each net plot was categorized into various grades, with classification determined by the average weight of the tuber, as outlined below.

Grade [A]	tuber weight [>75gm]
Grade [B]	tuber weight [50-75gm]
Grade [C]	tuber weight [< 50gm]

3.5.6 Soil studies:

a- Collection of soil sample:

Soil samples were gathered from both the surface and sub-surface layers for each treatment. Afterward, the specimens underwent air-drying in a shaded environment, were ground using a pestle and mortar, and filtered through a 2mm strainer for subsequent chemical analysis. However, to examine soil enzymes, fresh soil samples were gathered from each treatment. Standard procedures were applied for analyzing both the physicochemical and biological attributes of the soil.

b- Analysis of Soil texture:

The hydrometer method, as outlined by Bouyoucos (1962), was utilized to determine the mechanical composition of the experimental soil, including the content of sand, silt, and clay in percent. The textural triangle elaborated by the USDA, as described by Brady and Weil (2002), was employed to identify the soil texture.

c- Analysis of bulk density [gm^{-3}]:

1- Samples of the soil were obtained both before and after the crop harvest from depths of 0-5 cm and 5-10 cm using an auger.

2- These collected soil samples were blended and subjected to oven drying at 105 ^{0}C for 48 hrs.

3- The calculation of soil bulk density was performed using the formulae elaborated by Blake and Hartage (1986).

Bulk density [gm^{-3}] = X-Y / Y

Whereas X= Core weight along with oven-dried soil

Y= Core weight V= Core volume

d- Analysis of particle density:

1- The procedure began by measuring the weight of a dry, clean pycnometer with a glass stopper. Following this, 10 grams of oven-dried soil were transferred to the dry pycnometer, the stopper was removed, and the weight was noted. Subsequently boiled and cooled water was then added to fill up to two-thirds of the pycnometer, and the mixture was allowed to stand undisturbed for 10 minutes.

2- To remove trapped air, the pycnometer was subjected to boiling water and agitated with a glass rod. Following this, the pycnometer was filled with air-free boiled water and cooled water up to the brim, and a stopper was tightly secured on it.

3- The outer surface of the pycnometer was dried by wiping it with a dry cloth, and its weight was measured to the nearest 0.01 grams. Subsequently, the weight of the pycnometer filled with water was recorded, and the particle density was calculated using the formulae outlined by Blake and Hartge (1986).

Particle density = Wps- Wp / Wpw + (Wps-Wp)

4- Chemical Properties:

a- Soil pH:

1- The soil pH was assessed according to the procedure provided by Jackson (1973) employing a pH meter with Model number LT-49.

2- Before utilization, the pH meter underwent calibration by employing two buffer solutions with neutral pH values of 7 and 9. These buffer solutions were placed in distinct beakers, and the electrodes were alternately introduced into the beakers to calibrate the pH meter.

3- To measure soil pH, 10 grams of soil were deposited in a 100ml beaker, and 25ml of distilled water was introduced. The soil underwent a 30-minute equilibration with periodic stirring. Subsequently, the pH meter electrode was inserted into the suspension, and the pH reading was documented.

b- Electrical conductivity:

The supernatant extract obtained from the soil-water suspension, which was used for pH estimation, was left undisturbed overnight. This supernatant was then utilized for the determination of electrical conductivity (EC) in deci Siemens per meter (dSm^{-1}), following the method described by Jackson (1973), using an EC meter (Model-LMCM-20).

c- Analysis of organic carbon [%]:

1- The process began with weighing 2g of soil, which was then placed in a 500ml volumetric flask. Subsequently, 10ml of 1N potassium dichromate ($K_2Cr_2O_7$) was added and thoroughly shaken, followed by the addition of 20ml of concentrated H_2SO_4.

2- The flask was then shaken on a mechanical shaker for 20 minutes. Afterward, 20ml of distilled water was introduced into the flask. Following this, 10ml of orthophosphoric acid (H_3PO_4) and 7-8 drops of diphenylamine (i.e. indicator) were added.

3- The burette was filled with 0.2N ferrous ammonium sulfate solution for titration and solution was titrated until the violet color changed to a bright green color, and the volume of ferrous ammonium sulfate was recorded. The OC percentage in the soil was calculated using the provided formula.

OC (%) = (Blank reading – Final reading) X 0.003 X 100 / 2

d- Analysis of Soil microbial biomass carbon [SMBC]:

1- The determination of soil microbial biomass carbon followed the method outlined by Vance *et al.,* (1987). The process involved the extraction of organic carbon from both fumigated and unfumigated soils using K_2SO_4.

2- Fresh soil samples, approximately 10 g on an oven-dry basis, were collected. These samples underwent fumigation with ethanol-free chloroform for 24 hours within a vacuum desiccator. Following fumigation, the soil samples were evacuated and subjected to fumigation again. Subsequently, both the fumigated and unfumigated soil samples were extracted using 0.5 M K_2SO_4 at a soil-to-solution ratio of 1:4. This extraction process involved shaking the samples on a mechanical shaker for 30 minutes.

3- The subsequent step in the process included passing the soil suspension through Whatman filter paper to facilitate filtration. Likewise, non-fumigated soil samples underwent extraction with 0.5 M K_2SO_4 using the same method.

4- The determination of readily oxidizable carbon in extracts from both fumigated and non-fumigated soil samples was conducted through the dichromate digestion method. The outcomes were expressed based on the oven-dry weight, which was achieved by drying the samples at 105 ^{0}C for a duration of 24 hours.

5- To represent microbial biomass carbon (MBC) on an oven-dry weight basis, the moisture content was analyzed utilizing the gravimetric method. The computed outcomes were then presented in terms of MBC per microgram of soil (MBC μg^{-1} soil).

e- Permanganate oxidizable carbon (Labile carbon):

Permanganate oxidizable carbon, also known as active or labile carbon, was determined following the procedure outlined by Weil *et al.,* (2003). The method involves the oxidation of soil carbon by 333 mM KMnO4, and the amount of carbon oxidizable by this oxidant is considered labile carbon. Here are the steps involved:

1- **Sample preparation:**

2g of soil was taken in a centrifuge tub

2- **Oxidation process:**

3- The soil underwent oxidation using 25 ml of 333 mM KMnO4, and the mixture was agitated on a mechanical shaker for duration of 1 hour.

4- **Centrifugation:**

The contents were then centrifuged for 5 minutes at 4000 rpm.

5- **Supernatant analysis:**

i- 1 ml of the supernatant solution was taken and diluted to 250 ml with double-distilled water.

ii- The concentration of $KMnO_4$ was measured at a wavelength of 565nm using a spectrophotometer.

iii- The alteration in the $KMnO_4$ concentration was employed to gauge the quantity of oxidized carbon.

iv- This method provides a measure of labile carbon in the soil based on its oxidizability by $KMnO_4$.

$$\text{Lebile carbon [mg per kg]} = \frac{(B\text{-}S) \times 50 \times \text{volume of } KMnO4 \times 1000 \times 9}{2 \times 1000 \times \text{Soil weight}}$$

f- Amount of POC (g kg^{-1}):

The estimation of particulate organic carbon was conducted using the method outlined by Cambardella and Elliot (1992).

1- **Sample preparation:**

10g of a 2mm sieved air-dried soil sample was used for the analysis

2- **Shaking with Sodium Hexa-metaphosphate:**

The soil sample was shaken with 0.5% sodium hexa-metaphosphate in a shaker for 15 hours.

3- **Sieving:**

The soil suspension was passed through a 0.053mm sieve by spraying water from the top of the sieve.

4- **Particulate organic matter separation:**

The solid portion remaining on the sieve after sieving was termed particulate organic matter.

5- Transfer to plastic bottle:

The solid portion, comprised of organic matter and sand particles, was transferred to pre-weighed plastic bottles by washing with a spray of water.

6- Drying:

The plastic bottles with the solid material were placed inside a forced-air oven at 50°C for 3 days for drying and thereafter, the weight of the bottles were recorded.

7- Grinding:

The solid material in the bottles was ground with a pestle and mortar to form a fine powder

8- Calculation:

The organic carbon content is then calculated based on the volume of FAS consumed in the titration. The Walkley and Black (1934) method is a widely used technique for determining total organic carbon in soil samples and provides valuable information about the soil's organic content.

a- Available soil N (kg ha^{-1}):

The estimation of available soil nitrogen using the alkaline potassium permanganate method involves the following steps:

1- **Oxidation of organic matter:**

20g of soil is placed in a distillation flask. Subsequently 20 ml of distilled water (DW) and 100 ml of 0.32% $KMnO_4$ solution are added to the soil.

2- **Preparation of boric acid solution:**

In a 250ml volumetric flask, 20 ml of boric acid and 4-5 drops of a mixed indicator are added to the boric acid solution. The flask is placed below the receiver tube, and the tip of the receiver tube is dipped into a boric acid solution.

3- **Distillation process:**

To the distillation flask containing soil, 100 ml of 0.32% $KMnO_4$ and 100 ml of 2.5% NaOH are added. The distillation flask is connected to the distillation apparatus. The flask is heated, and the free ammonia is released and absorbed in the boric acid solution.

4- **Titration process:**

The burette is filled with 0.02N H_2SO_4 while the boric acid solution is titrated with concentrated H_2SO_4 until a pink color.

5- **Recording readings:**

The initial and final readings on the burette are noted down

$$\text{Available nitrogen} = \frac{R \times 0.2 \times 14 \times 2.24 \times 1.06}{W \times 100}$$

b- Available phosphorus in soil (kg ha^{-1}):

1- The soil phosphorus content was assessed through the utilization of sodium bicarbonate ($NaHCO_3$) at a pH of 8.5 (Olsen's reagent). The quantity of phosphorus present in the extracted solution was determined employing the chloro-stannous reduced phosphomolybdate blue color method, and the analysis was conducted using a spectrophotometer set at 660nm, as outlined by Olsen (1954).

2- 250ml volumetric flask containing 5g of soil, phosphorus-free activated charcoal

(Darco G-60) was introduced using a spoon subsequently; 100ml of a 0.5M $NaHCO_3$ solution was poured into the flask.

3- The flask underwent a shaking process for 25-30 minutes on a mechanical shaker, and the resulting suspension was filtered through Whatman's filter paper. While the 5ml of filtrate was transferred into a 25ml volumetric flask and to this, 5ml of ammonium molybdate was added, and the solution was mixed with distilled water.

4- In a separate 50ml volumetric flask, 1ml of working $SnCl_2$ was combined with distilled water to make up the volume to 25ml, and the mixture was shaken thoroughly.

5- The OD of the blue colour solution was measured using a spectrophotometer at 660nm between 10-20 minutes of adding $SnCl_2$ while a parallel procedure was conducted as a blank, excluding soil sample.

i- Available Potassium in soil (kg ha^{-1}):

1- Soil potassium levels were determined utilizing a flame photometer, following the method described by (Jackson, 1973). In which, 1 N ammonium acetate solution was employed to analyse potassium in the soil.

2- In a 250 ml volumetric flask, 5g of soil was placed, followed by the addition of 25 ml of ammonium acetate solution.

3- The flask underwent hand shaking for 20 minutes and mechanical shaking for an additional 5 minutes.

4- The resulting suspension was then filtered through Whatman's filter No.1 while the Measurements were recorded using a flame photometer to determine the soil's available potassium content.

j- Ammonical form of nitrogen (mg kg^{-1}):

The estimation of ammonical and nitrate forms of nitrogen was carried out according to the procedure given by (Dhyan *et al.*, 2005**).**

Reagents:

Sodium Chloride (10%): dissolved 10 g of NaCl in 100ml of DW

Nessler's reagent:

Dissolve 45.5 and 35 g of HgI_2 and potassium iodide (KI) in a small amount of DW (less than 1 liter) and add 112 g of KOH into them. Mixed well and raised the final volume to 1 liter by DW. Allow standing for at least one day and filter it well in the amber color bottle through filter paper.

Sodium tartrate (10%): dissolve 10 g of sodium tartrate in 100 ml of DW

Procedure

1- Weigh 100 g of soil and place it into the volumetric flask of 500 ml

2- Add 200 ml acidified sodium chloride into them and shake well for 30 for half an hour

3- Place filter paper (Whatman 42) in the buchner funnel and pour the sample into the funnel to filter it in a separate conical flask.

4- Add 25 ml of NaCl into the conical flask and place it again in the funnel to rinse out and collected leachate.

5- Place the in a volumetric flask and maintain a final volume of up to 500 ml followed by pipetting out 50 ml leachate in the separate conical flask and adding 2 ml each of sodium tartrate and acidified NaCl.

6- Incorporate 5 ml of Nessler's reagent into the mixture and adjust the final volume to 100 ml.

7- Gauge the intensity of the samples 25 minutes after incorporating Nessler's reagent, measuring at a wavelength of 410 nm.

8- Prepared a standard cure by using the NH_4Cl to calculate the ammonical form of nitrogen present in the samples.

9- The following formula has been used for the calculation of the ammonical form of nitrogen from the soil sample.

$$\text{Ammonical form Nitrogen} = \frac{\text{R X Volume of extract used}}{\text{Volume of aliquot taken}} \mathbf{X} \frac{100}{100\text{-M}}$$

k- Nitrate form of nitrogen (mg kg^{-1}):

Reagents:

Extraction solution:

20 ml of 0.5 M of copper sulfate solution mixed with 100 ml of 6 % silver sulfate and the final volume was raised to 1 liter by DW.

Procedure:

1- Retrieve a fresh soil sample weighing between 5-10 g and transferred it into a 100 ml conical flask. Introduce 25 ml of the extracting solution (reagent) and agitate the mixture upto 10 minutes.

2- Add 0.2 g of calcium hydroxide to the flask and shake vigorously for 5 minutes. Subsequently, include 0.5 g of $MgCO_3$ and shake the mixture for an additional 5 minutes.

3- Filter it through Whatman no.42 filter paper after allow to stand for 5 minutes.

4- Place 10-15 ml clear filtrate in a 50 ml porcelain and evaporate the contents up to dryness.

5- Add 3ml of phenol disulphonic acid after cooling at room temperature.

6- Introduce 15 ml of distilled water (DW) into the mixture and stir thoroughly using a glass rod. Record the reading using a spectrophotometer.

7- Pipette out 5, 10, 15, 20, and 25 ml from the 10 mg L^{-1} NO_3-N solution into separate porcelain dishes. Additionally, conduct a blank run without any aliquot.

8- The absorbance of the yellow color was recorded through a spectrophotometer and draws the standard curve to calculate the NO_3 form of nitrogen.

The formula for the calculation:

$$\textbf{Nitrate form of N (mg kg}^{-1}\textbf{ of soil)} = \frac{25}{\text{Volume of aliquot (ml)}} \times \frac{1}{\text{Wt. of soil (g)}}$$

3.6.7 Soil enzyme analysis:

a- Dehydrogenase activity in soil sample (µg TPF 24 h^{-1} g^{-1} of soil):

Enzyme dehydrogenase activity in the soil samples was estimated by the procedure given by (Tabatabai, 1983). In which 5g of soil and 1.5ml of distilled water was taken in the test tube.

1- Seal the test tubes with cotton plugs and incubate them at 30°C for 24 hours. After the 24-hour incubation period, transfer the resulting slurry to Whatman filter paper.

2- Extract the triphenyl-formazan (TPF) with concentrated methanol in a 50 ml volumetric flask.

3- Observe the development of a pink color and measure the absorbance of the pink solution using a spectrophotometer at 485 nm. Methanol, without soil, serves as the control.

4- Express the dehydrogenase activity as micrograms of triphenyl-formazan (TPF) per gram of dry soil per 24 hours.

Activity of enzyme Dehydrogenase = C X 50 / W

b- Analysis of acid and alkaline phosphatase activity

1- The method outlined by Tatabai and Bremner (1969) was employed to assess the combined activity of acid and alkaline phosphatase in the soil.

2- Acid phosphatase activity was determined using a solution of p-nitro phenyl phosphate tetra-hydrate at pH 6.5, while alkaline phosphatase was assayed with the same substrate at pH 11.

3- A 1g soil sample was placed in a 100 ml conical flask while 0.25ml toluene, 1ml p-nitro phenyl phosphate, and 4 milliliters of adjusted universal buffer were introduced, with a pH of 6.5 for acid phosphatase and pH 11 for alkaline phosphatase.

4- The flasks were shaken thoroughly for a brief period, then stopped and pour in an incubator at 37 ^{0}C for 1 hour.

5- After the incubation period, the stopper was taken off, and 1 milliliter of 0.5 M $CaCl_2$ and 4 milliliters of 0.5 M NaOH were added.

6- The flask was shaken briefly, and the aliquot was transferred to Whatman number 12 filter paper while the resulting yellow-colored filtrate was utilized for recording readings through a spectrophotometer at a wavelength of 430 nm.

7- In the control group, 1ml p-nitro phenyl phosphate was added after the addition of $CaCl_2$ and NaOH into the mixture, excluding soil, just before filtration.

$$\text{Acid/Alkaline phosphatase } (\mu g \text{ p-NPP } g^{-1} \text{dry soil } h^{-1}) = \frac{C \times 100}{W}$$

3.7 Statistical analysis:

Data obtained from the present piece of work was subjected to statistical analysis where the difference among the mean value was estimated by one-way ANOVA by the use of SPSS software version 23. To find the most significant treatments out of the entire set, DMRT was applied with probability (p 0.05%).

PLATE 1: DEMARCATION AND PLACEMENT OF SEED OVER RESEARCH FIELD [2017-18]

PLATE 2: STAKING AND DEMARCATION OF RESEARCH FIELD [2018-19]

PLATE 3: PREPARATION OF RESEARCH FIELD FOR THE SOWING [2017-18]

PLATE 4: PREPARATION OF RESEARCH FIELD FOR THE SOWING [2018-19]

PLATE 5:PREPARATION OF RIDGES AND FURROW AS PER THE SOWING PLAN[2017-18]

PLATE 6:PREPARATION OF RIDGES AND FURROW AS PER THE SOWING PLAN[2018-19]

PLATE 7: FIELD VIEW AFTER PLACING THE POTATO TUBERS IN TO THE FIELD

PLATE8: FIELD VIEW AT INITIAL GROWTH STAGES OF POTATO CROP [2017-18]

PLATE9: FIELD VIEW AT INITIAL GROWTH STAGES OF POTATO CROP [2018-19]

PLATE10: FIELD VIEW AT TUBER FORMATION STAGE [2017-18]

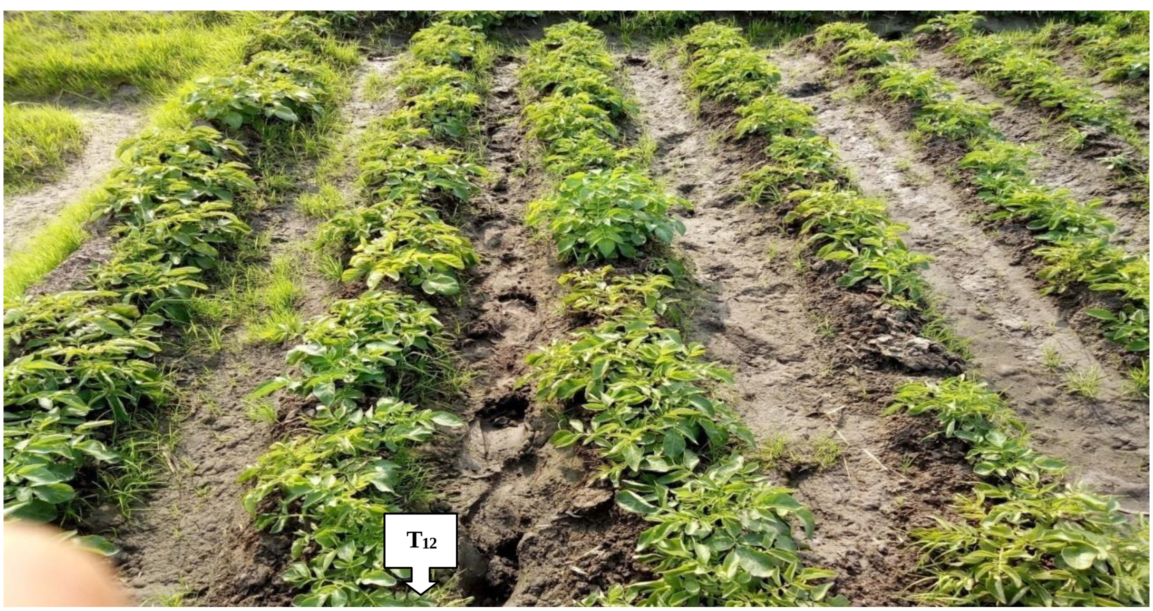


PLATE11: FIELD VIEW AT TUBER FORMATION STAGE [2018-19]

PLATE12: FIELD VIEW OFEARTHINGUPOF SOIL

PLATE13: FIELD VIEW OFTRIAL AT MATURITY STAGE [2017-18]

PLATE14:FIELD VIEW OFTRIAL AT MATURITY STAGE [2018-19]

PLATE15:FIELD VIEW OF TRIAL DURING THE VISIT

PLATE16:FIELD VIEW AT THE TIME HARVESING [2017-18]

PLATE17: FIELD VIEW AT THE TIME OF HARVESING [2018-19]

PLATE18: FIELD VIEW AT THE TIME OF POTATO GRADING [2017-18]

PLATE19: FIELD VIEW AT THE TIME OF POTATO GRADING [2018-19]

CHAPTER-IV

RESULTS AND DISCUSSION

The present research work entitled, '**Effect of bio-char based organic amendments on soil biological and biochemical indicators about increase soil nutrient release potential and yield of potato**' was conducted in the Rabi season of 2017-18 and 2018-19 as part of a field study at the farmer field in the village Kalloh, Mansa (Punjab). It has been attempted to describe the observations made regarding soil nutrient release, soil biological and biochemical indicators, carbon and nitrogen sequestration, soil enzymes, soil nutrient status and soil physical status concerning growth parameters. The findings were assessed with a critical difference of 0.05 between the mean (average) value. Statistical analyses were performed on all results gathered over both years, and the outcomes were systematically organized into tables and figures. The presentation was structured according to the relevant headings corresponding to the statistical findings.

Impact of different treatments on the liberation of soil nutrients

4.1.1 Nitrogen, phosphorus and potassium in the soil

4.2.1 Ammonical and nitrate form of nitrogen

The impact of various treatments on indicators related to soil biology and biochemistry

4.3.1 Soil's organic carbon (OC) and microbial biomass carbon (SMBC).

4.4.1 pH and EC

Influence of various treatments on the sequestration of carbon and nitrogen in soil.

4.5.1 Labile carbon and Particulate organic carbon

Effect of different treatments on soil enzymes

4.6.1 Dehydrogenase activity, phosphatase activity and alkaline phosphatase activity

4.6.2 Influence of treatments on the growth, development, & yield of potato

4.7.1 Emergence percent

4.8.1 Plant height

4.9.1 Dry matter accumulation

4.10.1 Leaf area index (LAI)

4.11.1 Number of haulms

4.12.1 Days to emergence and days to maturity

4.13.1 Number of plant m^{-1} row length and tubers $plant^{-1}$

4.14.1 Average weight of tuber, weight of tuber $plant^{-1}$ and yield q ha^{-1}

4.15.1 Starch content

Impact of different treatments on the liberation of soil nutrients

4.1.1 Nitrogen, phosphorus and potassium in the soil (kg ha^{-1}):

During the period from 2017-2018 to 2018-19, soil sample samples were collected and analyzed to estimate the release of nitrogen P_2O_5 and potassium K_2O kg ha^{-1} from organic amendments based on the use bio-char. The outcome of the research (Table-4.1.1a and b) suggest that using bio-char as an organic amendment to the soil was effective at releasing nutrients into the soil in both years (2017-18) and that it was a positive influence on the soil's nutrients. A significant amount of nitrogen content was found in T_4 (i.e. 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%) which contained 198.99 kg ha^{-1} of nitrogen. This was followed by T_3> T_2> T_{12}> T_{11}> T_{13}> T_8> T_9> T_{10}> T_6> T_5> T_7 as compared with T_1 (Control) which showed the lowest amount of nitrogen with 171.50 kg ha^{-1} being recorded (Fig-4.1.1 a). In terms of nitrogen released into the soil during the 2018-19 growing season, it was recorded as being higher than in the 2017-18 growing season. A similar trend of nitrogen release was noted in 2018-19 in which the absolute amount of nitrogen (N) released was detected in T_4, which was 209 kg ha^{-1}, followed by T_3> T_2> T_{11}> T_{12}> T_{13}> T_9> T_8> T_{10}> T_5> T_7> T_6, whereas the least amount of nitrogen release in T_1 (Control) was found to be 173.5 kg ha^{-1} (Fig-4.1.1 b).

Based on the data displayed in Tables 4.1.1a and 4.1.1b, it is evident that the use of bio-char-based organic amendments releases P_2O_5 into the soil. It is worth mentioning that the highest amount of P_2O_5 release in 2017-18 was recorded in T_3 (25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 30%) 17.4 kg ha^{-1}. Other notable results include T_4> T_2> T_{12}> T_{13}> T_{11}> T_{10}> T_8> T_9> T_5> T_7> T_6, whereas the least amount of P_2O_5 release was quantified in T_1 (control) i.e. 12.0 kg ha^{-1}.

As of 2018-19, the amount of P_2O_5 released in the soil was higher than in 2017-18, while the trends of the treatments were nearly the same as last year. As compared to the control T_1 12.4 kg ha^{-1}, the highest concentration of P_2O_5 in T_4 was 19.8 kg ha^{-1}, followed by T_2, T_{11}, T_{12}, T_{13}, T_8, T_9, T_{10}, T_5, T_7, and T_6 as opposed to the control T_1 12.4 Kg ha^{-1} (Fig-4.1.1b).

In the following table (Table-4.1.1a and b) there is evidence that bio-char-based organic amendments release K_2O into the soil once they are applied. In both years 2017-18 and 2018-19, the level of K_2O in the soil differed substantially from one another when compared to the previous year. T_3 (i.e. 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 30%) was observed to contain a significant amount of K_2O with 255 kg ha^{-1}. As a result, the highest amount of K_2O release was observed in T_1 (control) 232.7 kg ha^{-1} in 2017-18 while the significantly lowest amount of K_2O release was recorded in $T_2 > T_4 > T_{12} > T_{11} > T_{13} > T_6 > T_8 > T_5 > T_9 > T_{10} > T_7$. In contrast to the preceding year, the quantity of released K_2O in the soil exhibited an increase during 2018-19 compared to the levels observed in 2017-18. Moreover, the trend in the efficacy of treatments remained largely consistent with that observed in the previous year. The T_4, which had the biggest amount of K_2O recorded, had a value of 261.0 kg ha^{-1}, followed by $T_4 > T_2 > T_{12} > T_{11} > T_{13} > T_5 > T_8 > T_6 > T_{10} > T_9 > T_7$ as compared to T_1 235.0 kg ha^{-1} (Fig-4.1.1b). Furthermore, the findings from the current study pertaining to the percentage increase or decrease in nitrogen release, as well as the performances of P_2O_5 and K_2O for both years under examination, aligned with the trends observed in the performance of treatments for these parameters. (Table-4.1.1 a and b).

Table 4.1.1a: Release of nitrogen, P_2O_5, and K_2O in kg ha^{-1} in the soil during 2017-18

Treatments	Nitrogen	P2O5	K2O
T_1	171.50 ± 5.5^{a}	12.0 ± 1.1^{a}	232.7 ± 1.5^{a}
T_2	189.00 ± 5.0^{bc} [9.26]	15.1 ± 0.3^{bc} [20.53]	245.3 ± 4.5^{bc} [5.16]
T_3	191.83 ± 2.0^{bc} [10.60]	17.4 ± 0.8^{d} [11.17]	255.0 ± 5.6^{c} [8.76]
T_4	198.33 ± 7.5^{bc} [13.53]	16.5 ± 0.5^{cd} [27.42]	244.0 ± 4.0^{abc} [4.65]
T_5	178.33 ± 10.2^{ab} [3.83]	13.6 ± 0.9^{ab} [11.76]	239.0 ± 2.6^{ab} [2.65]
T_6	179.00 ± 13.2^{ab} [4.19]	13.1 ± 0.2^{ab} [8.40]	239.3 ± 2.9^{ab} [2.79]
T_7	178.20 ± 11.2^{ab} [3.76]	13.4 ± 1.0^{ab} [10.45]	234.7 ± 7.0^{ab} [0.85]
T_8	183.00 ± 9.8^{ab} [6.28]	14.0 ± 2.0^{ab} [14.29]	239.3 ± 8.0^{ab} [2.79]
T_9	182.67 ± 4.0^{ab} [6.11]	13.8 ± 1.3^{ab} [12.83]	238.1 ± 6.2^{ab} [2.28]
T_{10}	179.73 ± 3.2^{ab} [4.58]	14.0 ± 2.0^{ab} [14.29]	237.1 ± 10.4^{ab} [1.87]
T_{11}	186.90 ± 1.7^{bc} [8.24]	14.3 ± 0.6^{b} [15.89]	241.7 ± 9.0^{ab} [3.72]
T_{12}	187.00 ± 3.0^{bc} [8.29]	15.0 ± 0.3^{bc} [20.18]	242.8 ± 1.5^{ab} [4.16]
T_{13}	184.67 ± 8.9^{ab} [7.13]	14.6 ± 0.5^{b} [17.62]	241.0 ± 9.6^{ab} [3.46]
C. D. at	**12.26**	**1.85**	**10.40**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.1.1 b: Release of nitrogen, P_2O_5, and K_2O in kg ha^{-1} in the soil during 2018-19

Treatments	Nitrogen	P2O5	K2O
T_1	173.5 ± 4.5^{a}	12.4 ± 1.3^{a}	235.0 ± 2.0^{a}
T_2	193.0 ± 3.0^{cd} [10.10]	16.5 ± 1.7^{cd} [24.70]	247.7 ± 3.5^{ab} [5.11]
T_3	203.0 ± 3.5^{de} [14.53]	19.8 ± 1.5^{e} [37.27]	261.0 ± 3.6^{c} [9.96]
T_4	209.0 ± 6.6^{e} [16.99]	17.4 ± 2.2^{de} [28.87]	250.0 ± 4.6^{bc} [6.0]
T_5	180.3 ± 9.5^{ab} [3.79]	13.8 ± 1.3^{abc} [10.14]	242.8 ± 2.6^{ab} [3.23]
T_6	180.0 ± 10.0^{ab} [3.61]	13.2 ± 1.7^{ab} [6.1]	241.9 ± 5.6^{ab} [2.84]
T_7	180.2 ± 8.0^{ab} [3.71]	13.6 ± 1.6^{abc} [8.82]	237.3 ± 10.5^{ab} [0.98]
T_8	185.0 ± 6.6^{abc} [6.22]	14.4 ± 1.8^{abcd} [13.69]	242.7 ± 12.0^{ab} [3.16]
T_9	185.5 ± 3.2^{bc} [6.47]	14.2 ± 1.8^{abc} [12.68]	239.4 ± 7.3^{ab} [1.85]
T_{10}	183.4 ± 2.3^{abc} [5.40]	14.1 ± 1.9^{abc} [12.06]	241.4 ± 7.0^{ab} [2.66]
T_{11}	191.3 ± 8.0^{bc} [9.32]	16.2 ± 1.5^{bcd} [23.46]	245.4 ± 4.5^{ab} [4.25]
T_{12}	189.2 ± 2.5^{bc} [8.28]	15.5 ± 1.2^{abcd} [20.17]	246.4 ± 4.7^{ab} [4.64]
T_{13}	186.0 ± 5.3^{bc} [6.72]	15.0 ± 1.2^{abcd} [17.33]	243.7 ± 11.1^{ab} [3.56]
C.D.	**10.9**	**2.7**	**12.04**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Fig-4.1.1 a: Release of nitrogen, P_2O_5, and K_2O in kg ha^{-1} in the soil during 2017-18

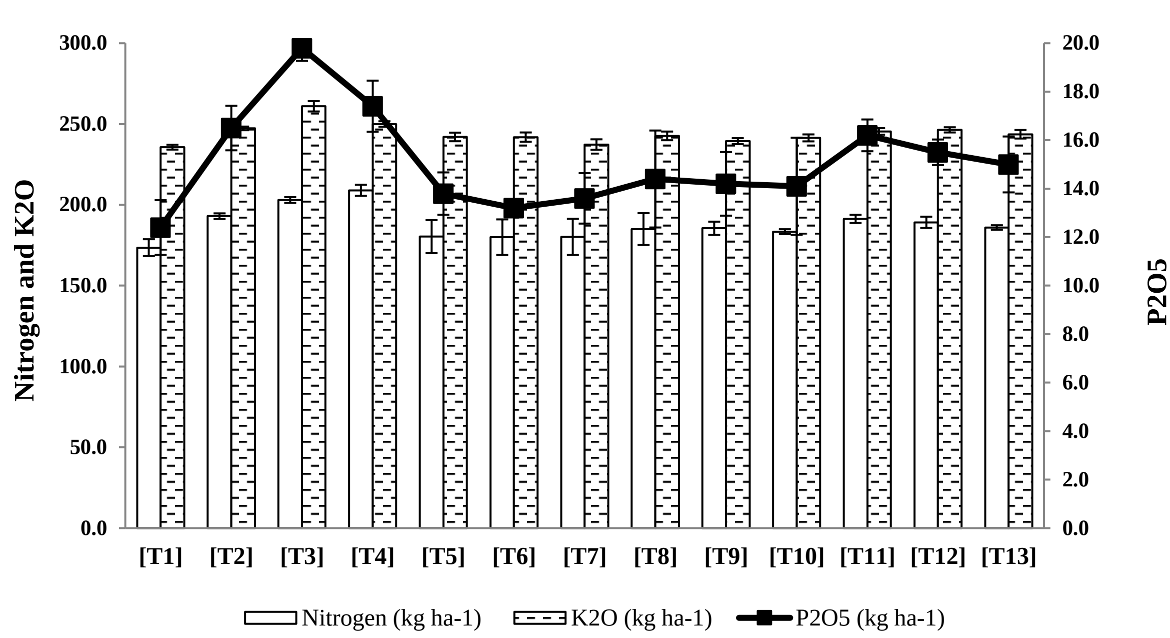
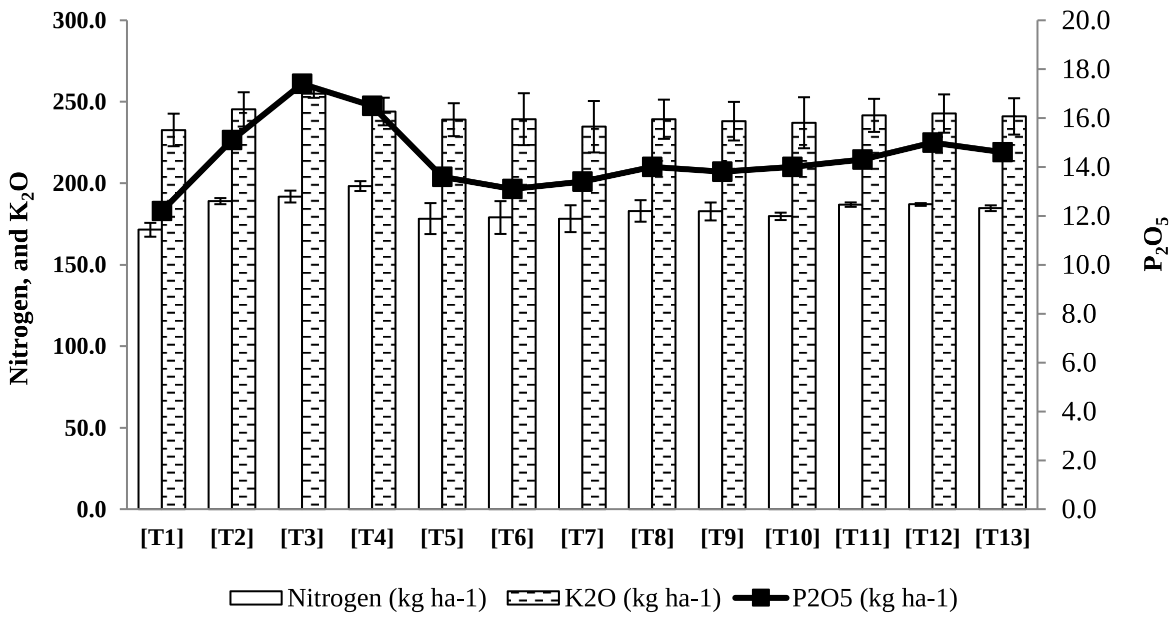


Fig-4.1.1 b: Release of nitrogen, P_2O_5, and K_2O in kg ha^{-1} in the soil during 2018-19



Note: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

4.2.1 Ammonical and nitrate form of nitrogen

The incorporation of organic treatments based on bio-char into the soil resulted in variations in the levels of ammonical and nitrate forms of nitrogen. The outcomes presented in (Table-4.2.1 a & b) no notable disparity in the concentration of ammonia and nitrate in in 2017-18, while both parameters were indicated to have a substantial difference in 2018-19.

As of 2017-18, there were the least amounts of ammonia and nitrate nitrogen detected in T_2 (i.e. 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 20 %) soil samples containing 1.24 and 3.40 mg kg^{-1}, while T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13} were found to have the least amounts of these forms. (Fig-4.2.1 a) compared to T_1 (control) 1.42 and 3.70 mg kg^{-1} soil samples. Compared to the previous year, the performance of the bio-char- based organic amendment in 2018-19 showed a significantly different pattern along with a more significant quantity of the organic amendment compared to the year before. According to the results of our study, the ammonical form of nitrogen was found to be significantly lower in T_2 (i.e. 1.26 and 3.41 mg kg^{-1} of soil) as compared to T_1 (control), which was found to contain the highest levels of the two forms of nitrogen 1.49 and 4.04 mg kg^{-1}.

As a result, it has been found that $T_3 > T_{10} > T_8 > T_7 > T_9 > T_{11} > T_5 > T_6 > T_4 > T_{13} > T_{12}$ work best for the ammonia form of nitrogen in soil while $T_3 > T_6 > T_9 > T_8 > T_5 > T_7 > T_{10} > T_{13} > T_{11} > T_{12} > T_4$ are the most effective for the nitrate form of nitrogen in the soil (Table-4.2.1 b and Fig-4.2.1).

Table-4.2.1 a: Release of Ammonical and Nitrate form of nitrogen (mg kg^{-1} of soil) 2017-18

Treatments	NH_4^+N	NO_3^-N
T_1	1.42±0.043[a]	3.70±0.15[a]
T_2	1.24±0.12[a] [-14.78%]	3.40±0.38[a] [-8.82%]
T_3	1.25±0.13[a] [-13.87%]	3.43±0.23[a] [-7.77%]
T_4	1.26±0.13[a] [-13.26%]	3.46±0.30[a] [-7.04%]
T_5	1.30±0.25[a] [-9.49%]	3.50±0.29[a] [-5.71%]
T_6	1.32±0.19[a] [-7.56%]	3.53±0.19[a] [-4.72%]
T_7	1.33±0.23[a] [-6.75%]	3.56±0.19[a] [-3.93%]
T_8	1.33±0.33[a] [-6.75%]	3.56±0.24[a] [-3.93%]
T_9	1.36±0.18[a] [-4.91%]	3.56±0.26[a] [-3.74%]
T_{10}	1.37±0.23[a] [-4.15%]	3.58±0.16[a] [-3.26%]
T_{11}	1.38±0.31[a] [-2.89%]	3.60±0.21[a] [-2.78%]
T_{12}	1.39±0.20[a] [-2.15%]	3.61±0.11[a] [-2.49%]
T_{13}	1.40±0.20[a] [-1.67%]	3.63±0.07[a] [-1.83%]
C.D.	**NS**	**NS**

Notes:

1. **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.
2. Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.2.1 b: Release of Ammonical and Nitrate form of nitrogen (mg kg^{-1} of soil) 2018-19

Treatments	NH_4^+N	NO_3^-N
T_1	1.49 ± 0.06^{d}	4.04 ± 0.06^{c}
T_2	1.26 ± 0.02^{a} [-18.21%]	3.41 ± 0.15^{a} [-18.69%]
T_3	1.27 ± 0.02^{ab} [-16.94%]	3.48 ± 0.04^{a} [-16.08%]
T_4	1.42 ± 0.03^{cd} [-5.41%]	3.79 ± 0.04^{bc} [-6.68%]
T_5	1.41 ± 0.09^{bcd} [-6.04%]	3.56 ± 0.24^{ab} [-13.47%]
T_6	1.41 ± 0.06^{bcd} [-5.91%]	3.48 ± 0.09^{ab} [-16.08%]
T_7	1.37 ± 0.06^{abcd} [-9.0%]	3.56 ± 0.02^{ab} [-13.58%]
T_8	1.35 ± 0.05^{abc} [-10.29%]	3.52 ± 0.06^{ab} [-14.81%]
T_9	1.39 ± 0.08^{abcd} [-7.59%]	3.51 ± 0.10^{ab} [-15.19%]
T_{10}	1.34 ± 0.05^{abc} [-11.17%]	3.57 ± 0.15^{ab} [-13.36%]
T_{11}	1.40 ± 0.17^{abcd} [-6.92%]	3.61 ± 0.06^{ab} [-12.11%]
T_{12}	1.43 ± 0.04^{cd} [-4.19%]	3.66 ± 0.06^{ab} [-10.57%]
T_{13}	1.42 ± 0.06^{cd} [-5.54%]	3.57 ± 0.03^{ab} [-13.68%]
C.D.	**0.11**	**0.29**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Fig-4.2.1 a: Release of Ammonical and Nitrate form of nitrogen (mg kg^{-1} of soil) 2017-18

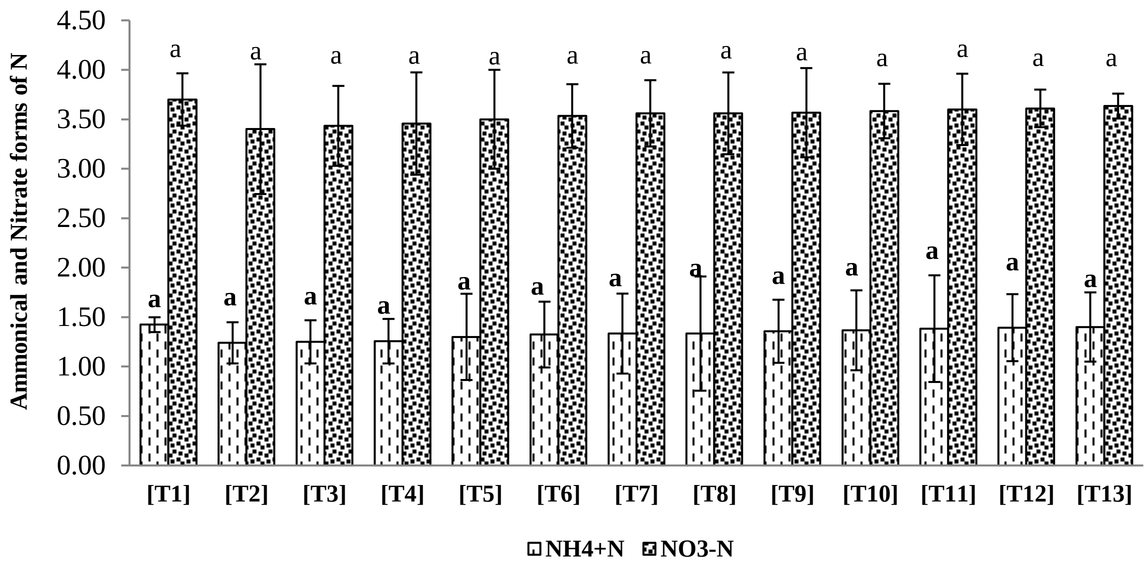
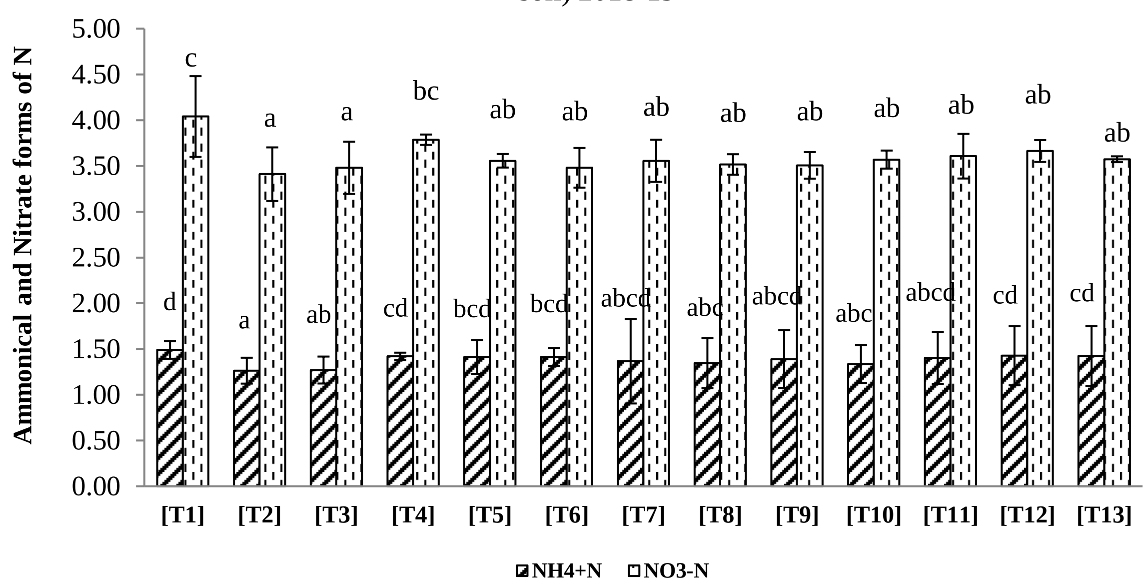


Fig-4.2.1 b: Release of Ammonical and Nitrate form of nitrogen (mg kg^{-1} of soil) 2018-19



Note: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

4.3.1 Soil's organic carbon (OC) and microbial biomass carbon (SMBC).

Considering the results stated in (Table-4.3.1 a and b), there were prominent differences between 2017-18 and 2018-19 regarding the amount of organic carbon (OC) and SMBC (µg g^{-1}) produced by bio-char-based organic amendment. The statistical analysis of the data (OC% and SMBC g g^{-1}) in both years (2017-18 and 2018-19) also revealed that both years' results exhibited high statistical significance at a probability of ($P \leq 0.05$).

There was a substantial variation in organic carbon percentage between T_4 and T_3 in 2017-18 i.e. 25 % recommended dose of fertilizers + 75% (bone meal +vermicompost + poultry manure) + 40% bio-char and 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + 30 % bio-char. The remaining treatments, including control T_1, were found to be 0.44 percent, followed by T_2> T_{11}> T_{13}> T_{12}> T_{10}> T_8> T_5> T_9> T_6> T_7, while the treatment T_{12}, T_{10} and T_8 recorded 0.49 percent, the rate of organic carbon in the composition of T_5 and T_9 of 0.48 percent and the ratio of organic carbon was recorded at 0.44 percent (Table-4.3.1a). This positive impact of bio-char- based organic amendments could also be seen in soil microbial biomass carbon, which recorded 333.83 g g^{-1} as compared to 232.33 g g^{-1} from the control. The highest amounts were recorded in T_4 as compared to the control and followed by T_3>T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 (Fig-4.3.1a). In addition, the percent increase/decrease in organic carbon and soil microbial biomass carbon (g g^{-1}) over control was also justified as the treatment performed well in terms of OC (%) as well as SMBC (µg g^{-1}).

In the entire set of treatments, including the control group, the content of OC % and SMBC µg g^{-1} was recorded to be exceeding the value recorded in 2017-18 in comparison with 2018-19. Both parameters were statistically significant according to the results of 2018-19, and T_4, T_3, T_2, and T_{11} were found to be one of the best treatments out of all for the OC, recording 0.55 and 0.54 percent, despite being considered nonsignificant among them as a result. In comparison to T_1 (control), T_{13}>T_8> T_{10}> T_{12}> T_5> T_6> T_7> T_9 is followed by T_{13}>T_8> T_{10}> T_{12}> T_5> T_6> T_7> T_9. There was also a significant increase in SMBC µg g^{-1} as a result of bio-char base organic amendments using the data presented in (Table-4.3.1b). The T_4 indicated a remarkable rise in the amount of SMBC compared to T_1, with 343.64 g g^{-1} compared to 242.35 g g^{-1} for T_4. On the other hand, the performance trends of the rest of the treatments are noted as T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 while the performance of the treatments is also confirmed by the data percentage increase/decrease over control (Fig-4.3.1b).

Table-4.3.1 a: Release of OC and Soil microbial biomass in 2017-18

Treatments	**Organic carbon (%)**	**SMBC (µg g^{-1})**
T_1	0.44±0.03[a]	232.33±1.01[a]
T_2	0.51±0.02[bc] [+13.16%]	325.33±1.05[i] [+28.59%]
T_3	0.53±0.01[c] [+16.46%]	330.33±1.28[j] [+29.67%]
T_4	0.53±0.01[c] [+16.46%]	333.33±0.88[k] [+30.30%]
T_5	0.48±0.01[ab] [+7.69%]	277.33±0.54[d] [+16.23%]
T_6	0.47±0.01[ab] [+7.04%]	271.33±0.85[b] [+14.37%]
T_7	0.47±0.02[ab] [+5.71%]	274.33±1.01[c] [+15.31%]
T_8	0.49±0.01[abc] [+9.59%]	290.33±1.09[f] [+19.98%]
T_9	0.48±0.01[ab] [+7.69%]	287.33±0.86[e] [+19.14%]
T_{10}	0.49±0.01[abc] [+9.59%]	289.33±0.91[ef] [+19.70%]
T_{11}	0.51±0.02[bc] [+13.73%]	297.33±0.72[h] [+21.86%]
T_{12}	0.49±0.02[abc] [+9.59%]	293.33±0.91[g] [+20.80%]
T_{13}	0.50±0.01[bc] [+11.41%]	294.33±1.17[g] [+21.06%]
C. D.	**0.04**	**0.70**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers +

75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.3.1 b: Release of organic carbon (OC) and Soil microbial biomass in 2018-19

Treatments	**Organic carbon (%)**	**SMBC ($\mu g\ g^{-1}$)**
T_1	0.48^{a}	242.35 ± 1.88^{a}
T_2	0.54^{e} [+10.49%]	335.55 ± 1.36^{i} [+27.78%]
T_3	0.55^{e} [+11.59%]	340.50 ± 1.14^{j} [+28.83%]
T_4	0.55^{e} [+11.59%]	343.64 ± 1.09^{k} [+29.48%]
T_5	0.51^{b} [+5.23%]	287.00 ± 0.84^{d} [+15.56%]
T_6	0.51^{b} [+5.23%]	281.32 ± 0.58^{b} [+13.85%]
T_7	0.51^{b} [+5.84%]	284.76 ± 0.74^{c} [+14.89%]
T_8	0.52^{bc} [+6.45%]	300.37 ± 1.79^{f} [+19.32%]
T_9	0.51^{b} [+5.23%]	297.13 ± 0.60^{e} [+18.44%]
T_{10}	0.52^{cd} [+7.64%]	299.33 ± 0.94^{ef} [+19.04%]
T_{11}	0.54^{e} [+11.04%]	307.89 ± 0.84^{h} [+21.29%]
T_{12}	0.52^{cd} [+7.64%]	303.59 ± 1.79^{g} [+20.17%]
T_{13}	0.53^{d} [+8.81%]	304.73 ± 1.23^{g} [+20.47%]
C.D.	**0.01**	**1.87**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Fig-4.3.1 a: Release of organic carbon (OC%) in 2017-18

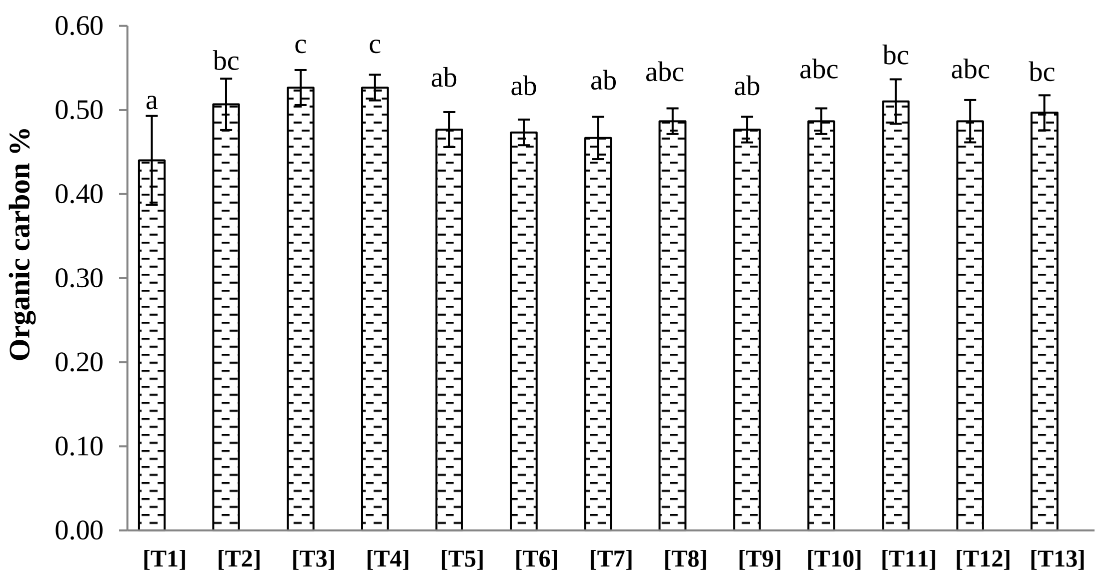


Fig-4.3.1 a: Release of SMBC (µg g-1) in 2017-18

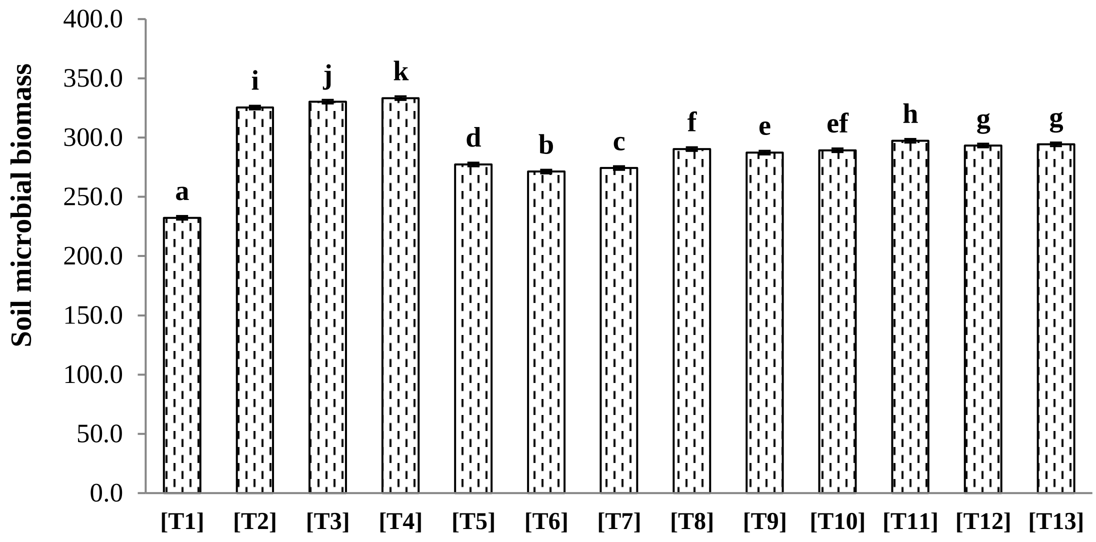


Fig-4.3.1 b: Release of organic carbon (OC%) in 2018-19

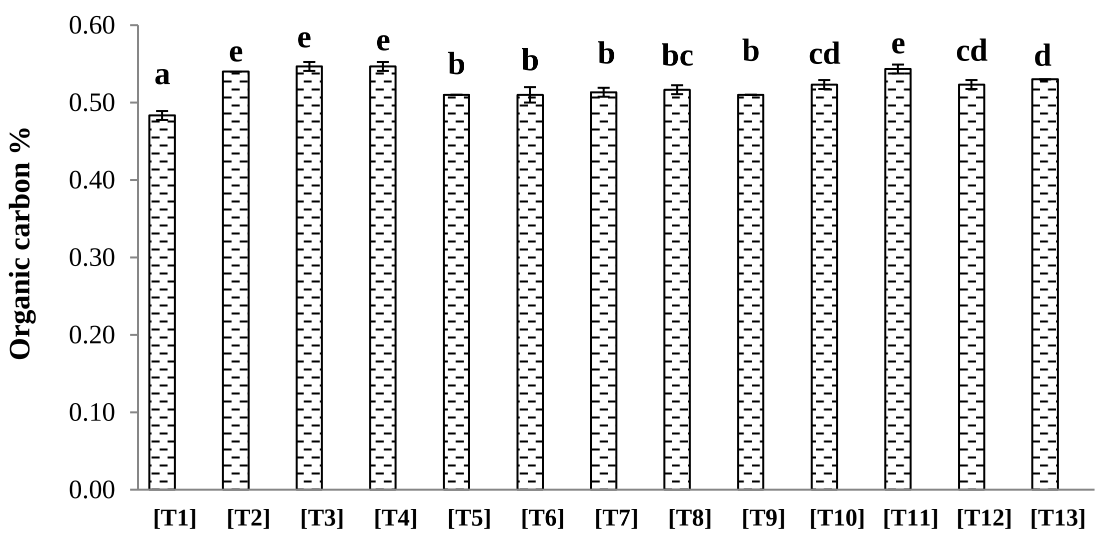
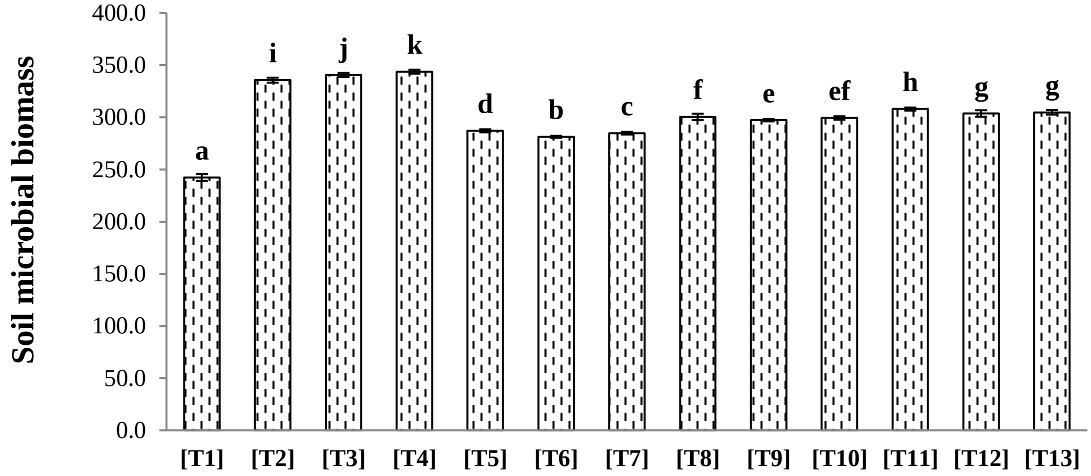


Fig-4.3.1 b: Release of SMBC (µg g^{-1}) in 2018-19



1- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

4.4.1 pH and EC (dSm^{-1}):

There was a significant impact of the bio-char-based organic amendment on pH and EC in the soil in 2017-18 and 2018-19 as shown in (Table-4.4.1 a & b). During both 2017-18 and 2018-19, the statistical analysis of the data for pH and EC indicated the significance of both variables at $P < 0.05$.

In 2017-18, the significantly highest value of pH 7.58 was found in T_4 i.e. 25 % recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + 40% bio-char and 7.56 in T_7 i.e. 50 % recommended dose of fertilizers + 75% poultry manure + 20 % bio-char) compared with the remaining treatments, including control T_1. The pH of T_3, were followed by the pH values of T_6> T_5> T_{12}> T_9> T_8 compared to those of T_2, T_{12}, T_{11} respectively, resulting in a pH value of 7.48. It was also observed that bio-char-based organic amendments had a positive impact on electrical conductivity (EC) and that the highest amounts were recorded in T_4 at 0.39 compared to T_8 at 0.30, followed by T_7> T_{13}> T_{12}> T_6> T_{11}> T_5> T_3> T_2> T_{10}> T_1> T_9 (Fig-4.2.2 a).

Likewise, the data concerning the percentage increase/decrease over control also justified the trends of the performance of the treatment regarding both the parameters pH and electrical conductivity (EC) of the soil in comparison with the control condition.

As a whole, the pH and EC values were significantly higher in 2018-19 compared to 2017-18 in the entire set of treatments that were performed. As a result of the results of the study for 2018-19, it was found that both parameters were statistically significant. A pH level of 7.60 was recorded in treatment T_4, followed by a pH level of 7.58 in treatment T_7 (7.58), 6.55 in treatment T_3, and 7.55 in treatment T_3. The results indicate that T_{13}> T_5> T_{12}> T_{11}> T_2> T_{10}> T_9 showed a higher pH difference than T_8 and T_1 (control), which recorded a pH value of 7.38 in each of their treatments. According to the data shown in (Table-4.4.1 b), there is also a correlation between the impact of bio-char base organic amendments on electrical conductivity (EC). In this study, we found that the amount of EC was significantly higher in T_4 (0.40) than in T_8 (0.30). On the other hand, the performance trends for the rest of the treatments were recorded as T_7>T_{13}> T_{12}> T_{11}> T_6> T_3> T_5> T_2> T_1> T_9, while the data % increase/decrease over control of any of the treatments were also supported by the data % increase/decrease over the control (Fig-4.4.1 b).

Table-4.4.1 a: Influence of organic amendments containing bio-char on soil pH and EC (dSm^{-1}) during 2017-18

Treatments	pH	EC (dSm^{-1})
T_1	7.38 ± 0.11^{a}	0.32^{abc}
T_2	7.48 ± 0.06^{ab} [+1.43%]	0.34^{cde} [+5.83%]
T_3	7.53 ± 0.3^{a} [+2.08%]	0.35^{def} [+8.49%]
T_4	7.58 ± 0.0^{b} [+2.68%]	0.39^{h} [+17.80%]
T_5	7.51 ± 0.0^{ab} [+1.78%]	0.35^{def} [+8.49%]
T_6	7.53 ± 0.03^{b} [+2.08%]	0.36^{efg} [+11.01%]
T_7	7.56 ± 0.03^{a} [+2.38%]	0.38^{gh} [+15.65%]
T_8	7.38 ± 0.10^{a} [+0.0%]	0.30^{a} [-6.59%]
T_9	7.40 ± 0.0^{a} [+0.32%]	0.31^{ab} [-3.19%]
T_{10}	7.43 ± 0.0^{a} [+0.67%]	0.33^{bc} [+3.0%]
T_{11}	7.48 ± 0.0^{ab} [+1.43%]	0.36^{efg} [+11.01%]
T_{12}	7.48 ± 0.0^{ab} [+1.38%]	0.36^{defg} [+10.19%]
T_{13}	7.53 ± 0.0^{ab} [+1.99%]	0.37^{fgh} [+13.39%]
C. D.	**0.092**	**0.021**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.4.1 b: Influence of organic amendments containing bio-char on soil pH and EC (dSm^{-1}) during 2018-19

Treatments	pH	EC (dSm^{-1})
T_1	7.40±0.20^{a}	0.33±0.02^{abc}
T_2	7.50±0.17^{a} [+1.33%]	0.35±0.02^{cde} [+5.77%]
T_3	7.55±0.04^{ab} [+1.99%]	0.36±0.01^{def} [+9.26%]
T_4	7.60±0.11^{b} [+2.67%]	0.40±0.01^{h} [+18.33%]
T_5	7.53±0.06^{a} [+1.77%]	0.36±0.02^{def} [+8.41%]
T_6	7.55±0.04^{ab} [+1.99%]	0.37±0.01^{efg} [+12.50%]
T_7	7.58±0.10^{ab} [+2.42%]	0.39±0.01^{gh} [+15.52%]
T_8	7.40±0.20^{a} [+0.0%]	0.31±0.01^{a} [-4.26%]
T_9	7.42±0.03^{a} [+0.22%]	0.32±0.001^{ab} [-1.03%]
T_{10}	7.45±0.07^{a} [+0.67%]	0.34±0.01^{bcd} [+3.92%]
T_{11}	7.50±0.10^{a} [+1.33%]	0.37±0.01^{efg} [+11.71%]
T_{12}	7.50±0.17^{a} [+1.99%]	0.37±0.01^{defg} [+11.71%]
T_{13}	7.55±0.05^{ab} [+%]	0.38±0.01^{fgh} [+14.04%]
CD	**0.15**	**0.02**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Fig- 4.4.1 a: Influence of organic amendments containing bio-char on soil pH and EC (dSm^{-1}) during 2017-18

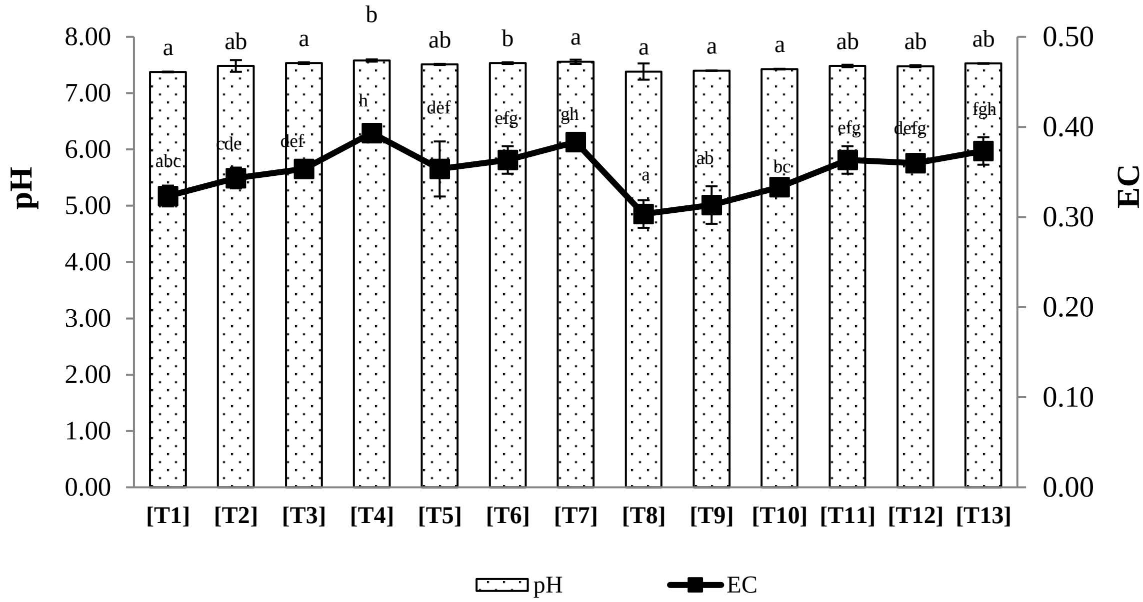
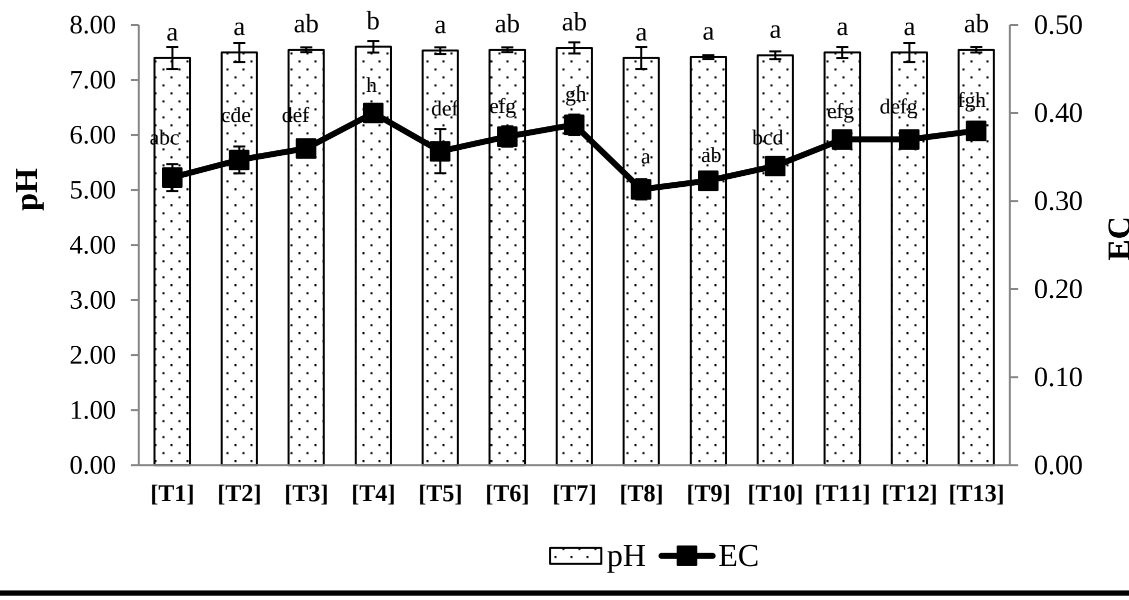


Fig. 4.4.1 b: Influence of organic amendments containing bio-char on soil pH and EC (dSm^{-1}) during 2018-19



Note: Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

4.5.1 Labile carbon/permanganate oxidizable carbon (POXC) and POC (g kg^{-1})

Based on soil samples taken during 2017-18 and 2018-19, it was possible to estimate the influence of treatments with bio-char on the labile carbon and particulate organic carbon (g kg^{-1}) in soil. Statistical analysis revealed that bio-char-based organic amendments have a positive impact on the concentrations of labile carbon in soil (g kg^{-1}) as well as particulate organic carbon concentrations in soil (g kg^{-1}) in both years (2017-18), as observed in (Table-4.5.1a and b). In compared to T_1 (control), in which significantly the lowest amount of labile carbon was recorded at 2.33 (Fig-4.5.1 a). It has been observed that the amount of labile carbon in the soil has increased throughout 2018-19 as compared to 2017-18. In 2018-19, there was evidence indicating the presence of a comparable treatment trend, where the highest amount was recorded in T_4 i.e. 7.17, followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 (Fig- 4.3.1 b).

Data depicted from (Table-4.5.1a and b) reveals the POC (g kg^{-1}) in the tested soil after the use of bio-char-base organic amendment. The significantly highest amount of POC (g kg^{-1}) was recorded in T_4 (i.e. 25 % recommended dose of fertilizer + 75 % (bone meal + vermicompost + poultry manure) + bio-char 40 %) (7.03 g kg^{-1}) which was followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 while the significantly least amount of POC (particulate organic carbon) was recorded in control 3.00 g kg^{-1}in 2017-18. The value of POC in the soil was recorded as a greater amount in 2018-19 as compared to 2017-18 while the trends of the treatments were almost similar to the previous year. The significantly highest amount of particulate organic carbon was recorded in T_4 7.17g kg^{-1} followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as compared to control T_1 3.04 g kg^{-1} (Fig-4.5.1b).

Data related to percentage increase/decrease over control also support the trends of treatments performance on the labile carbon (LC) and particulate organic carbn (POC) in the present study of both years (Table-4.5.1 a and b).

Table-4.5.1 a: Release of labile carbon, and POC in g kg^{-1} in 2017-18

Treatments	Labile Carbon / POXC	Particulate Organic Carbon
T_1	2.33±0.17^{a}	3.00±0.01^{a}
T_2	3.28±0.14^{def} [+29.96%]	6.24±0.12^{j} [+51.87%]
T_3	3.48±0.19^{ef} [+33.11%]	6.58±0.05^{k} [+54.38%]
T_4	3.71±0.15^{f} [+37.14%]	7.03±0.03^{l} [+57.30%]
T_5	2.61±0.20^{ab} [+10.61%]	4.00±0.06^{d} [+24.92%]
T_6	2.49±0.15^{ab} [+6.43%]	3.50±0.0^{b} [+14.19%]
T_7	2.58±0.19^{ab} [+9.69%]	3.72±0.02^{c} [+19.34%]
T_8	2.80±0.15^{abcd} [+16.69%]	4.70±0.01^{f} [+36.05%]
T_9	2.71±0.18^{ab} [+13.92%]	4.33±0.07^{e} [+30.69%]
T_{10}	2.77±0.18^{abc} [+15.78%]	4.67±0.04^{f} [+35.64%]
T_{11}	3.22±0.06^{cde} [+27.71%]	6.02±0.04^{i} [+50.11%]
T_{12}	2.96±0.03^{bcd} [+21.37%]	5.16±0.03^{g} [+41.83%]
T_{13}	3.20±0.02^{cde} [+27.19%]	5.53±0.03^{h} [+45.72%]
C.D.	**0.23**	**0.13**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.5.1 b: Release of labile carbon, and particulate organic carbon (POC) in g kg^{-1} in 2018-19

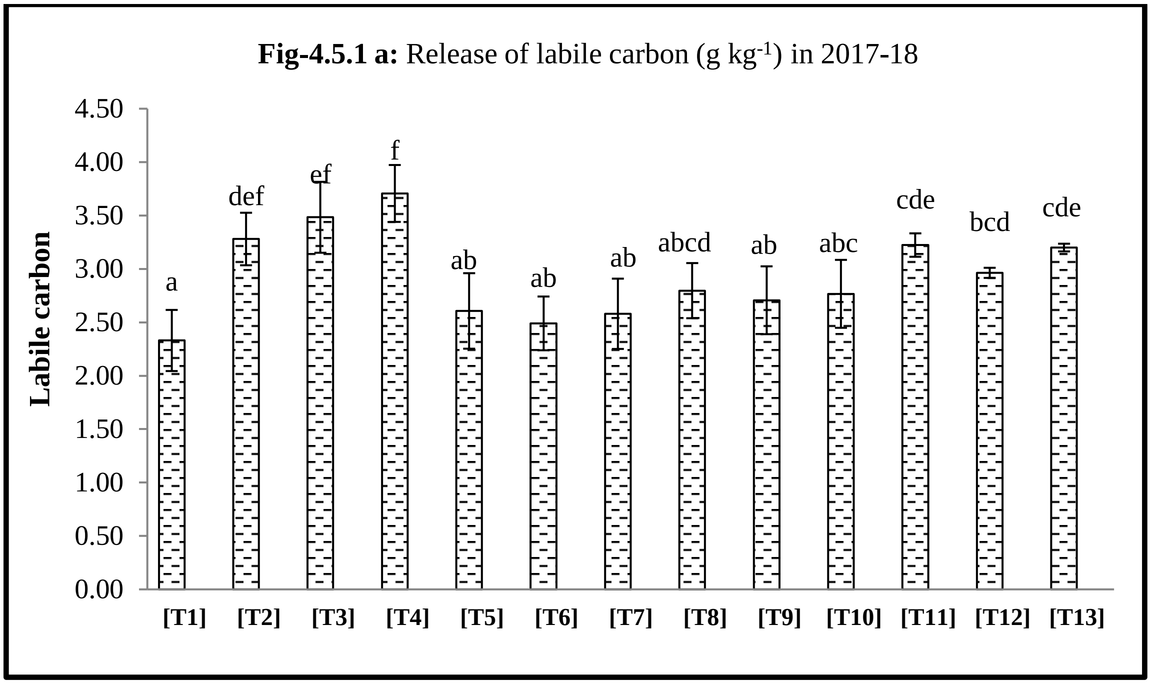
Treatments	Labile Carbon/ (POXC)	Particulate Organic Carbon
T_1	$2.50±0.01^{a}$	$3.04±0.03^{a}$
T_2	$3.48±0.01^{i}$ [+28.19%]	$6.39±0.03^{j}$ [+52.35%]
T_3	$3.69±0.02^{j}$ [+32.34%]	$6.62±0.03^{k}$ [+54.03%]
T_4	$3.90±0.04^{k}$ [+35.93%]	$7.17±0.07^{l}$ [+57.53%]
T_5	$2.82±0.02^{bcd}$ [+11.47%]	$4.08±0.06^{d}$ [+25.41%]
T_6	$2.69±0.02^{b}$ [+7.07%]	$3.68±0.02^{b}$ [+17.23%]
T_7	$2.77±0.01^{bc}$ [+9.98%]	$3.82±0.03^{c}$ [+20.33%]
T_8	$3.00±0.04^{ef}$ [+16.78%]	$4.83±0.04^{c}$ [+36.99%]
T_9	$2.91±0.02^{cde}$ [+14.11%]	$4.46±0.03^{e}$ [+31.76%]
T_{10}	$2.97±0.02^{def}$ [+15.84%]	$4.72±0.02^{f}$ [+35.52%]
T_{11}	$3.31±0.03^{h}$ [+24.57%]	$6.08±0.06^{i}$ [+49.92%]
T_{12}	$3.10±0.2^{fg}$ [+19.38%]	$5.24±0.03^{g}$ [+41.88%]
T_{13}	$3.22±0.04^{gh}$ [+22.38%]	$5.62±0.01^{h}$ [+48.88%]
C.D.	**0.12**	**0.08**

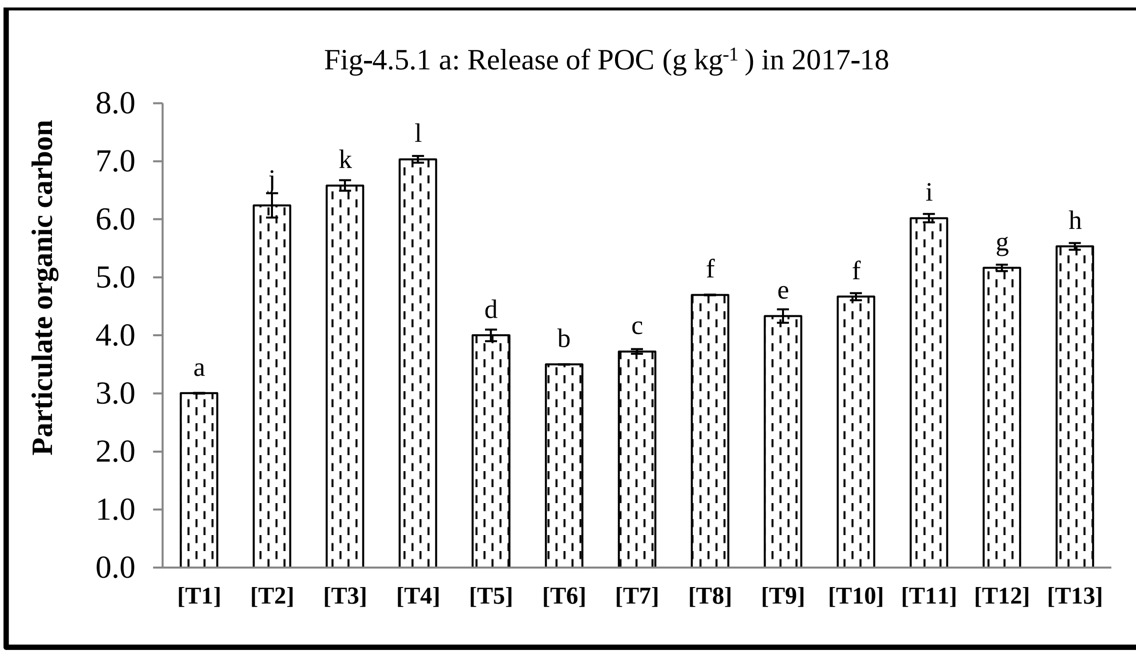
Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).





Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$)

Fig-4.5.1 b: Release of labile carbon (g kg^{-1}) in 2018-19

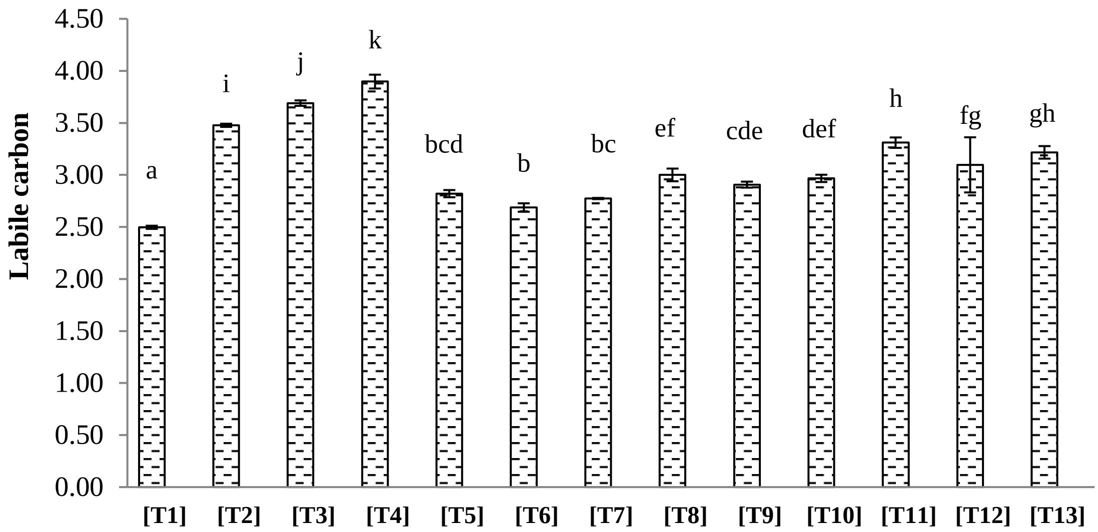
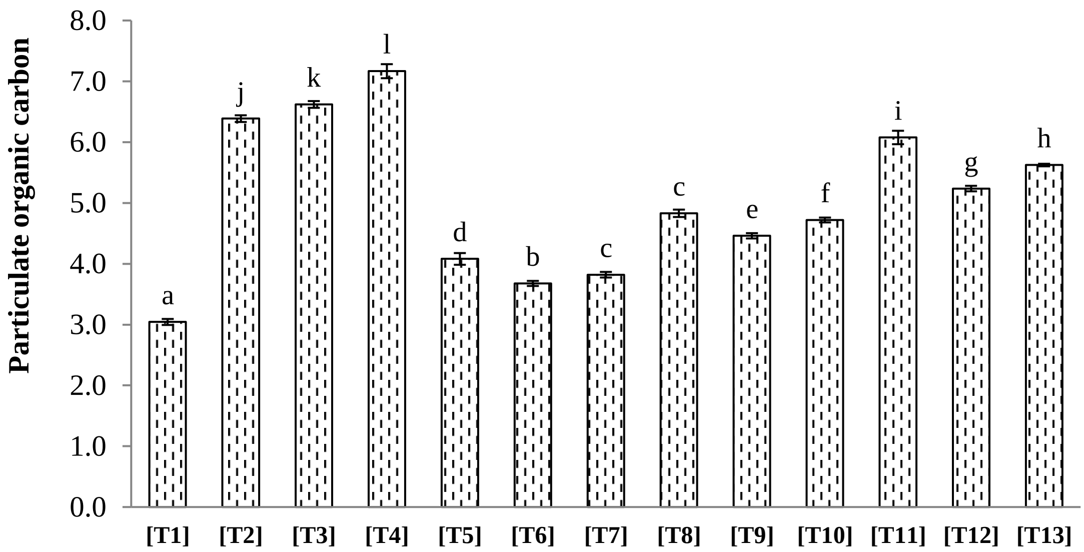


Fig-4.5.1 b: Release of POC (g kg^{-1}) in 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$)

4.6.1 Levels of dehydrogenase, acid and alkaline phosphatase activity

As a result of soil samples taken during 2017-18 and 2018-19, the impact of organic treatments based on bio-char on the activity of dehydrogenase, acid phosphatase, and alkaline phosphatase has been estimated. Based on the results reported in Table-4.6.1 a and b, it is clear that the incorporation of organic treatments to the soil had a positive impact on the dehydrogenase, acid and alkaline phosphatase activity in both years. In the year 2017-18, it has been documented or reported that the highest amount of dehydrogenase activity (g TPF $24h^{-1}$ g^{-1} soil) was recorded in T4 (i.e. 25 % recommended dose of fertilizer + 75% (bone meal + vermicompost) + bio-char 40%). This resulted in 1.97 µg TPF $24h^{-1}$ g^{-1} soil, followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as compared to T_1 (Control) that demonstrated the lowest level of dehydrogenase activity (1.03 µg of TPF $24h^{-1}$ g^{-1} soil) (Fig-4.6.1a). There was an increase in the amount of nitrogen released into the soil in 2018-19 when compared with 2017-18. We observed 2018-19 a similar pattern of dehydrogenase activity which was significantly higher in T4 2.07 µg $24h^{-1}$ g^{-1} soil than in T_3, which had the same amount of dehydrogenase activity. The most dehydrogenase activity was found in T3> T2> T11> T13> T12> T8> T10> T9> T5> T7> T6, while the least amount of dehydrogenase activity was found in T_1 (Control) 1.08 µg of $24h^{-1}$ g^{-1} soil.

The presented data in (Table-4.6.1a and b) reveals a noteworthy rise in acid phosphatase activity in the soil following the application of an organic amendment with a bio-char. The significantly highest amount of acid phosphatase activity was recorded in T_4 (i.e. 25 % recommended dose of fertilizer + 75% (bone meal + vermicompost) + bio-char 40%) 96.00 (µg PNP h^{-1} g^{-1} soil) which was followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 while the significantly lowest amount of acid phosphatase activity release was recorded in control 65.33 µg PNP h^{-1} g^{-1} soil in 2017-18. The amount of acid phosphatase in the soil was recorded as a greater amount in 2018-19 as compared to 2017-18, while the trends of the treatment were almost similar to the previous year. The acid phosphatase level was notably highest in T_4 101 µg PNP h^{-1} g^{-1} soil, and this difference was found to be statistically significant, followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as compared to control 70.00 µg PNP h^{-1} g^{-1} soil (Fig-4.6.1b).

Data presented (Table-4.6.1a and b) reveals alkaline phosphatase activity in the soil after the use of bio-char-base organic amendment. There was a significant disparity in the levels of alkaline phosphatase activity in the soil between the two consecutive years, 2017-18 and 2018-19. A significantly highest amount of alkaline phosphatase activity was recorded in T_4 (25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%) 36.33 µg PNP h^{-1} g^{-1} soil which was followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 while the significantly lowest amount of alkaline phosphatase activity was recorded in control 11.13 µg PNP h^{-1} g^{-1} soil in 2017-18.

The activity of enzyme alkaline phosphatase from soil samples of experimental field was recorded in greater amounts in 2018-19 as compared to 2017-18 while the trend of the performance of the treatment was almost similar to the previous year. The significantly highest amount of alkaline phosphatase activity was recorded in T_4 38.20mgNH^{4+}/g soil/h followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as compared to T_1 13.10 µg PNP h^{-1} g^{-1} soil (Fig-4.6.1b). Data related to % increase/decrease over control also support the trends of treatments performance of the activity the dehydrogenase, acid and alkaline phosphatase in the present study of both the year (Table-4.6.1 a and b).

Table-4.6.1 a: Levels of dehydrogenase (µg TPF 24 h^{-1} g^{-1} soil), acid and alkaline phosphatase (µg PNP h^{-1} g^{-1} soil) during 2017-18

Treatments	Dehydrogenase activity	Acid phosphatase	Alkaline phosphatase
T_1	1.03±0.03[a]	65.33±0.3[a]	11.13±0.13[a]
T_2	1.83±0.03[jk] [+43.45%]	93.33±1.20[i] [+30.0%]	31.80±0.42[h] [+64.99%]
T_3	1.91±0.06[kl] [+45.80%]	94.33±1.20[i] [+30.74%]	33.33±0.88[h] [+66.60%]
T_4	1.97±0.03[l] [+47.46%]	96.00±0.58[i] [+31.94%]	36.33±0.88[i] [+69.36%]
T_5	1.38±0.02[cd] [+25.12%]	74.33±1.45[cd] [+12.11%]	17.33±0.33[c] [+35.77%]
T_6	1.21±0.03[b] [+14.60%]	69.33±1.20[b] [+5.77%]	14.00±0.75[b] [+20.48%]
T_7	1.30±0.0[c] [+20.51%]	72.00±1.16[bc] [+9.26%]	16.00±0.58[c] [+30.42%]
T_8	1.58±0.02[fg] [+34.46%]	83.33±0.67[f] [+21.60%]	23.00±0.58[e] [+51.59%]
T_9	1.44±0.04[de] [+28.07%]	77.00±1.16[d] [+15.15%]	19.33±0.67[d] [+42.41%]
T_{10}	1.51±0.01[ef] [+31.57%]	80.00±0.58[e] [+18.33%]	21.67±0.88[e] [+48.62%]
T_{11}	1.76±0.03[ij] [+41.29%]	90.33±0.33[h] [+27.68%]	29.33±0.67[g] [+62.05%]
T_{12}	1.63±0.02[gh] [+36.73%]	86.33±0.88[g] [+24.32%]	25.40±0.40[f] [+56.17%]
T_{13}	1.68±0.02[hi] [+38.49%]	88.00±1.16[gh] [+25.76%]	27.00±0.58[f] [+58.77%]
C.D.	**0.09**	**2.98**	**1.76**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.6.1 b: Levels of dehydrogenase (µg TPF 24 $h^{-1}g^{-1}$ soil), acid and alkaline phosphatase (µg PNP h^{-1} g^{-1} soil) during 2018-19

Treatments	Dehydrogenase activity	Acid phosphatase	Alkaline Phosphatase
T_1	1.08±0.02^{a}	70.00±0.38^{a}	13.10±0.49^{a}
T_2	1.92±0.05^{j} [+43.48%]	98.00±0.76^{k} [+28.57%]	33.800.76^{i} [+61.24%]
T_3	2.01±0.03^{k} [+46.19%]	99.00±0.55^{k} [+29.29%]	35.00±0.58^{i} [+62.57%]
T_4	2.07±0.07^{k} [+47.75%]	101.00±0.81^{l} [+30.69%]	38.20±0.76^{j} [+65.71%]
T_5	1.48±0.03^{cd} [+26.80%]	79.00±0.98^{d} [+11.39%]	19.00±0.58^{c} [+31.05%]
T_6	1.31±0.02^{b} [+17.51%]	74.00±0.81^{b} [+5.41%]	16.57±0.30^{b} [+20.93%]
T_7	1.40±0.02^{c} [+22.80%]	77.00±1.34^{c} [+9.09%]	18.00±0.58^{bc} [+27.22%]
T_8	1.67±0.02^{fg} [+35.26%]	88.00±0.58^{g} [+20.45%]	25.00±0.58^{e} [+47.60%]
T_9	1.54±0.02^{de} [+29.81%]	82.00±0.17^{e} [+14.63%]	21.93±0.52^{d} [+40.27%]
T_{10}	1.61±0.02^{ef} [+32.57%]	85.00±0.81^{f} [+17.65%]	23.10±0.49^{d} [+43.29%]
T_{11}	1.86±0.02^{ij} [+41.86%]	95.00±0.73^{j} [+26.32%]	31.70±0.30^{h} [+58.68%]
T_{12}	1.73±0.03^{gh} [+37.26%]	91.00±0.61^{h} [+23.08%]	27.40±0.83^{f} [+52.19%]
T_{13}	1.78±0.03^{hi} [+39.02%]	93.00±0.81^{i} [+24.73%]	29.50±0.64^{g} [+55.59%]
C.D.	**0.06**	**0.90**	**0.68**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Fig-4.6.1 a: Impact of organic amendmnets containing bio-char on the activity of dehydrogenase (µg TPF 24 $h^{-1}g^{-1}$ soil) 2017-18

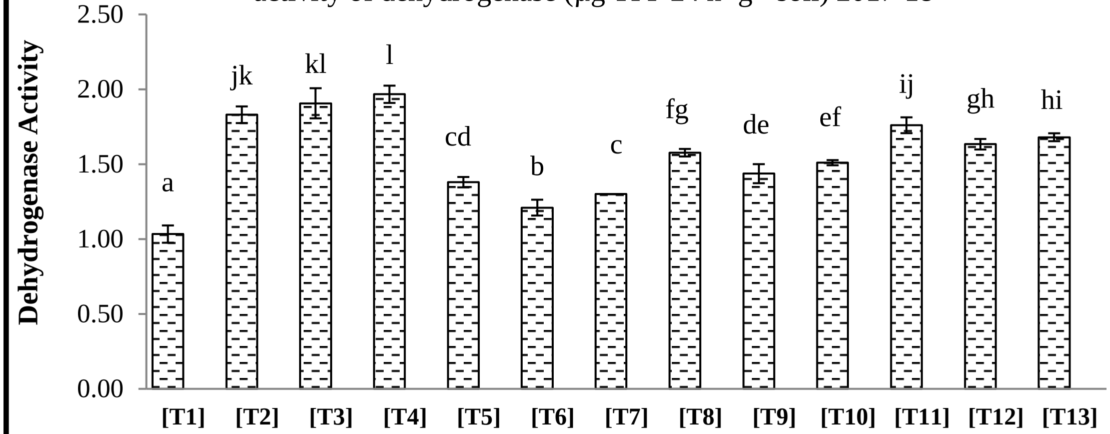


Fig-4.6.1 a: Impact of organic amendmnets containing bio-char on the acid phosphatase (µg PNP h^{-1} g^{-1} soil) 2017-18

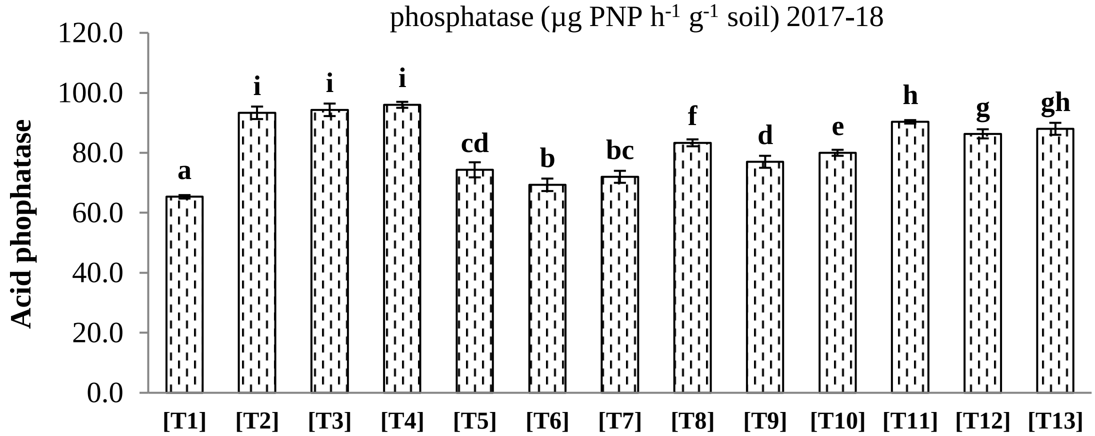


Fig-4.6.1 a: Impact of organic amendmnets containing bio-char on the alkaline phosphatase (µg PNP $h^{-1}g^{-1}$ soil) 2017-18

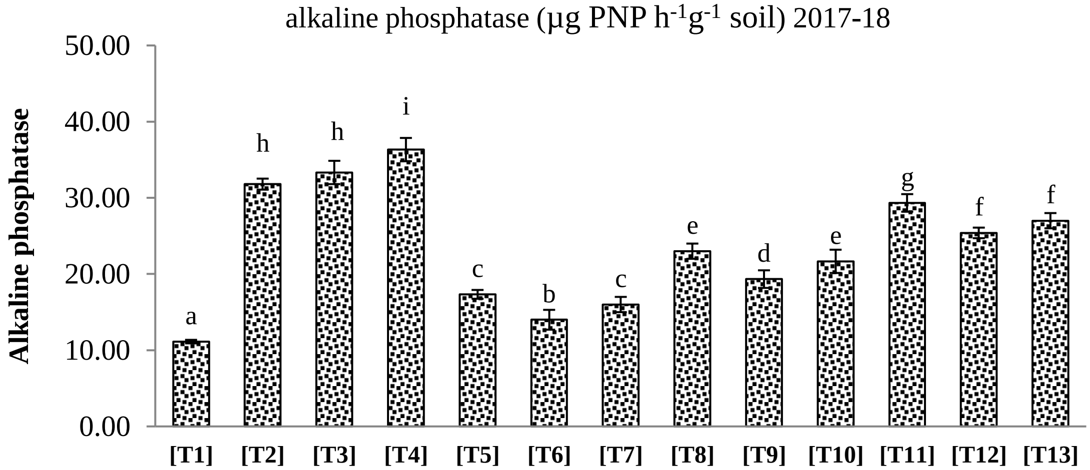


Fig-4.6.1 b: Impact of organic amendmnets containing bio-char on the activity of dehydrogenase (µg TPF 24 h^{-1} g^{-1} soil)) 2018-19

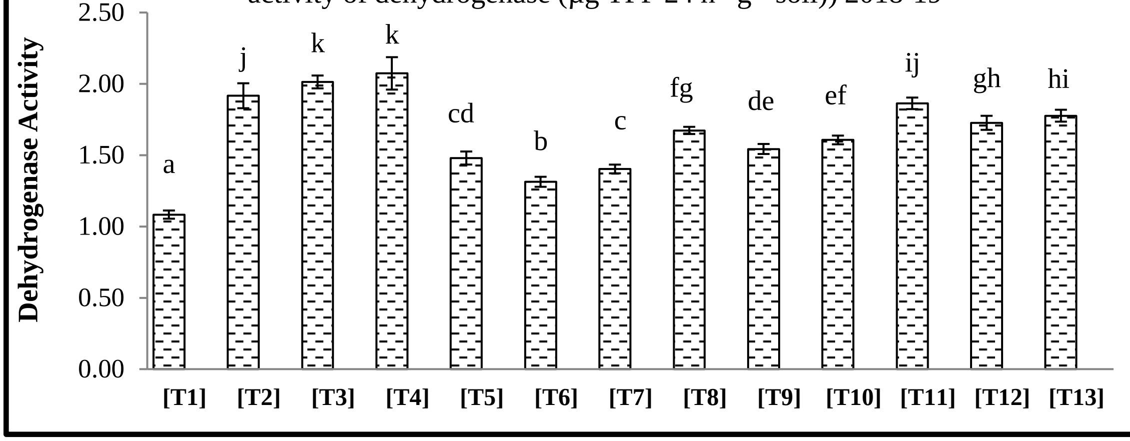


Fig-4.6.1 b: Impact of organic amendmnets containing bio-char on the acid phosphatase (PNPµg h^{-1} g^{-1} soil) 2018-19

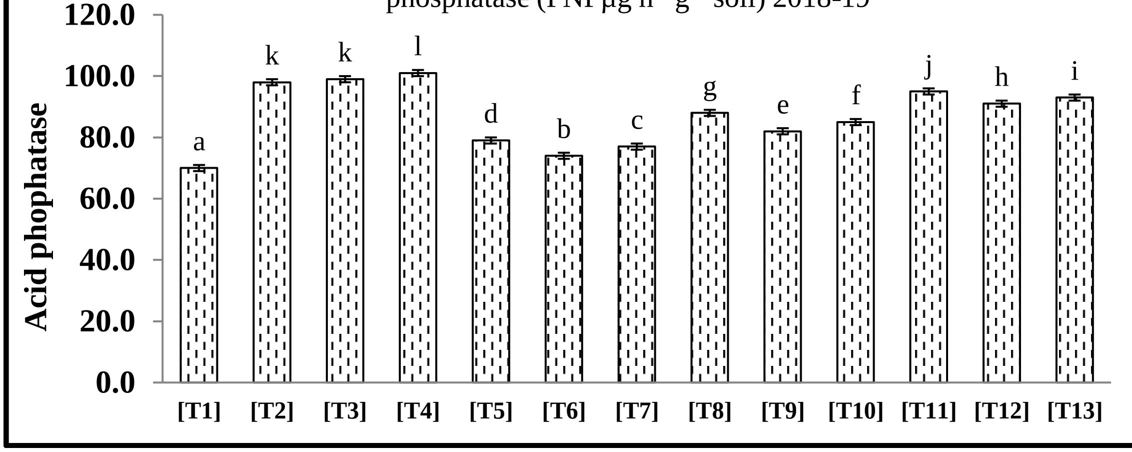
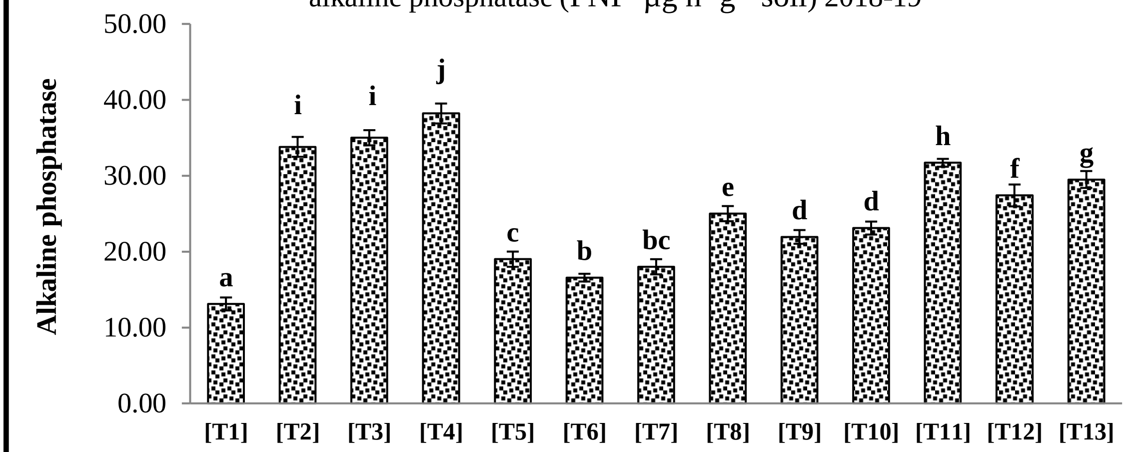


Fig-4.6.1 b: Impact of organic amendmnets containing bio-char on the alkaline phosphatase (PNP µg $h^{-1}g^{-1}$ soil) 2018-19



4.7.1 Emergence percent (%):

A variation in the emergence percentage was also observed when the potato tubers were treated with a bio-char-based organic amendment. The findings from (Table-4.7.1 a & b) suggested a lack of significant difference among the treatments concerning emergence (%) in 2017-18. However, this parameter exhibited a highly significant difference ($p<0.05$) in 2018-19, as illustrated by the graphs. The highest emergence (%) was observed in the treatment T_4 (i.e. 25 % recommended dose of fertilizers + 75 % (bone meal + vermicompost + poultry manure) + bio-char 40%) 96.83 (%) in potato tubers among all the treatments, however, these results were not significant (Fig-4.7.1 a).

Relative to preceding years, the performance of the bio-char-based organic amendment in 2018-19 showed a significant change in pattern and quantity in comparison to that of the previous year.

This study found that T_6 (25% recommended dose of fertilizers + 75% vermicompost + bio-char 20%) had the lowest emergence rate (%) in tubers, whereas T_4 (25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%) had the highest emergence rate (%) in tubers, 98.67 (%). The performance of the rest treatments was determined as follows: T_3> T_2> T_{13}> T_7> T_1> T_{10}> T_{12}> T_6> T_9> T_{11}> T_5 (Presented in table-4.7.1 b and Fig. 4.7.1 b).

Table 4.7.1 a: Impact of bio-char based organic amendments on emergence (%) in Potato (*Solanum tuberosum*) 2017-18

Treatments	**Emergence %**
T_1	96.0±0.58[a]
T_2	96.13±1.33[a] [+0.14%]
T_3	96.50±0.99[a] [+0.52%]
T_4	96.83±0.32[a] [+0.86%]
T_5	94.93±1.23[a] [-1.12%]
T_6	95.20±1.18[a] [-0.84%]
T_7	96.0±0.95[a] [0.0]
T_8	95.0±0.87[a] [-1.05%]
T_9	95.13±0.90[a] [-0.91%]
T_{10}	95.73±0.86[a] [-0.28%]
T_{11}	95.0±0.95[a] [-1.05%]
T_{12}	95.60±0.83[a] [-0.42%]
T_{13}	96.03±0.74[a] [+0.03%]
C.D.	**NS**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets

denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table 4.7.1 b: Impact of bio-char based organic amendments on emergence (%) in Potato (*Solanum tuberosum*) 2018-19

Treatments	Emergence %
T_1	96.03±0.29[ab]
T_2	96.80±0.61[abc] [+0.80%]
T_3	96.60±0.90[abc] [+0.59%]
T_4	98.67±0.14[d] [+2.68%]
T_5	96.63±0.61[abc] [+0.62%]
T_6	95.43±0.39[a] [-0.63%]
T_7	96.40±0.51[abc] [+0.38%]
T_8	96.0±0.72[ab] [-0.03%]
T_9	95.67±0.67[a] [-0.38%]
T_{10}	95.97±0.98[ab] [-0.06%]
T_{11}	96.00±0.31[ab] [-0.03%]
T_{12}	98.10±0.60[cd] [+2.11%]
T_{13}	96.70±0.30[bcd] [+1.71%]
C.D.	**1.73**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.
3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Fig-4.7.1 a: Impact of bio-char based organic amendments on emergence (%) in Potato (*Solanum tuberosum*) 2017-18

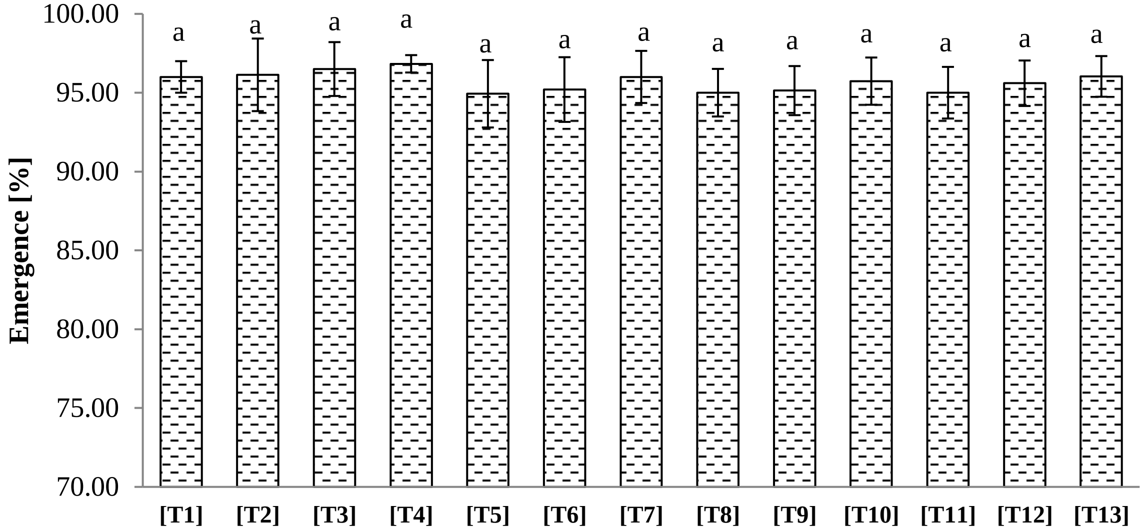
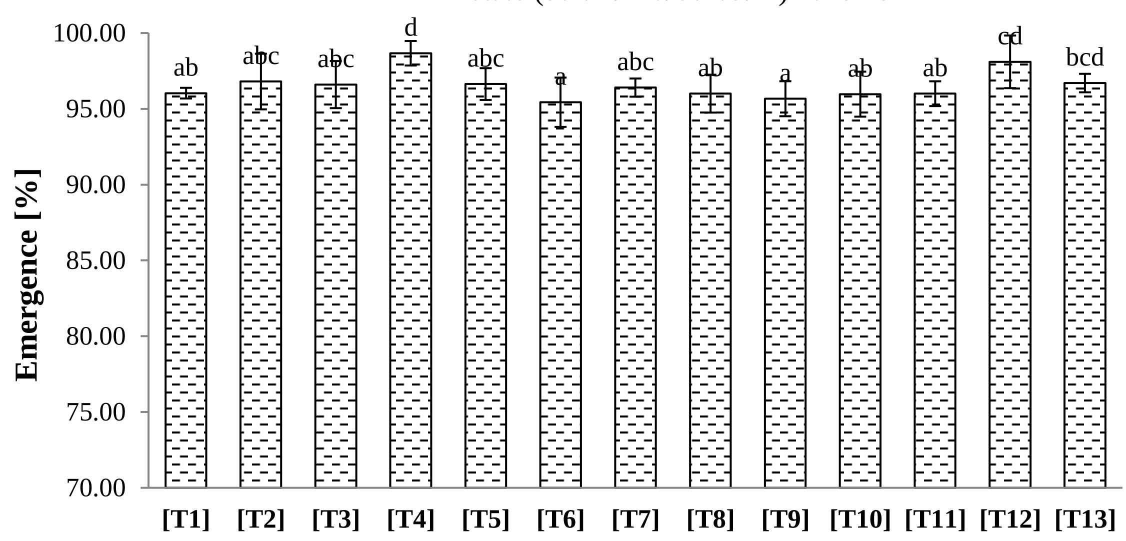


Fig-4.7.1 b: Impact of bio-char based organic amendments on emergence (%) in Potato (*Solanum tuberosum*) 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$)

4.8.1 Plant height (cm):

Research was undertaken to evaluate the potential influence of a bio-char-based organic amendment on potato plant height (cm) at 30 and 60 days after sowing (DAS), as well as at the time of harvest during the years 2017-18 and 2018-19.

During the season of 2017-18, with advancement in the number of days after sowing, a gradual increase has been recorded in the entire sets of treatments along with the control up until the harvest of the crop. The increase in size towards harvest was relatively higher than what it should have been at 30 and 60 DAP (days after planting).

The results showed from the data that T_4 (i.e. 25 % recommended dose of fertilizers + 75 % (bone meal + vermicompost + poultry manure) + bio-char 40%) showed statistically significant differences in all the treatments on the following days after sowing: 27.19, 48.88 and 58.92 cm, followed by T_3 and T_2 i.e. (25 % recommended dose of fertilizers + 75 % (bone meal + vermicompost + poultry manure) + bio-char 30% and 25 % recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 20 %) at 26.20, 47.70, 57.30 and 25.80, 46.42, 56.42cm were compared to T_1 (positive amendment – 100% NPK) 23.0, 40.0 and 49.0 cm that was used as a control set (Fig-4.8.1a).

Compared to 2017-18, the results obtained in 2018-19 showed similar trends in terms of time progression from the day of sowing and treatments as recorded in 2017-18, however, the plant height data demonstrated a statistically significant increase in each treatment with respect to 2017-18. Among the values presented in (Table- 4.8.1 b), it is evident that the significantly highest value of plant height was recorded in T_4 at 27.33, 49.0 and 59.0 cm, which was followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}.

Both in 2017-18 and 208-19, the data about the % increase/decrease over the control showed the same trend and found that the maximum growth occurred in T_4 and then followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10} in respect to the control.

Table-4.8.1 a: Influence of treatments on plant height (cm) in Potato during 2017-18

Treatments	PH at 30 DAS	PH at 60 DAS	PH at Harvest
T_1	23.00±0.50^{a}	40.00±0.52^{a}	49.00±0.16^{a}
T_2	25.80±0.25^{ef} [+10.86%]	46.42±0.73^{g} [+13.82%]	56.42±0.51^{f} [+13.14%]
T_3	26.20±0.16^{fg} [+12.21%]	47.70±0.55^{gh} [+16.14%]	57.53±0.61^{fg} [+14.82%]
T_4	27.19±0.06^{g} [+15.42%]	48.88±0.12^{h} [+18.17%]	58.92±0.61^{g} [+16.83%]
T_5	24.00±0.58^{abc} [+4.17%]	41.96±0.36^{bcd} [+4.67%]	52.00±0.58^{bcd} [+5.76%]
T_6	23.20±0.47^{a} [+0.86%]	41.00±1.0^{ab} [+2.45%]	51.07±0.83^{b} [+4.04%]
T_7	23.42±0.57^{ab} [+1.78%]	41.60±0.89^{abc} [+3.85%]	51.50±0.87^{bc} [+4.85%]
T_8	24.44±0.40^{abcde} [+5.89%]	43.00±0.57^{cdef} [+6.98%]	53.00±0.58^{cde} [+7.54%]
T_9	24.14±0.49^{abcd} [+4.72%]	42.08±0.58^{bcd} [+4.95%]	52.10±0.68^{bcd} [+5.94%]
T_{10}	24.44±0.52^{abcde} [+5.89%]	42.47±0.73^{bcde} [+5.81%]	52.56±0.35^{bcd} [+6.77%]
T_{11}	25.47±0.32^{def} [+9.69%]	44.50±0.26^{f} [+10.11%]	54.60±0.20^{e} [+10.25%]
T_{12}	24.75±0.44^{bcde} [+7.06%]	43.60±0.23^{def} [+8.26%]	53.51±0.36^{de} [+8.43%]
T_{13}	25.00±0.58^{cdef} [+8.0%]	44.30±0.48^{ef} [+9.71%]	54.42±0.42^{e} [+9.95%]
C.D.	**1.07**	**1.77**	**1.64**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.8.1 b: Influence of treatments on plant height (cm) in Potato during 2018-19

Treatments	PH at 30 DAS	PH at 60 DAS	PH at harvest
T_1	23.22±0.38[a]	40.24±0.38[a]	49.24±0.38[a]
T_2	26.11±0.61[efg] [+11.07%]	46.83±0.56[f] [+14.09%]	56.83±0.56[f] [+13.37%]
T_3	26.52±0.16[fg] [+12.44%]	47.91±0.56[fg] [+16.01%]	57.91±0.56[fg] [+14.97%]
T_4	27.33±0.11[g] [+15.04%]	49.00±0.33[g] [+17.88%]	59.00±0.57[g] [+16.55%]
T_5	24.12±0.59[abc] [+3.73%]	42.12±0.52[bc] [+4.46%]	52.12±0.52[bc] [+5.53%]
T_6	23.61±0.62[ab] [+1.65%]	41.23±0.84[ab] [%2.40%]	51.23±0.84[b] [+3.88%]
T_7	23.98±0.90[ab] [+3.17%]	41.77±0.86[ab] [+3.67%]	51.77±0.86[b] [+4.89%]
T_8	24.66±0.58[abcd] [+5.84%]	43.07±0.59[bcd] [+6.58%]	53.07±0.59[bcde] [+7.72%]
T_9	24.32±0.58[abcd] [+4.52%]	42.32±0.58[bc] [+4.92%]	52.32±0.73[bc] [+5.90%]
T_{10}	24.51±0.58[abcd] [+5.26%]	42.80±0.59[bc] [+5.98%]	52.80±0.59[bcd] [+6.74%]
T_{11}	25.62±0.37[def] [+9.37%]	44.90±0.50[e] [+10.39%]	54.90±0.50[e] [+10.32%]
T_{12}	24.92±0.58[bcde] [+6.82%]	43.80±0.26[cde] [+8.13%]	53.80±0.26[cde] [+8.48%]
T_{13}	25.35±0.58[cdef] [+8.40%]	44.67±0.58[de] [+9.92%]	54.67±0.58[de] [+9.94%]
C.D.	**0.72**	**1.62**	**1.65**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets

denote nonsignificant variations, as determined by DMRT (p < 0.05).

Table-4.8.1 a: Influence of treatments on plant height (cm) in Potato (*Solanum tuberosum*) during 2017-18

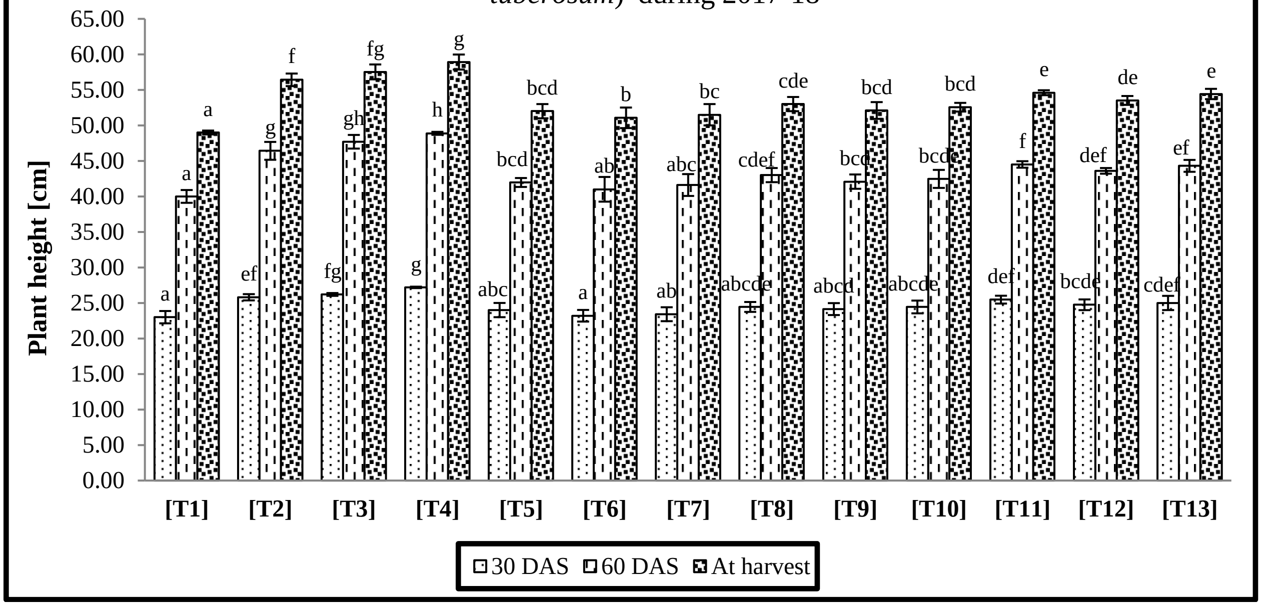
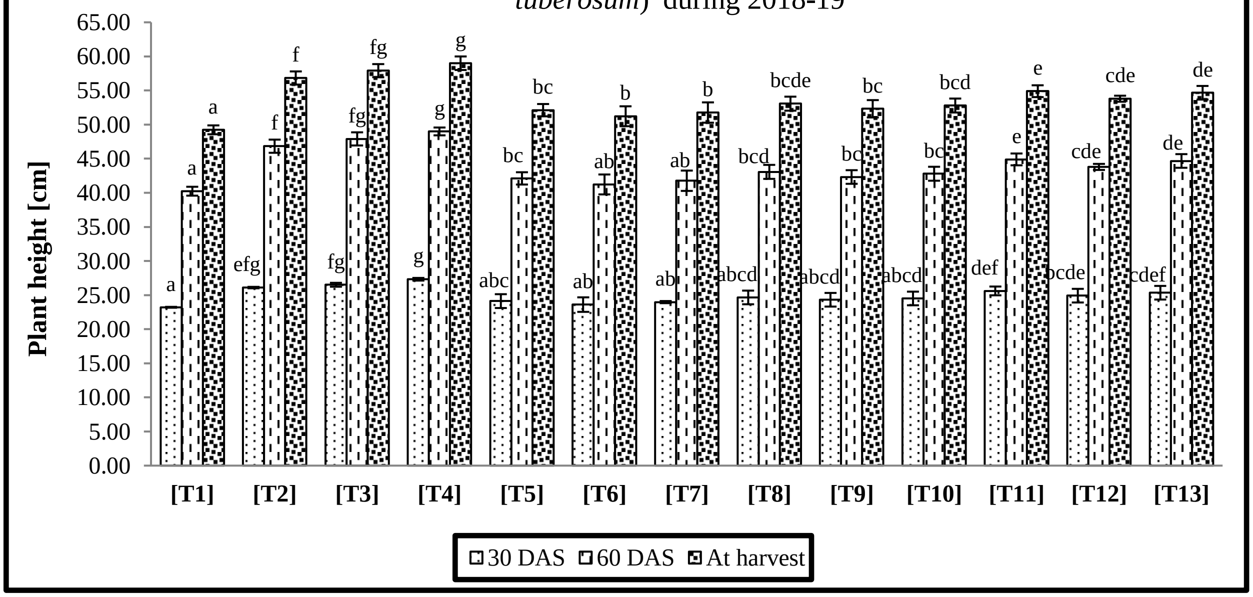


Table-4.8.1 b: Influence of the treatments on plant height (cm) in Potato (*Solanum tuberosum*) during 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p < 0.05)

4.9.1 Dry matter accumulation (%)

The effect of organic based treatments on the percentage of dry matter accumulation in potatoes was found to be statistically significant during both the 2017-18 and 2018-19 periods. It was recorded from the data, that T_4 (25% recommended dose of fertilizers + 75 % (bone meal + vermicompost + poultry manure) + bio-char 40%) recorded considerably highiest dry matter accumulation (18.20 %) compared to the remaining treatments following this by T_3 and T_{11} (i.e. 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 30% and 25 % recommended dose of fertilizers + 75% bone meal + bio-char 40 %) 18.07 % and 18.07 % as compared to T_1 (positive amendments – 100% NPK) 15.07 % which was treated as a control set (Table-4.9.1 a and Fig-4.9.1 a).

Results obtained in 2018-19, also showed significant dry matter accumulation (%) as recorded in 2017-18 but the dry matter accumulation was recorded significantly ($p<0.05$) higher in each treatment as compared to 2017-18. It was depicted (Table- 4.9.1 b and Fig-4.9.1 b), that the significantly highest value of dry matter accumulation (%) was recorded in T_4 18.52 % which was followed by $T_3 > T_2 > T_{11} > T_{13} > T_{12} > T_8 > T_{10} > T_5 > T_9 > T_7 > T_6$ and lowest was observed in control treatment 16.53 %.

The information depicted in Figures 4.9.1a and b, which illustrates the % increase/decrease over the control, provides additional support for the observed accumulation of dry matter in both the years 2017-18 and 2018-19.

Table-4.9.1 a: Impact of organic amendments based on bio-char on dry matter accumulation (%) in Potato during 2017-18

Treatments	Dry matter accumulation (%)
T_1	15.97±0.18[a]
T_2	18.04±0.29[de] [+11.49%]
T_3	18.07±0.09[de] [+11.96%]
T_4	18.20±0.42[e] [+12.27%]
T_5	17.25±0.12[bcd] [+7.58%]
T_6	17.00±0.08[b] [+6.08%]
T_7	17.14±0.16[bc] [+6.83%]
T_8	17.67±0.43[bcde] [+9.66%]
T_9	17.27±0.37[bcd] [+7.53%]
T_{10}	17.50±0.26[bcde] [+8.76%]
T_{11}	18.07±0.34[de] [+11.64%]
T_{12}	17.86±0.17[bcde] [+10.61%]
T_{13}	17.95±.13[cde] [+11.05%]
C.D.	**0.77**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets

denote nonsignificant variations, as determined by DMRT ($p < 0.05$).

Table-4.9.1 b: Impact of organic amendments based on bio-char on dry matter accumulation (%) in Potato during 2018-19

Treatments	Dry matter accumulation (%)
T_1	16.53±0.28[a]
T_2	18.34±0.37[ef] [+9.83%]
T_3	18.44±0.33[fg] [+10.32%]
T_4	18.52±0.46[g] [+10.74%]
T_5	17.44±0.16[abc] [+5.22%]
T_6	17.13±0.15[a] [+3.46%]
T_7	17.23±.14[ab] [+4.02%]
T_8	17.87±0.27[abcde] [+7.48%]
T_9	17.40±0.31[abcd] [+4.97%]
T_{10}	17.70±0.33[abcde] [+6.59%]
T_{11}	18.16±0.42[def] [+8.96%]
T_{12}	18.00±.26[bcde] [+8.15%]
T_{13}	18.06±0.24[cdef] [+8.45%]
C.D.	**0.86**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Fig-4.9.1 a: Impact of organic amendments based on bio-char on dry matter accumulation (%) in Potato (*Solanum tuberosum*) during 2017-18

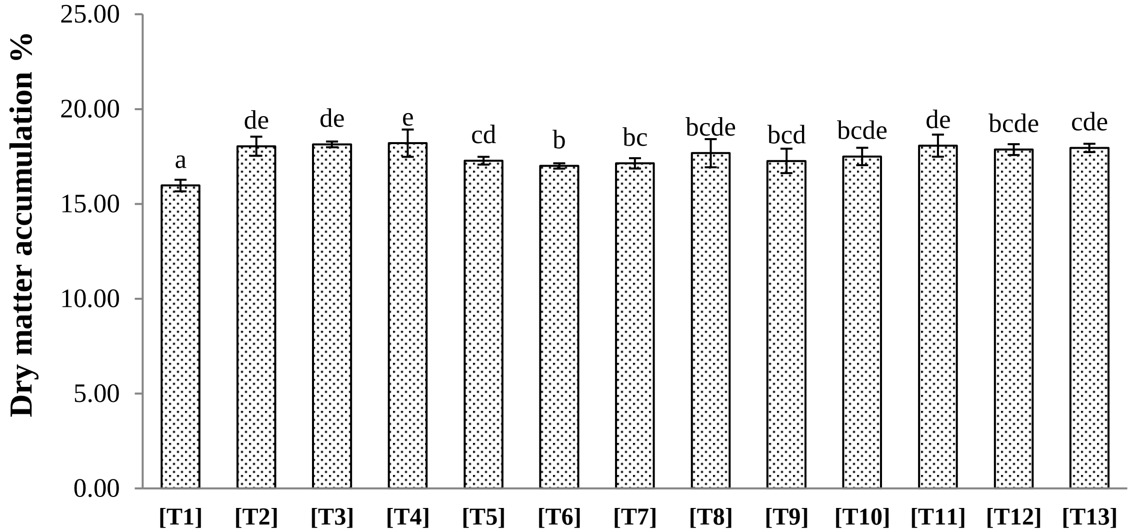
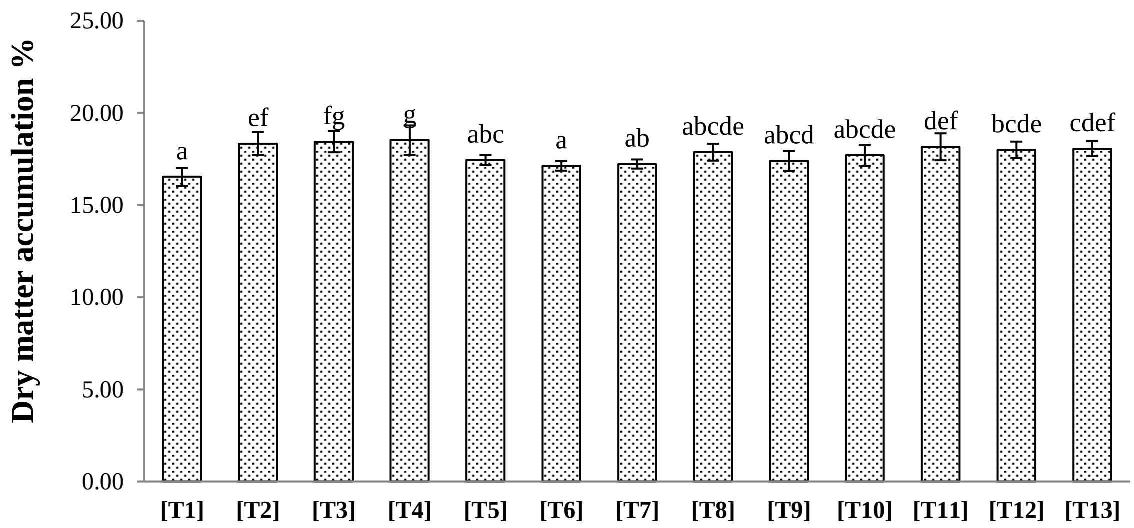


Fig-4.9.1 b: Impact of organic amendments based on bio-char on dry matter accumulation (%) in Potato (*Solanum tuberosum*) during 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05)

4.10.1 Leaf area index (LAI):

The introduction of bio-char-based organic amendments to potato leaves during both 2017-18 and 2018-19 has been noted in a greater capacity to increase the leaf area index (LAI) during the 30 days following sowing.

During the growing season of 2017-18, with the advancement in days after sowing, the gradual increase was recorded up to the harvest of the crop for all the sets of treatments, including the control. In comparison with 30 DAS, the increment at harvest was relatively higher. From the data, it was found that T_4 (25% recommended dose of fertilizers + 75% (bone meals + vermicompost + poultry manure) + bio-char 40%) showed a significantly higher LAI in both parameters as compared to the remaining of the treatments 2.54 and 3.00, which was followed by T_3 and T_2 i.e. 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 30% and 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 20%) 2.33, 2.64 and 2.30, 2.60 when compared to the control set (positive amendments – 100% NPK) 1.60 and 2.00.

The table and figure depicted in Figure 4.10.1b and Table-4.10.1b illustrate that the leaf area index reached the highest significant values in T_4 at 2.64 and 3.04 which was followed by $T_3 > T_2 > T_{11} > T_{13} > T_{12} > T_8 > T_7$.

During 2018-19, there were consistent trends observed in both days after sowing and treatments. Notably, the Leaf area index (LAI) data for each treatment exhibited a significant increase ($p<0.05$) compared to the values recorded in 2017-18.

There is also evidence that the leaf area index gradually increased in 2017-18 as well as in 2018-19. The data showing a % increase/decrease in the leaf area index also shows a gradual increase in leaf area index in both years 2017-18 and 2018-19, with maximum growth seen in T_4 followed by $T_{11}> T_{13}> T_{12}> T_8$ as the main growth zones.

Table-4.10.1 a: Impact of bio-char based organic amendments on LAI in Potato (*Solanum tuberosum*) during 2017-18

Treatments	LAI at 30 DAS	LAI at harvest
T_1	1.60±0.10[a]	2.00±0.06[a]
T_2	2.30±0.05[e] [+30.33%]	2.60±0.15[f] [+23.08%]
T_3	2.33±0.03[e] [+31.43%]	2.64±0.01[g] [+24.15%]
T_4	2.54±0.03[f] [+37.09%]	3.00±0.01[ab] [+33.41%]
T_5	1.74±0.03[ab] [+8.22%]	2.14±0.03[ab] [+6.69%]
T_6	1.70±0.06[a] [+5.88%]	2.10±0.06[ab] [+4.76%]
T_7	1.78±0.03[ab] [+9.94%]	2.15±0.05[ab] [+7.12%]
T_8	1.94±0.01[bcd] [+17.53%]	2.30±0.06[bcd] [+13.17%]
T_9	1.80±0.06[abc] [+11.11%]	2.24±0.07[bc] [+10.85%]
T_{10}	1.82±0.06[abc] [+11.93%]	2.26±0.07[bc] [+11.63%]
T_{11}	2.22±0.06[e] [+27.82%]	2.60±0.08[ef] [+23.18%]
T_{12}	2.00±0.15[cd] [+20.0%]	2.40±0.10[cde] [+16.67%]
T_{13}	2.12±0.08[de] [+24.53%]	2.50±0.06[def] [+20.0%]
C.D.	**0.18**	**0.20**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets

denote nonsignificant variations, as determined by DMRT (p 0.05).

Table-4.10.1 b: Impact of bio-char based organic amendments on LAI in Potato (*Solanum tuberosum*) during 2018-19

Treatments	LAI at 30 DAS	LAI at harvest
T_1	1.76±0.06[a]	2.16±0.09[a]
T_2	2.41±0.06[e] [+26.97%]	2.81±0.07[d] [+23.34%]
T_3	2.43±0.06[e] [+25.57%]	2.83±0.05[d] [+23.79%]
T_4	2.64±0.06[f] [+33.33%]	3.04±0.03[e] [+29.06%]
T_5	1.84±0.06[ab] [+4.35%]	2.24±0.06[a] [+3.72%]
T_6	1.77±0.06[a] [+0.56%]	2.170.06[a] [+0.46%]
T_7	1.80±0.06[a] [+2.22%]	2.200.07[a] [+1.97%]
T_8	1.97±0.01[bc] [+10.81%]	2.37±0.05[ab] [+8.87%]
T_9	1.85±0.02[ab] [+4.86%]	2.25±0.07[ab] [+4.15%]
T_{10}	1.88±0.06[ab] [+6.38%]	2.280.06[ab] [+5.27%]
T_{11}	2.28±0.06[de] [+22.81%]	2.68±0.09[d] [+19.43%]
T_{12}	2.06±0.01[c] [+14.56%]	2.46±0.09[bc] [+12.21%]
T_{13}	2.23±0.06[d] [+21.08%]	2.63±0.06[cd] [+18.10%]
C.D.	**0.15**	**0.18**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Fig-4.10.1 a: Impact of bio-char based organic amendments on LAI in Potato (*Solanum tuberosum*) during 2017-18

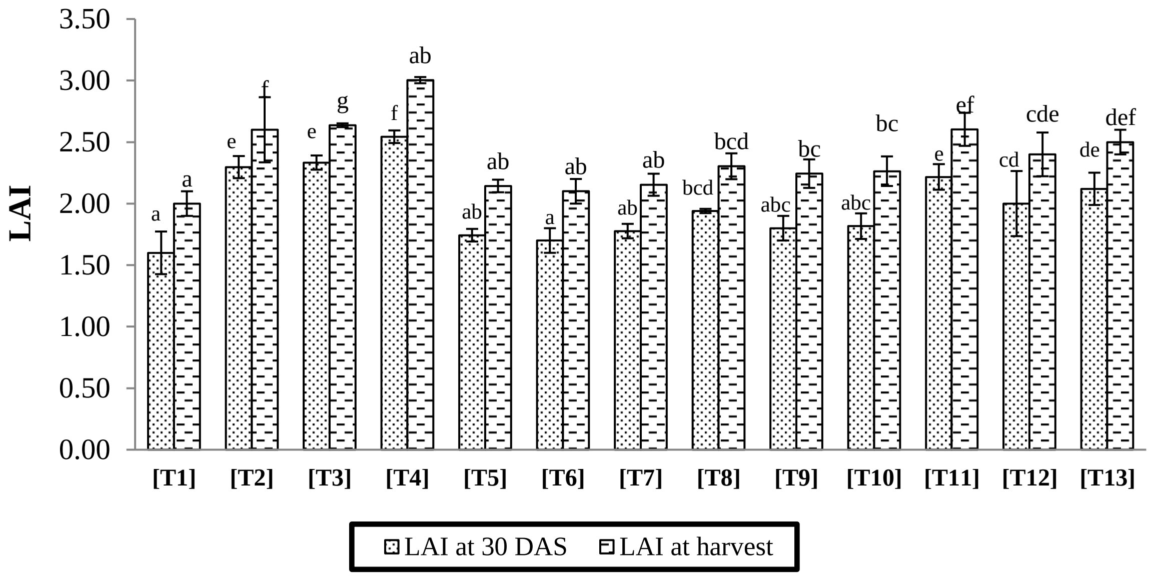
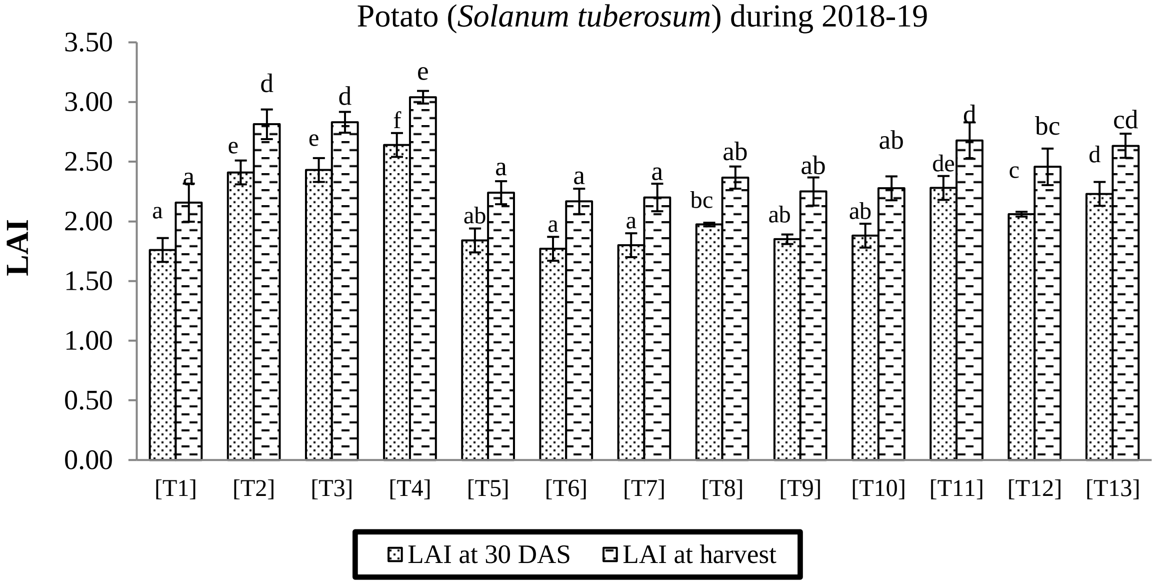


Fig-4.10.1b: Impact of bio-char based organic amendments on LAI in Potato (*Solanum tuberosum*) during 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05)

4.11.1 Number of haulms:

The influence of organic amendments using bio-char had an effect on the potato plant haulm count from the 2017-18 to the 2018-19 period, as indicated by the data presented in (Tables 4.11.1a and 4.11.1b). The statistical investigation of the data (number of haulm plants^{-1}) was highly significant at $P<0.05$ in both the years (2017-18 and 2018-19).

During the 2017-18 period, the highest count of haulm plant^{-1} was notably observed in T_4, representing 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%. Following closely was T_3, which involved 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 30%. In contrast, the control group, T_1, exhibited the lowest count at 4.00. The descending order of values was as follows: $T_{11} > T_2 > T_{10} > T_8 > T_5 > T_9 > T_7 > T_6 > T_{13} > T_{12}$, as detailed in Table 4.11.1a.

As a result of the data regarding the percentage increase/decrease over the control, the trend in the treatment's performance concerning the parameter of the number of haulms plant^{-1} in potatoes (Fig. 4.11.1a) was substantiated. The analysis indicated that the count of haulms plant^{-1} in potatoes was higher in 2018-19 compared to 2017-18 across all treatments, including the control treatment.

This parameter was statistically significant in the 2018-19 study, according to the results of the study, which was conducted in 2018. Based on the data displayed in (Table 4.11.1b), It appears that the influence of organic amendments based on bio-char on the number of haulms plant^{-1} is directly correlated with the quantity of bio-char present in the soil. Because of this, the number of haulm plants^{-1} in potatoes has significantly increased in T_4 as compared to T_1, which has the lowest number of haulm plants^{-1}. It is worth noting that the performance trends of the rest of the treatments were shown as $T_3 > T_2 > T_{11} > T_{13} > T_{12} > T_8 > T_{10} > T_9 > T_5 > T_7 > T_6$ with the performance of treatments also being supported by the data of percentage increase/decrease over control (Fig-4.11.1b).

Table-4.11.1 a: Impact of organic amendments based on bio-char on the number of haulms plant^{-1} during the 2017-18

Treatments	Number of haulm plant^{-1}
T_1	4.00±^{a}
T_2	4.37±0.06^{bcd} [+8.54%]
T_3	4.40±0.05^{cd} [+9.16%]
T_4	4.43±0.06^{d} [+9.64%]
T_5	4.33±0.07^{bcd} [+7.69%]
T_6	4.28±0.04^{bcd} [+6.61%]
T_7	4.29±0.05^{bcd} [+6.83%]
T_8	4.34±0.05^{bcd} [+7.83%]
T_9	4.31±0.03^{bcd} [+7.26%]
T_{10}	4.35±0.06^{bcd} [+7.98%]
T_{11}	4.38±0.03^{bcd} [+8.61%]
T_{12}	4.17±0.04^{ab} [+4.00%]
T_{13}	4.20±0.12^{bc} [+4.76%]
C.D.	**0.19**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Table-4.11.1 b: Impact of organic amendments based on bio-char on the number of haulms plant^{-1} during the 2018-19

Treatments	Number of haulm plant^{-1}
T_1	4.23±0.06^{a}
T_2	4.47±0.07^{bcd} [+5.37%]
T_3	4.50±0.05^{cd} [+6.0%]
T_4	4.53±0.06^{d} [+6.63%]
T_5	4.34±0.05^{abc} [+2.61%]
T_6	4.31±0.05^{ab} [+1.93%]
T_7	4.32±0.06^{abc} [+2.16%]
T_8	4.39±0.05^{abcd} [+3.65%]
T_9	4.35±0.05^{abcd} [+2.76%]
T_{10}	4.38±0.05^{abcd} [+3.43%]
T_{11}	4.43±0.06^{bcd} [+4.52%]
T_{12}	4.40±0.05^{abcd} [+3.94%]
T_{13}	4.42±0.05^{bcd} [+4.30%]
C.D.	**0.14**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets

denote nonsignificant variations, as determined by DMRT (p 0.05).

Figure-4.11.1 a: Impact of organic amendments based on bio-char on the number of haulms plant^{-1} during the 2017-18

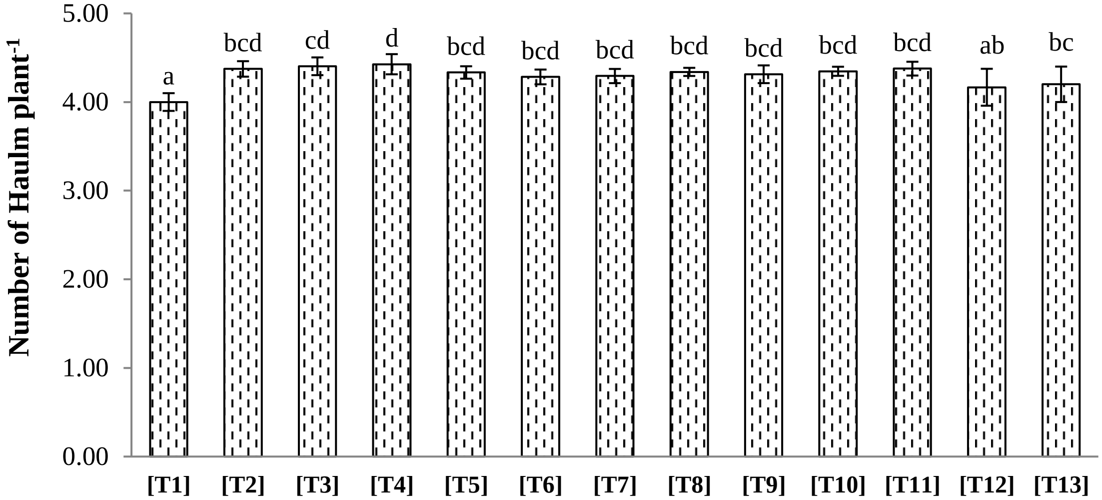
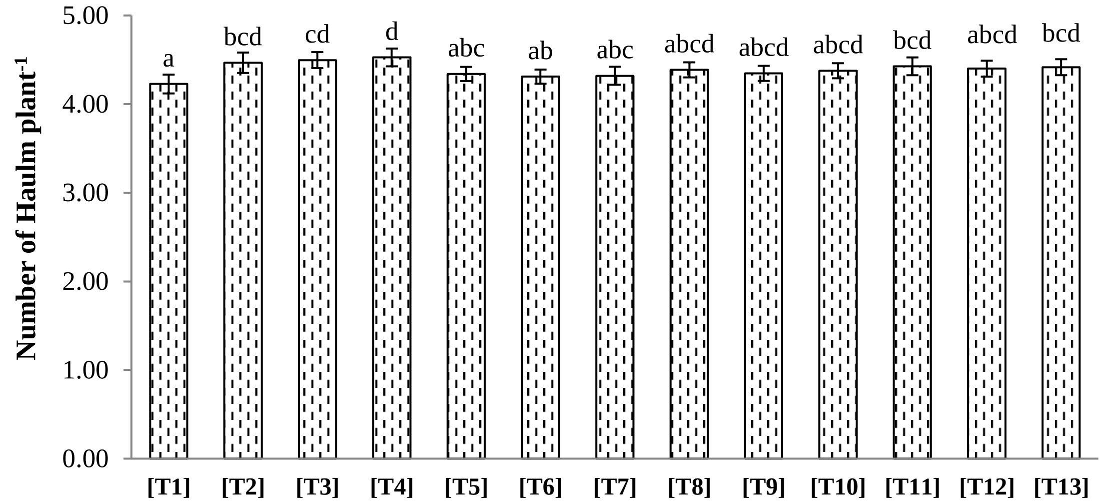


Figure-4.11.1 b: Impact of organic amendments based on bio-char on the number of haulms plant^{-1} during the 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

4.12.1 Days to emergence and maturity:

The influence of organic amendments incorporating bio-char on the duration of emergence and maturity in potatoes was examined for the 2017-18 and 2018-19 seasons. As indicated in Table-4.12.1 (a and b), the findings revealed a noteworthy impact of applying bio-char-based organic amendments on the timeframe for both emergence and maturity in both years. It was found in 2017-18 that plants took significantly fewer days for emergence when treatment T_4 (25 % recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%) was applied (17.59 days), followed by treatment T_2 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 20%) (17.63 days), and under treatment T_1 (Control) it took the most number of days (20 days) (Fig-4.12.1 a).

As a result of the research conducted in 2018-19, it was discovered that treatments T_4 i.e. 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40% and T_2 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 20% took about the same and shortest time to emerge (17.67 days) when compared to the other treatments.

However, T_1 (Control) took much longer to emerge (Fig-4.12.1 b) than the other treatments. As shown in Table-4.12.1 a and b, the data reflect the number of days to maturity in potatoes when an organic amendment based on bio-char has been used. A significantly longer period was required for a crop to mature with T_4 i.e. 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40% and T_{13} 25% recommended dose of fertilizers + 75% PM + bio-char 40% 115.00 days, followed by T_3> T9> T_{12}> T_{11}> T_{10}> T_8> T_2> T_5> T_6> T_7.

As compared to the control crops in 2017-18, which were recorded in 111.33 days, the crop took significantly less time to mature. In comparison to the previous year, in 2018-19, plants matured faster than in 2017-18, while the trends of the treatments were very similar to those of 2017-18 in terms of the number of days it took for plants to mature. The significantly highest number of days to maturity was recorded in T_4 and T_{13} 114.67 days 7.17 g followed by T_3> T_9> T_{12}> T_{11}> T_{10}> T_8> T_2> T_5> T_6> T_7 as compared to control T_1 111.67 days (Fig-4.12.1b). The current study, encompassing both the year and treatment factors, evaluates the performance concerning the days to emergence and days to maturity. Additionally, the percentage increase or decrease over the control is considered. The findings substantiate the trends in treatment performance regarding the days to emergence and days to maturity, as outlined in Table 4.12.1.

Table-4.12.1 a: Impact of organic amendments based on bio-char on days to emergence and maturity in potatoes during the 2017-18

Treatments	Days to emergence (number)	Days to maturity (number)
T_1	20.00±1.0±^{d}	111.33±0.67^{a}
T_2	17.63±0.32^{ab} [-13.42%]	112.33±1.20^{abc} [+0.89%]
T_3	18.33±0.88^{abc} [-9.09%]	114.67±0.67^{bc} [+2.91%]
T_4	17.59±0.26^{a} [-13.70%]	115.00±0.58^{c} [+3.19%]
T_5	19.20±0.42^{bcd} [-4.17%]	112.00±0.58^{abc} [+0.60%]
T_6	19.59±0.38^{cd} [-2.09%]	112.00±1.52^{abc} [+0.60%]
T_7	18.20±0.15^{abc} [-9.89%]	111.67±0.33^{ab} [+0.30%]
T_8	19.20±0.20^{bcd} [-4.17%]	113.00±1.15^{abc} [+1.47%]
T_9	19.00±0.0^{abcd} [-5.26%]	114.33±0.88^{abc} [+2.62%]
T_{10}	18.20±0.42^{abc} [-9.89%]	113.33±0.88^{abc} [+1.76%]
T_{11}	18.50±0.29^{abcd} [-8.11%]	113.33±1.20^{abc} [+1.76%]
T_{12}	18.50±0.29^{abcd} [-8.11%]	113.33±0.67^{abc} [+1.76%]
T_{13}	19.20±0.42^{bcd} [-4.17%]	115.00±0.58^{c} [+3.19%]
C.D.	**1.31**	**1.99**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+

bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Table-4.12.1 b: Impact of organic amendments based on bio-char on days to emergence and maturity in potatoes during the 2018-19

Treatments	**Days to emergence (number)**	**Days to maturity (number)**
T_1	20.00 ± 1.0^{b}	111.67 ± 0.88^{ab}
T_2	17.67 ± 0.67^{a} [-13.21%]	112.00 ± 1.0^{abc} [+0.30%]
T_3	18.33 ± 0.88^{ab} [-9.09%]	114.33 ± 0.33^{cd} [+2.33%]
T_4	17.67 ± 0.33^{a} [-13.21%]	114.67 ± 0.33^{d} [+2.62%]
T_5	19.33 ± 0.33^{ab} [-3.45%]	111.67 ± 0.88^{ab} [0.0%]
T_6	19.67 ± 0.33^{b} [-1.69%]	111.67 ± 1.20^{ab} [0.0%]
T_7	18.33 ± 0.33^{ab} [-9.09%]	111.33 ± 0.67^{a} [-0.30%]
T_8	19.33 ± 0.33^{ab} [-3.45%]	112.67 ± 0.88^{abcd} [+0.89%]
T_9	19.00 ± 0.0^{ab} [-5.26%]	114.00 ± 0.58^{bcd} [+2.05%]
T_{10}	18.33 ± 0.33^{ab} [-9.09%]	113.00 ± 0.58^{abcd} [+1.18%]
T_{11}	18.67 ± 0.33^{ab} [-7.14%]	113.00 ± 1.15^{abcd} [+1.18%]
T_{12}	18.67 ± 0.33^{ab} [-7.14%]	113.00 ± 0.58^{abcd} [+1.18%]
T_{13}	19.33 ± 0.33^{ab} [-3.45%]	114.67 ± 0.33^{d} [+2.62%]
C.D.	**1.41**	**2.02**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T10**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T11**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T12**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T13**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Figure-4.12.1 a: Impact of organic amendments based on bio-char on days to emergence and maturity in potatoes during 2017-18

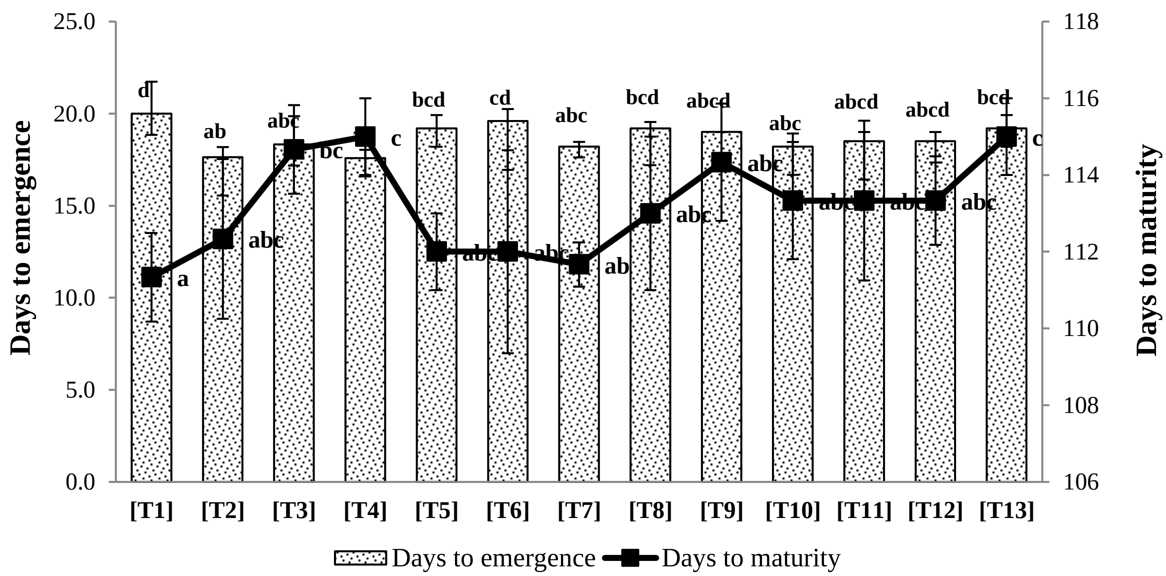
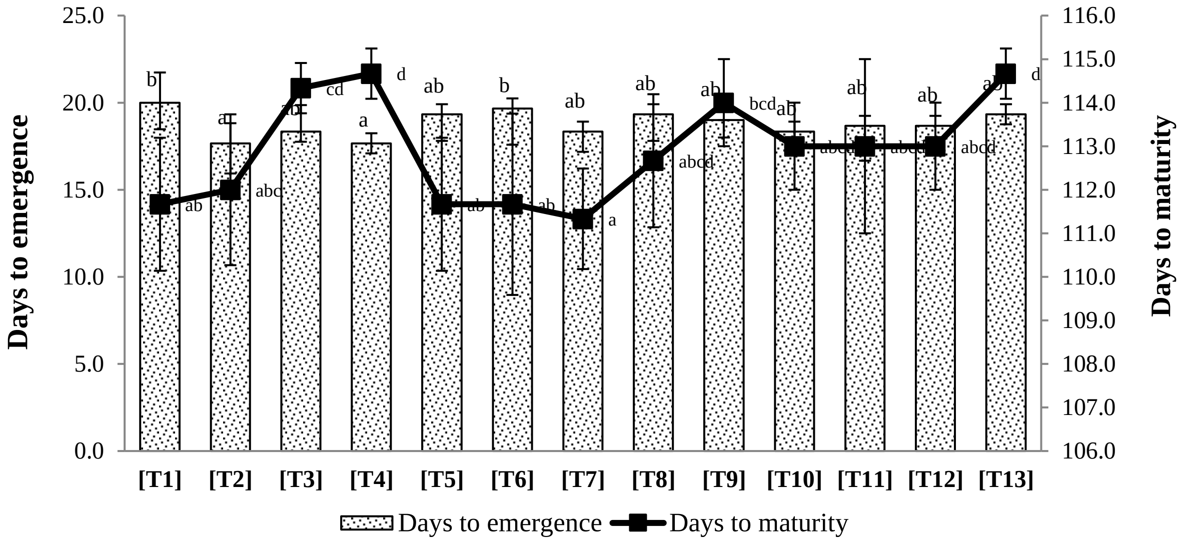


Figure-4.12.1 b: Impact of organic amendments based on bio-char on days to emergence and maturity in potatoes during 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05)

4.13.1 Plants m^{-1} row length and tubers $plant^{-1}$

The incorporation of a soil amendment based on bio-char led to variations in both the parameters (i.e. number of plants per meter row length and tubers $plant^{-1}$ in potatoes). In both 2017-18 and 2018-19, an on-significant difference was found between the set of treatments in (Table-4.13.1 a and b) for the number of plants m^{-1} row length. According to the data outlined in Table-4.13.1 (a and b), the utilization of a bio-char-based organic amendment significantly influenced the number of tubers generated $plant^{-1}$ when compared to the control. It is noteworthy that during the 2017-18 period, the highest number of tubers $plant^{-1}$ was recorded with the application of T_4 (11.6), closely followed by T_3 (11.6), meanwhile, the application of T_1 resulted in the lowest count of tubers, registering at 7.9, as depicted in Figure 4.13.1 a and b. There has been a notable rise in the variety of bio-char-based organic amendments tested in 2018-19 in comparison to preceding year. The number of tubers $plant^{-1}$ in T_1 was significantly lower at 8.1, while the number of tubers $plant^{-1}$ in T_4 was significantly higher at 11.7. There was an improvement in the performance of the rest treatments as follows: $T_3 > T_2 >$

$T_{11}>T_{13}>T_{12}>T_8>T_{10}>T_9>T_5>T_7>T_6$ in the potato (Fig-4.13.1 b).

Table-4.13.1 a: Impact of treatments on the number of plants per meter of row length and the quantity of tubers $plant^{-1}$ in Potato during the 2017-18

Treatments	Number of plant m^{-1} row length	Number of tuber $plant^{-1}$
T_1	4.75 ± 0.04^{a}	$7.9\pm0.27^{\mathbf{a}}$
T_2	4.76 ± 0.03^{a} [+0.21%]	$10.9\pm0.29^{\mathbf{efg}}$ [+26.99%]
T_3	4.78 ± 0.04^{a} [+0.70%]	$11.3\pm0.52^{\mathbf{fg}}$ [+30.0%]
T_4	4.79 ± 0.03^{a} [+0.84%]	$11.6\pm0.35^{\mathbf{g}}$ [+31.61%]
T_5	4.70 ± 0.5^{a} [-0.92%]	$9.2\pm0.15^{\mathbf{abcd}}$ [+13.77%]
T_6	4.71 ± 0.06^{a} [-0.78%]	$8.5\pm0.38^{\mathbf{ab}}$ [+7.03%]
T_7	4.74 ± 0.03^{a} [-0.21%]	$8.9\pm0.55^{\mathbf{abc}}$ [+10.53%]
T_8	4.70 ± 0.01^{a} [-1.06%]	$9.9\pm0.26^{\mathbf{bcde}}$ [+19.59%]
T_9	4.71 ± 0.03^{a} [-0.78%]	$9.5\pm0.34^{\mathbf{bcde}}$ [+16.78%]
T_{10}	4.73 ± 0.03^{a} [-0.28%]	$9.7\pm0.52^{\mathbf{bcde}}$ [+17.93%]
T_{11}	4.70 ± 0.04^{a} [-1.06%]	$10.5\pm0.35^{\mathbf{defg}}$ [+24.68%]
T_{12}	4.73 ± 0.02^{a} [-0.42%]	$10.1\pm0.86^{\mathbf{cdef}}$ [+21.71%]
T_{13}	4.75 ± 0.01^{a} [+0.07%]	$10.2\pm0.41^{\mathbf{cdefg}}$ [+22.48%]
C.D.	**NS**	**1.27**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Table-4.13.1 b: Impact of treatments on the number of plants per meter of row length and the quantity of tubers plant^{-1} in Potato during the 2018-19

Treatments	Number of plant m^{-1} row length	Number of tuber plant^{-1}
T_1	4.80±0.04^{a}	8.1±0.38^{a}
T_2	4.81±0.03^{a} [+0.21%]	11.0±0.33^{def} [+26.44%]
T_3	4.83±0.04^{a} [+0.69%]	11.4±0.56^{ef} [+29.03%]
T_4	4.84±0.03^{a} [+0.83%]	11.7±0.43^{f} [+30.86%]
T_5	4.75±0.05^{a} [-0.91%]	9.4±0.26^{abcd} [+14.18%]
T_6	4.76±0.06^{a} [-0.77%]	8.6±0.44^{ab} [+6.20%]
T_7	4.79±0.03^{a} [-0.21%]	9.1±0.61^{abc} [+11.03%]
T_8	4.75±0.01^{a} [-1.05%]	10.0±0.28^{bcde} [+19.06%]
T_9	4.76±0.03^{a} [-0.77%]	9.6±0.70^{abcd} [+15.97%]
T_{10}	4.78±0.03^{a} [-0.28%]	9.8±0.42^{bcde} [+17.69%]
T_{11}	4.75±0.04^{a} [-1.05%]	10.7±0.32^{def} [+24.37%]
T_{12}	4.78±0.02^{a} [-0.42%]	10.3±0.75^{cdef} [+21.93%]
T_{13}	4.80±0.01^{a} [+0.07%]	10.4±0.42^{cdef} [+22.44%]
C.D.	**NS**	**1.42**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50%

recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Fig-4.13.1a: Impact of treatments on on the number of plants per meter of row length and the quantity of tubers per plant in Potato during the 2017-18

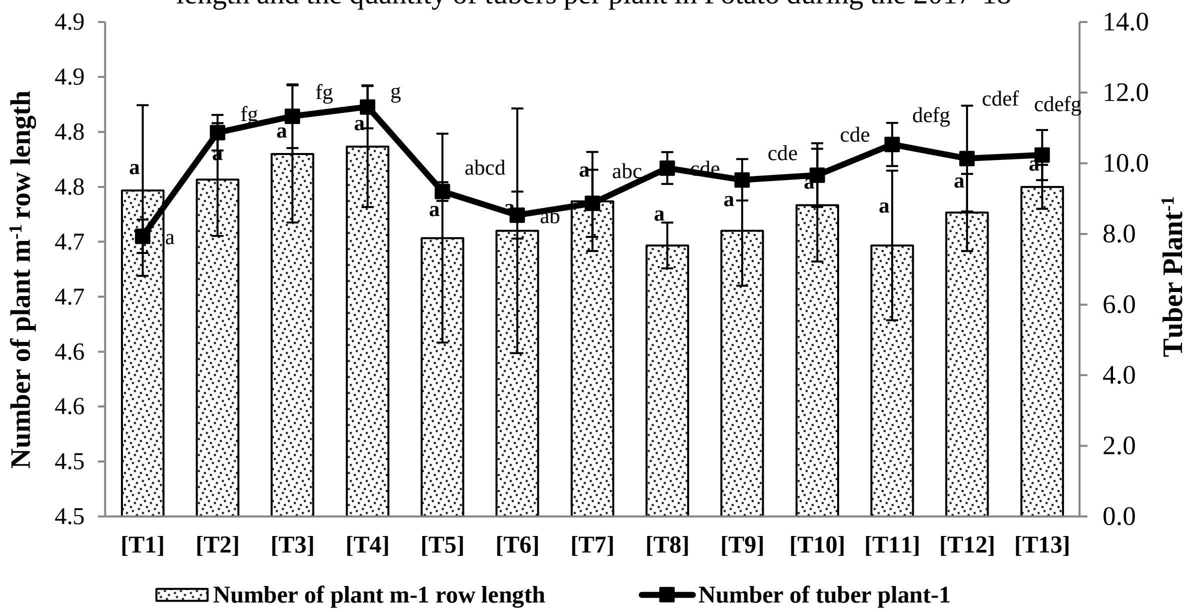
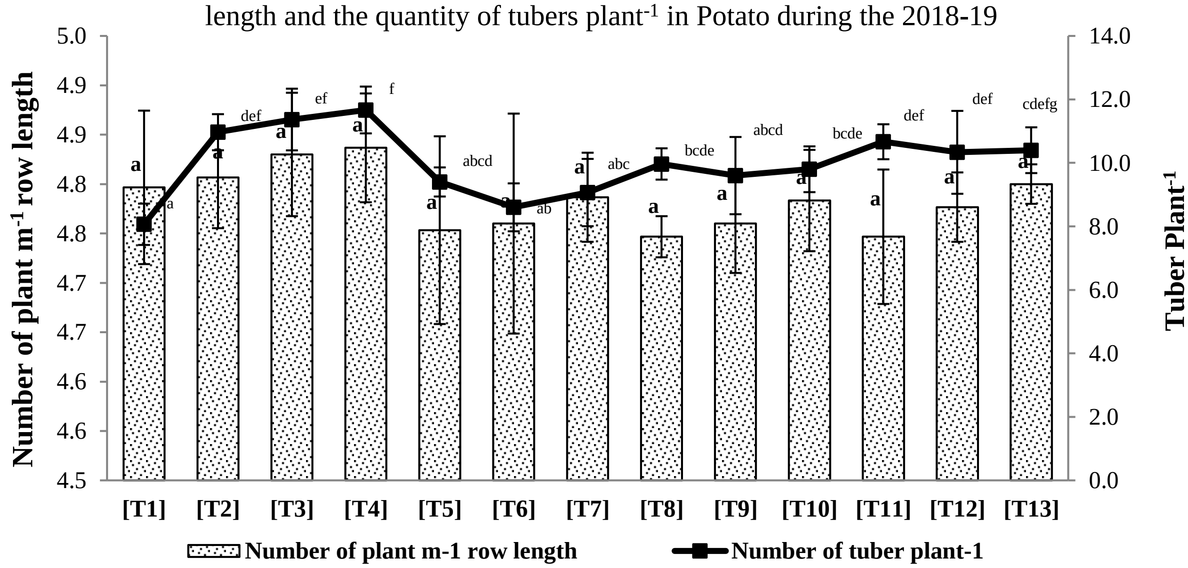


Fig-4.13.1 b: Impact of treatments on on the number of plants per meter of row length and the quantity of tubers $plant^{-1}$ in Potato during the 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05)

4.14.1 Average weight of tuber, average tuber weight plant^{-1} and yield quintal ha^{-1}

The application of organic-based treatments into the experimental field during 2017-18 and 2018-19 had a substantial impact on the tuber weight, tuber weight plant^{-1}, and potato yield. Additionally, it can be seen in (Table-4.14.1 a and b) that the application of bio-char-based organic amendments had a positive impact on tuber weight, tuber weight plant^{-1} and yield quintal ha^{-1} in potatoes in both of the years studied. In 2017-18, the average weight of tuber was notably highest in T_4 (25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%) 47.5 g which was followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as compared to T_1 (Control) in which the significantly lowest average weight of tuber was recorded (40.5 g) (Fig-4.14.1 a). It has been observed that the average weight of the tubers in potatoes has increased from 2017-18 to 2018-19. Almost similar trends were also observed in 2018-19 with the highest average weight of tuber being recorded in T_4, 47.8 g, followed by T_3> T_2> T_{11}> T_{13}> T_{12}>, T_8>, T_{10}> T_9, and T_5, T_7, and T_6 while the least amount of average weight of tuber was recorded in T_1 (Control), 40.8 g (Fig 4.14.1b). From the data depicted in (Table-4.14.1a and b), it can be seen that an average weight of tubers plant^{-1} (g) is obtained following the application of a bio-char-based organic amendment. A significant amount of average tuber weight plant^{-1} (g) was recorded in T_4 (25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%), weighing 399.1 (g), followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as the highest tuber weight in 2017-18. In the control group, the mean value of tuber weight plant^{-1} g was recorded to be 315.9 g in 2017-18. In 2018-19, the mean value of the weight of the tubers plant^{-1} g was recorded as being greater than it was in 2017-18, while the trends of the treatments were almost identical to the trends observed in 2017-18. According to the results of Fig-4.14.1b, T_4 had a significantly higher mean value of the weight of tubers plant^{-1} (g) than the control as compared to T_3, T_2, T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as compared to control 327.9g (Fig- 4.14.1b). Based on the data presented (Table-4.14.1a and b), it has been concluded that the tuber yield (q ha^{-1}) was improved when an organic amendment based on bio-char was used. During both the growing seasons of 2017-18 and 2018-19, there was a significant difference between the yields of tubers (q ha^{-1}) in potatoes. A significant amount of tuber yield (q ha^{-1}) was recorded in T4 (25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%) at 366.17q ha-1, followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6) while in 2017-18 the significant lowest yields were recorded in the control field with 26.00 q ha-1. Compared with 2017-18, the weight of the tuber yield (q ha-1) in potatoes appeared to be higher in 2018-19, while the trend of the treatment performance was almost similar to that of previous years as well. This figure shows that the weight of tuber yield plant-1 was substantially higher in T4 378.17 q ha^{-1} compared to T_1 278.00 q ha^{-1}. This was followed by T_3> T_2> T_{11}> T_{13}> T_{12}> T_8> T_{10}> T_9> T_5> T_7> T_6 as compared to T_1 278.00 (q ha^{-1}). The data in Table 4.14.1 (a and b), which indicates the percentage increase/decrease over the control, further aligns with the observed trend in the performance of treatments concerning the mean value of the weight of tubers (g), the mean value of the weight of tubers $plant^{-1}$ (g), and yield (q ha^{-1}) in both years of the present study.

Table-4.14.1 a: Impact of treatments on the average tuber weight , the average tuber weight plant$^{-1,}$ and yields of Potato (q ha^{-1}) during 2017-18

Treatments	Average tuber weight (g)	Average tuber weight plant^{-1} (g)	Yield q ha^{-1}
T_1	40.5±1.26^{f}	315.9±1.44^{a}	266.00±2.27^{a}
T_2	45.8±1.78^{a} [+11.71%]	388.7±1.62^{h} [+18.71%]	363.67±1.80^{f} [+26.86%]
T_3	46.7±0.42^{a} [+13.35%]	392.6±3.22^{hg} [+19.52%]	365.10±2.08^{f} [+27.14%]
T_4	47.5±0.67^{a} [+14.81%]	399.1±0.40^{g} [+20.84%]	366.17±2.16^{f} [+27.36%]
T_5	42.9±1.10^{cdef} [+5.67%]	349.5±5.83^{c} [+9.60%]	303.33±1.37^{b} [+12.31%]
T_6	42.1±1.65^{ef} [+3.96%]	337.9±5.13^{b} [+6.49%]	298.67±1.53^{b} [+10.94%]
T_7	42.6±0.78^{def} [+4.93%]	342.7±2.08^{bc} [+7.80%]	300.30±1.55^{b} [+11.42%]
T_8	44.1±1.16^{bcde} [+8.31%]	367.2±3.44^{def} [+13.97%]	343.40±1.34^{cde} [+22.54%]
T_9	43.2±0.78^{cdef} [+6.40%]	358.9±1.41^{d} [+11.98%]	338.12±1.58^{c} [+21.33%]
T_{10}	43.8±0.74^{bcde} [+7.54%]	362.6±2.0^{de} [+12.87%]	341.70±1.04^{cd} [+22.15%]
T_{11}	45.1±0.82^{bc} [+10.34%]	376.7±1.53^{g} [+16.13%]	347.33±1.80^{e} [+23.42%]
T_{12}	44.3±0.39^{bcd} [+8.72%]	369.5±1.04^{efg} [+14.50%]	344.70±1.67^{de} [+22.83%]
T_{13}	44.8±0.52^{bcd} [+9.61%]	373.1±1.54^{fg} [+15.31%]	346.66±1.87^{de} [+23.27%]
C.D.	**2.96**	**6.27**	**2.58**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25%

recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Table-4.14.1b: Impact of treatments on the average tuber weight , the average tuber weight plant$^{-1,}$ and yields of Potato (q ha^{-1}) during 2018-19

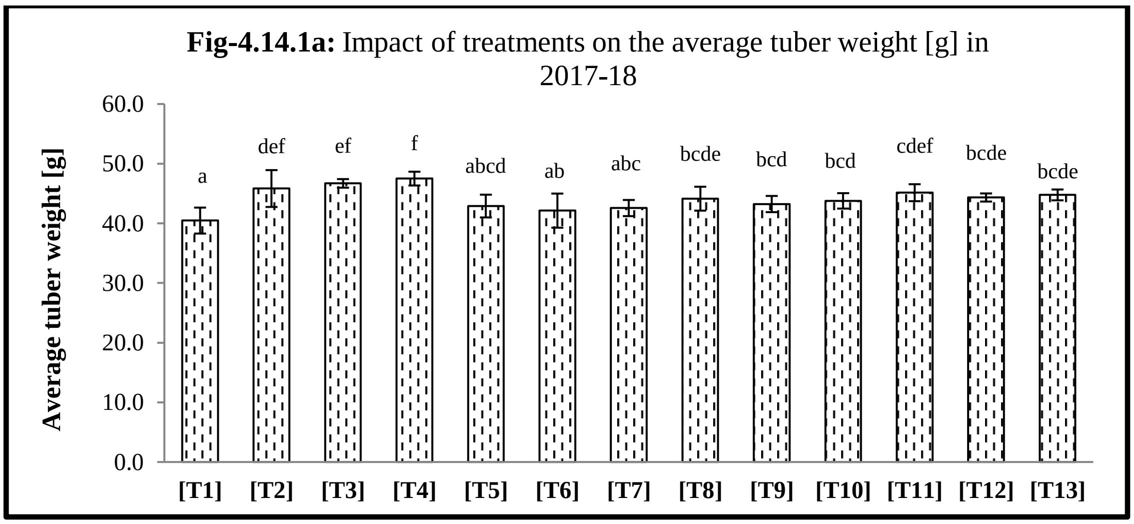
Treatments	Average tuber weight (g)	Average tuber weight plant^{-1} (g)	Yield q ha^{-1}
T_1	40.8±0.95^{a}	327.9±1.45^{a}	278.00±2.12^{g}
T_2	45.9±0.90^{def} [+11.18%]	400.7±1.62^{g} [+18.15%]	375.67±1.40^{a} [+26.0%]
T_3	46.9±1.1^{ef} [+13.08%]	404.6±2.09^{g} [+18.94%]	377.10±1.51^{a} [+26.28%]
T_4	47.8±0.52^{f} [+14.65%]	411.1±0.87^{g} [+20.24%]	378.17±1.58^{a} [+26.49%]
T_5	43.1±0.87^{abcd} [+5.49%]	361.5±5.84^{bc} [+9.29%]	315.33±1.03^{e} [+11.84%]
T_6	42.4±0.92^{ab} [+3.85%]	349.9±5.13^{b} [+6.27%]	310.67±1.17^{f} [+10.52%]
T_7	42.8±0.61^{abc} [+4.68%]	354.7±2.08^{b} [+7.54%]	312.30±0.98^{ef} [+10.98%]
T_8	44.3±1.04^{bcde} [+7.91%]	379.2±3.44^{def} [+13.53%]	355.40±1.11^{c} [+21.78%]
T_9	43.5±0.61^{bcd} [+6.28%]	370.9±1.41^{cd} [+11.59%]	350.12±1.09^{d} [+20.60%]
T_{10}	43.9±0.68^{bcd} [+7.14%]	374.6±2.0^{de} [+12.46%]	353.70±1.22^{cd} [+21.40%]
T_{11}	45.3±0.79^{cdef} [+10.07%]	388.7±1.53^{f} [+15.63%]	359.33±2.12^{b} [+22.63%]
T_{12}	44.6±0.79^{bcde} [+8.66%]	381.5±1.04^{def} [+14.04%]	356.70±1.38^{b} [+22.06%]
T_{13}	44.9±0.90^{bcde} [+9.21%]	385.1±1.55^{ef} [+14.84%]	358.66±1.28^{b} [+22.49%]
C.D.	**2.46**	**6.30**	**2.63**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T10**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T11**=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T12**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T13**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).



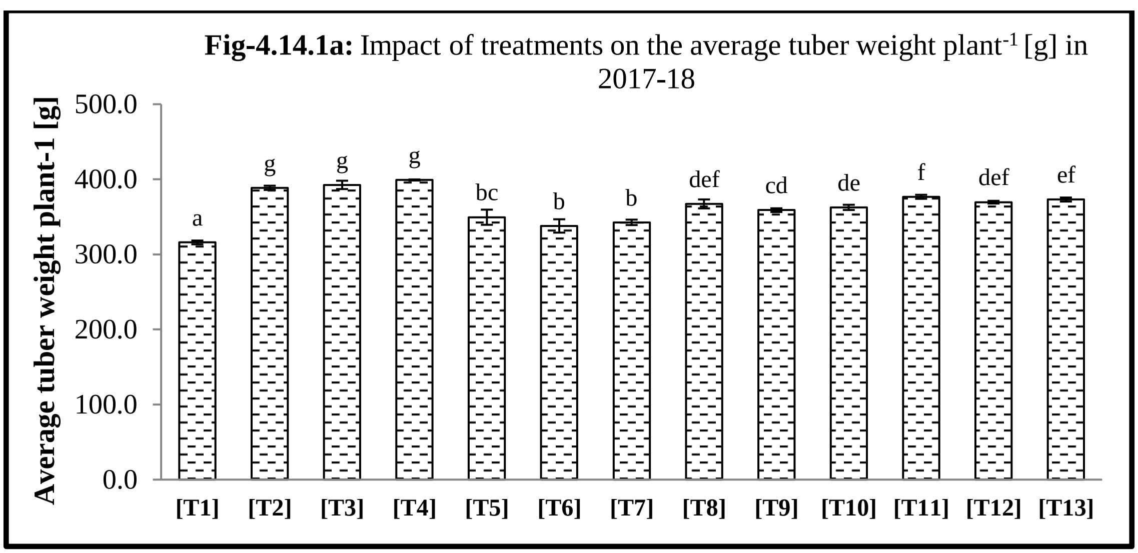


Fig-4.14.1a: Impact of treatments on the yield of potato q ha^{-1} in 2017-18

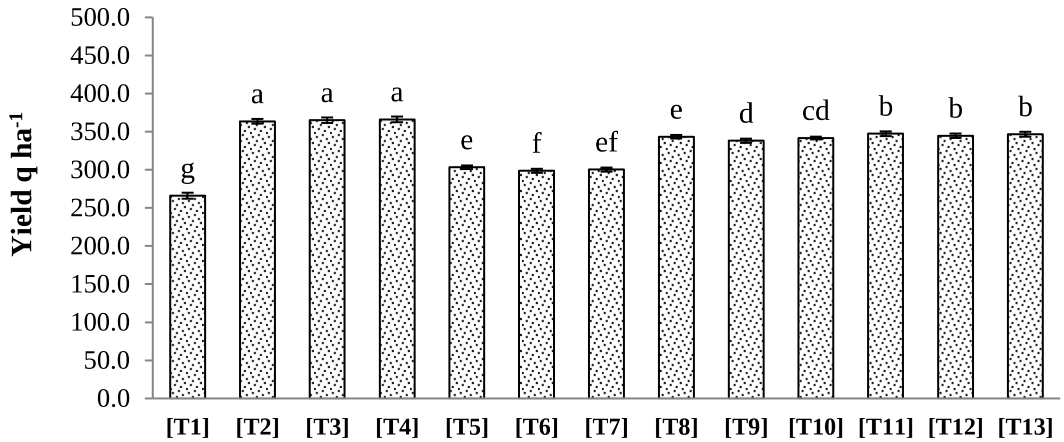


Fig-4.14.1b: Impact of treatments on the average tuber weight [g] in 2018-19

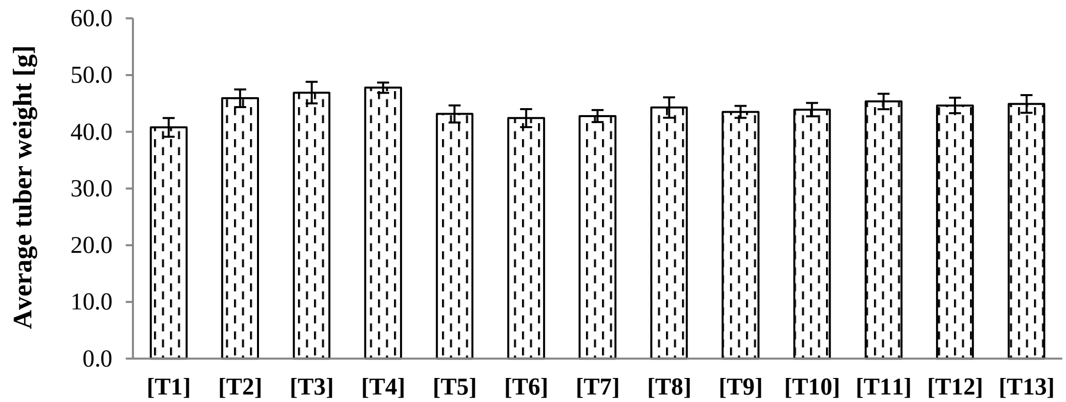


Fig-4.14.1b: Impact of treatments on the average tuber weight $plant^{-1}$ [g] in 2018-19

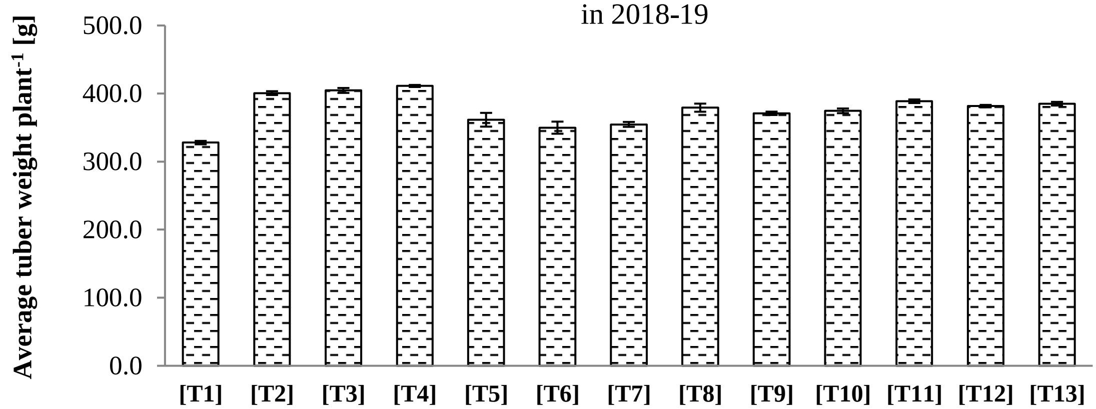
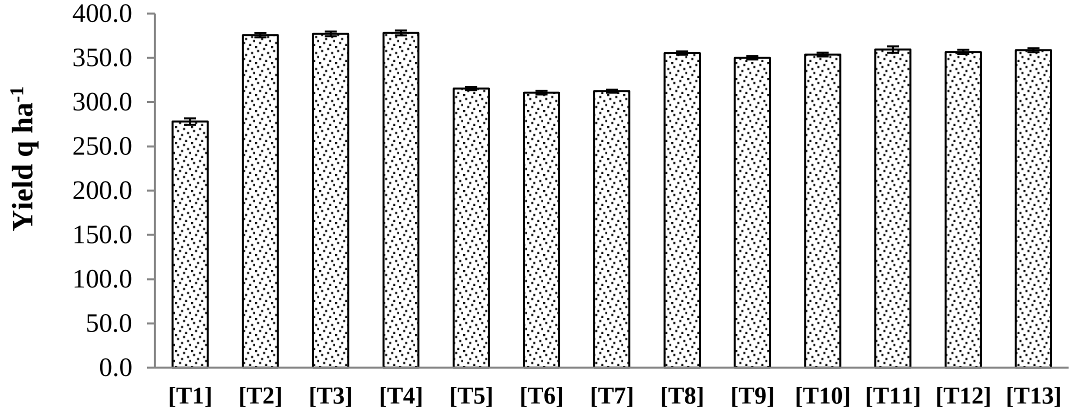


Fig-4.14.1.b: Impact of treatments on the yield of potato q ha^{-1} in 2018-19



4.15.1 Starch content (%):

Based on the data outlined in Table-4.15.1a and b, a substantial impact of bio-char-based organic amendments on starch content (%) in potatoes was observed during both the 2017-18 and 2018-19. The statistical analysis of the data pertaining to starch content revealed high significance at P 0.05 in both years. Significantly higher starch content was found in potatoes in T_4 (25% recommended dose of fertlizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40%) in 2017-18. This was followed by T3 (25% recommended dose of fertilizers + 75 % (bone meal + vermicompost + poultry manure) + bio-char 30%) in 2017. There were several other treatment groups, including control T1 at 47.0, followed by $T_2 > T_{11} > T_{13} > T_{12} > T_8 > T_{10} > T_9 > T_5 > T_7 > T_6$ (Table-4.15.1 a). It can also be seen from the data regarding the percentage increase or decrease in the potato starch content over the control that the treatment has performed reasonably well on the parameter starch content in potatoes (Fig-4.15.1a).

It has been observed that the starch content of potatoes has exceeded that of 2017 -18 in the entire set of treatments, including the control, for 2018-19. Based on the results for 2018-19, it was found that the parameter was statistically significant. As shown in (Table-4.15.1b), the findings of this study unveiled the impact of treatments on the starch content of potatoes. In T_4, the highest starch content was recorded as 55.6% over the control T_1 of 49.0%. However, the performance trends of the rest of the treatments were as follows: $T_3 > T_2 > T_{11} > T_{13} > T_{12} > T_8 > T_{10} > T_9 > T_5 > T_7 > T_6$, whereas the performance of the treatments was also demonstrated by their percentage increase/decrease over control (Fig-4.15.1b).

Table-4.15.1a: Impact of bio-char based organic amendments on starch content (%) during 2017- 18

Treatments	Starch content (%)
T_1	47.0±0.58[a]
T_2	53.0±0.29[de] [+11.32%]
T_3	53.2±1.62[de] [+11.71%]
T_4	53.6±0.87[e] [+12.31%]
T_5	48.3±0.88[ab] [+2.76%]
T_6	47.0±1.06[a] [0.0%]
T_7	47.8±0.42[ab] [+1.67%]
T_8	50.5±0.51[bcde] [+6.93%]
T_9	49.2±1.22[abc] [+4.47%]
T_{10}	50.0±1.16[abcd] [+6.0%]
T_{11}	52.5±1.26[de] [+10.48%]
T_{12}	51.7±0.91[cde] [+9.09%]
T_{13}	51.9±1.04[cde] [+9.38%]
C.D.	**2.69**

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 25% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**= 25% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**= 25% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=25% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=25% recommended dose of fertilizers+75% poultry manure+bio-char 20 %, **T_8**= 25% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=25% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 25% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %, **T_{11}**=25% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**= 25% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 25%

recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Table-4.15.1b: Impact of bio-char based organic amendments on starch content (%) during 2018-19

Treatments	**Starch content (%)**
T_1	49.0±0.72[a]
T_2	55.0±0.30[gh] [+10.86%]
T_3	55.2±0.20[gh] [+11.18%]
T_4	55.6±0.10[h] [+11.87%]
T_5	50.3±0.85[abc] [+2.52%]
T_6	49.0±0.87[a] [+0.0%]
T_7	49.8±0.72[ab] [+1.61%]
T_8	52.5±0.43[def] [+6.73%]
T_9	51.2±0.87[bcd] [+4.30%]
T_{10}	52.0±0.70[cde] [+5.77%]
T_{11}	54.5±0.30[gh] [+10.09%]
T_{12}	53.7±0.30[efg] [+8.70%]
T_{13}	53.9±0.18[fgh] [+9.03%]
C.D.	

Notes:

1- **T_1**= Control (positive amendments –100% NPK), **T_2**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+ poultry manure) + bio-char 20%, **T_3**= 50% recommended dose of fertilizers + 75% (bone meal+vermicompost+poultry manure)+bio-char 30%, **T_4**=50% recommended dose of fertilizers+75% (bone meal +vermicompost + poultry manure) + bio-char 40%, **T_5**=50% recommended dose of fertilizers + 75% bone meal+bio-char20%, **T_6**=50% recommended dose of fertilizers+75% vermicompost+ bio-char 20%, **T_7**=50% recommended dose of fertilizers+75% poultry manure+bio-char 20%, **T_8**= 50% recommended dose of fertilizers+75% bone meal + bio-char 30%, **T_9**=50% recommended dose of fertilizers+75% vermicompost + bio-char 30 %, **T_{10}**= 50% recommended dose of fertilizers+75% poultry manure+ bio-char 30 %,

T_{11}=50% recommended dose of fertilizers+75% bone meal +bio-char 40%,**T_{12}**=50% recommended dose of fertilizers + 75% vermicompost + bio-char 40%, **T_{13}**= 50% recommended dose of fertilizers + 75% poultry manure + bio-char 40%.

2- Values enclosed in parentheses indicate the percentage increase or decrease relative to the control.

3- Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05).

Fig-4.15.1a: Impact of bio-char based organic amendments on starch content (%) during 2017-18

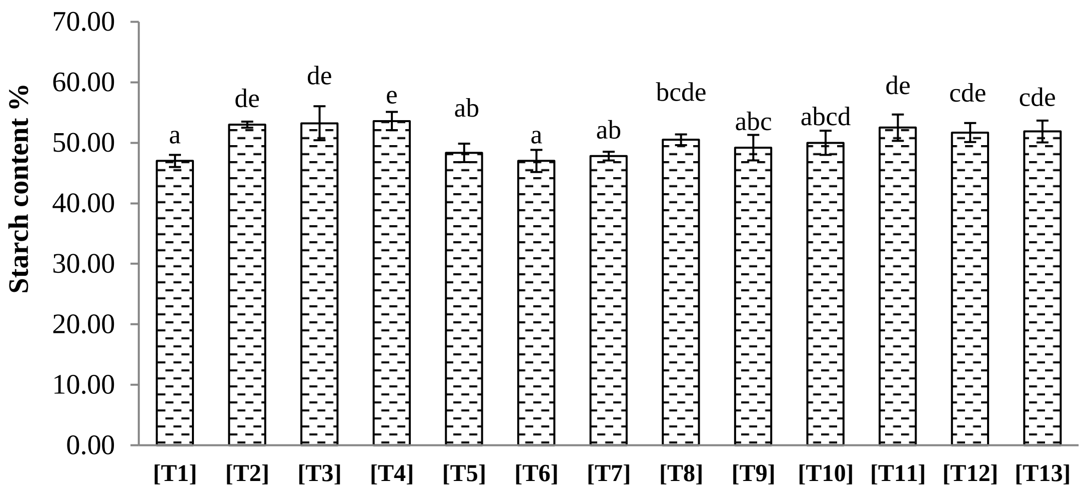
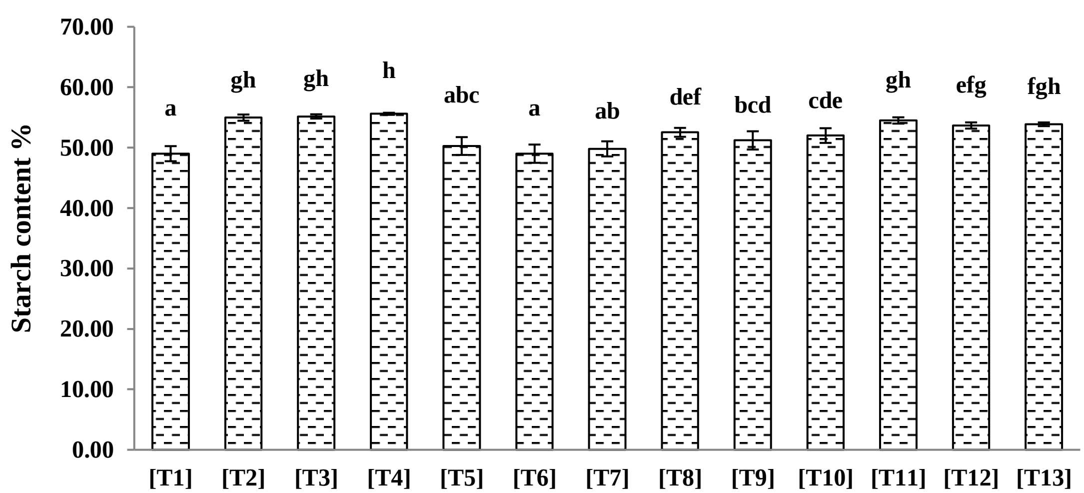


Fig-4.15.1b: Impact of bio-char based organic amendments on starch content (%) during 2018-19



Notes: Distinct alphabets indicate significant differences among treatments, whereas identical alphabets denote nonsignificant variations, as determined by DMRT (p 0.05)

DISCUSSION

The current research work entitled, "**Effect of bio-char based organic amendments on soil biological and biochemical indicators about increase soil nutrient release potential and yield of potato"** was carried out in the Rabi season of 2017-18 and 2018-19 at the farmer field of Village Kalloh, Mansa (Punjab). The discussion of the current study centered around the results obtained from the research, aiming to elucidate potential reasons for the observed variations. The results were thoroughly examined with substantial reference to existing literature. The outcomes presented in this chapter are rooted in the assessment of the potato crop's performance concerning growth, development, quality, and yield. This improvement is attributed to the enhanced physicochemical properties of the soil, increased activity of soil enzymes, and nutrient release facilitated by bio-char-based organic amendments. Additionally, favorable weather conditions were noted as contributing factors to the successful cultivation of the potato crop. The availability of potatoes around the world and the fact that they are among the lowest-priced crops on the market make them a very popular crop. It is also significant to note that the favorable climatic conditions for the cultivation of these crops in most countries make them even more valuable. In addition, there is a consistent increase in the demand for potatoes on the market due to increase in inflation and population growth worldwide (Mohajan, 2014). In order to meet the demand for potato crops, the scientific community faces several challenges. Based on the recommendations of the scientific community, farmers are using inorganic fertilizers to improve the yields of their crops following the green revolution. The available evidence indicates that depending exclusively on inorganic nutrient sources for an extended period can adversely impact the physical, biological, and chemical properties of the soil. Consequently, this may result in a prolonged decrease in crop yield for subsequent years, as observed by (Gong *et al.,* 2011 and Powell *et al.,* 2020). The soil plays a crucial role in various natural processes that contribute to enhancing water-holding capacity, nutrient release, and the efficiency of nutrient uptake by plants. It has been established that a strong correlation exists between the decomposition of organic base amendments in the soil and the activity of microorganisms. This correlation is tied to a biological process that encompasses the breakdown of complex molecules and their biochemical transformation, as emphasized by (Khatoon *et al.,* 2017). There are several reasons why the application of residue to soil increases the level of carbon in the soil and may also accelerate the carbon cycle during the continued application of residue (Laird *et al.,* 2009). In addition to releasing nutrients into the soil, when organic matter decomposes, it also supports the synthesis of a comparatively more complex compound known as humus, which is called humification (Kononova, 2013).

To combat this alarming situation, it is vital to maintain sustainable soil conditions and crop yields. In the present study, organic and inorganic sources were used in combination to achieve soil health and crop yield sustainability. In this section, we discuss the study in detail under the following headings, which are summarized below.

Influence of treatments based on organic resources on physicochemical and biological properties of soil

pH [Potential of hydrogen] and EC (Electrical conductivity dSm^{-1}):

As an assessment of the soil environment, pH and electrical conductivity (EC) are commonly employed to ascertain the soil's acidity or alkalinity. Additionally, EC serves as an indicator of the presence of soluble salts that could dissolve within the soil (Kumari *et al.,* 2014). Generally, it is reasonable to conclude that the pH of the soil alone is sufficient to modify the impact of treatments towards the positive or negative in both directions owing to the fact that it facilitates nutrient uptake by plants in both directions (Silber *et al.,* 2010). It is also relevant to note that the release of $NH4^{+}$ is a pH-dependent process, whereas the release of $NO3^{-}$ is an independent process (Zheng *et al.,* 2013). The data displayed in Table-4.2.2 a and b suggests a positive impact of treatments based on organic resources on increasing soil pH and electrical conductivity (EC). This observation aligns with the conclusions drawn by Mollick *et al.,* (2020) and Hossain *et al.* (2010), supporting the openion that the enhancement in soil pH and EC may be attributed to the synergistic application of treatments based on organic resources and bio-char. In the past, the modification in pH was linked to the heightened pH levels of both bio-char and organic compounds within the soil. This association was believed to boost calcium concentrations while diminishing aluminum concentrations in the soil, as suggested by (Steiner *et al.*, 2007). There are many reasons behind this but one of the possible reasons for improving soil pH is the presence of the basic compounds in bio-char, such as potassium (K^{+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}) (Yuan *et al.,* 2011). From the results of the trial (Table-4.2.2 a and b), it can be seen that the EC was higher in the subsequent year of the trial as compared to the previous year in the entire set of treatments that were compared to the control as well. The result of the finding is well correlated with (Masto *et al.*, 2013) who reported that the increase in EC is due to the presence of soluble salt i.e., Ca^{2+} and Mg^{2} released from weekly bound cation and anion from bio-char (Kumar *et al.,* 2013 and Abujabhah *et al.,* 2016). Both of these parameters are on the rise, contributing not only to increased nutrient availability in the soil but also enhancing the efficiency of nutrient uptake by plants. This improvement is a consequence of the increased nutrient availability in the soil.

The organic carbon percentage and soil microbial biomass carbon (μg g^{-1}) of the experimental field.

The existence of organic carbon (OC) and soil microbial biomass carbon (SMBC) functions as a crucial indicator of soil quality. Organic carbon comprises a blend of organic substances, and SMBC represents one of the labile pools of OM responsible for organic matter conversion, as noted by (Baath and Anderson, 2003). The outcomes of the experiment demonstrated that utilizing bio-char-based organic amendments had a beneficial impact, leading to an elevation in both organic carbon and soil microbial biomass carbon (SMBC) when compared to the control. Notably, T_4 demonstrated the highest levels of OC and SMBC in both years, with the subsequent year showing further improvement over the preceding one (Table-4.2.1 a and b). These outcomes align with the conclusion of Che and Zhang, (2021), and Zhang *et al.,* (2018), who observed that the adoption of bio-char-based organic amendments contributes to an augmentation in soil organic carbon (SOC) levels (Schulz *et al.*, 2013). The rise in SOC enhances water-holding capacity and nutrient retention efficiency, establishing it as a significant soil fertility index (Laird *et al.*, 2010 and Sukartono, 2011).

The utilization of bio-char in agricultural fields not only enhances the soil's physicochemical attributes but also positively influences its biological characteristics (Liang *et al.,* 2010 and Laird *et al.,* 2010). Previous studies conducted by Paz-Ferreiro *et* *al.,* (2012) have already documented a rise in soil microbial biomass carbon (SMBC) resulting from the application of bio-char Ding *et al.,* (2016). Our findings align with these reports, demonstrating an increase in SMBC that not only varies among different treatments but persists into the subsequent year, particularly when employing bio-char-based organic manures. The potential explanation for this rise in SMBC could be attributed to bio-char offering a substrate, habitat, and expanded surface area, thereby promoting enhanced microbial activity in the soil (Atkinson *et al.,* 2010 and Lehmann *et al.,* 2011). Similar outcomes were observed by Albiach *et al.,* (2000), who found that the combined application of bio-char and organic manure not only enhances bacterial populations but also improves overall microbial activity in the soil. In summary, our results, in conjunction with previous studies, emphasize the multifaceted benefits of bio-char application, highlighting its capacity to improve both the physical and biological aspects of the soil.

Nitrogen, phosphorus and potassium content in the soil:

Nitrogen:

In our current study, various combinations of synthetic fertilizers, manures, and bio-char were employed, resulting in an overall increase in soil nitrogen (N) availability across all treatments. The treatment denoted as T_4 exhibited the highest level of available nitrogen, surpassing both the control and other treatments (Table 4.1.1a & b). This finding aligns with the findings reported by Pietikainen *et al.,* (2000), who observed a similar increase in available nitrogen and provided a plausible explanation for this phenomenon.

The enhancement in available nitrogen is attributed to the surface properties of bio-char, which effectively retains the nitrogen content made available by manures and fertilizers (Deluca *et al.,* 2015). Additionally, the use of bio-char in conjunction with organic manures plays a role in reducing nitrogen leaching, consequently contributing to an increase in available nitrogen within the soil. This approach also has positive effects on soil mineralization (Prosdocimi *et al.,* 2016; Atkinson *et al.,* 2010 and Borchard *et al.,* 2014). In summary, our study corroborates previous research and underscores the beneficial impact of incorporating bio-char into soil management practices for improving nitrogen availability.

Phosphorus:

The concentration of soil phosphorus is crucial for enhancing crop yield, and in our study, the application of bio-char-based organic amendments led to a significant increase in soil phosphorus content across all treatments in both years. Notably, treatments T_4 and T_3 emerged as particularly effective, as evidenced by the results presented in (Table 4.1.2a & b). The incorporation of bio-char into the soil contributes to the enhanced retention of phosphorus and other nutrients, attributed to its improved cation exchange capacity (CEC) (Krull *et al.*, 2012). This, in turn, positively influences soil fertility and production capacity, maintaining elevated levels of essential nutrients such as phosphorus. The observed release of nutrients into the soil may be associated with the production of organic acids from the organic-based manures. This mechanism contributes to the improved availability of phosphorus in the soil. Our findings align with the research of Ghos and Wilson (2015), who reported that the application of bio-char in conjunction with manures results in a substantial release of phosphorus into the soil. Overall, our study supports the notion that bio-char, particularly when combined with organic-based manures, enhances soil phosphorus availability, thereby promoting soil fertility and crop production.

Potassium:

Similar to nitrogen (N) and phosphorus (P), the presence of available potassium (K) increased when bio-char was applied in conjunction with fertilizers and manures. bio-char, renowned for its high surface area, has the capability to enhance the soil's nutrient retention capacity, as emphasized by Lehmann and Joseph (2009). Notably, studies by Kloss *et al.*, (2014) and Lashari *et al.*, (2015) highlighted that the application of fresh bio-char, containing soluble P and K, contributed to the plant-available nutrient pool upon its incorporation into the soil.

In the current study, the rise in available potassium (K) concentration in experimental soils may be attributed to the release of naturally soluble potassium from bio-char. The content of available potassium (K) was significantly influenced by the introduction of organic matter into the soil, likely due to increased potassium mineralization at higher levels of organic matter. This finding is consistent with the results reported by (Rathod *et al.,* 2013; Kumari *et al.*, 2014, and Pawar *et al.,* 2019).

Labile carbon/permanganate oxidizable C (POXC) and particulate organic carbon

Labile carbon:

The POXC values indicate the presence of relatively younger and less resistant organic compounds, such as labile humic materials and polysaccharides. In both years of potato crop cultivation, bio-char-amended plots exhibited a higher content of labile carbon (C) compared to the control plots, suggesting the introduction of more readily decomposable organic materials. Specifically, treatment T_4 (4.3.1 a and b) in potato crops contributed significantly more labile carbon to the soil, as reported by (Bhattacharya *et al.,* 2012). This finding aligns with the results of Thorburn *et al.,* (2012), who observed elevated POXC concentrations in soils treated with bio-char.

The study's outcomes are consistent with the findings of Tian *et al.,* (2016), who proposed that the integrated application of bio-char with manures and fertilizers leads to an increase in POXC concentration. This is attributed to the higher input of organic matter through this integrated approach.

Particulate organic carbon:

Particulate organic carbon (POC) functions as a biologically available source of carbon and energy for soil microorganisms, as highlighted by (Gregorich *et al.,* 2005). The application of bio-char in conjunction with poultry manure, vermicompost, bone meal, and fertilizer (specifically, treatment T_4 4.3.1 a and b) led to an increase in POC levels in the soil. Notably, all treatments, except for the control, demonstrated a significantly higher presence of POC in both years of the study.

The noteworthy augmentation of POC in soil resulting from the combination of bio-char with manures is a key finding in this study. This phenomenon is attributed to the rapid conversion of applied carbon to humified carbon, as suggested by Chan *et al.,* (2007). Additionally, Prabha *et al.,* (2013) reported that bio-char-treated plots contributed more POC to soil organic carbon (SOC), indicating the potential for stabilizing and retaining carbon in the lower fractions of the soil.

Activity of dehydrogenase, acid phosphatase and alkaline phosphatase in the experimental field (soil samples)

Dehydrogenase:

The activity of dehydrogenase serves as a comprehensive gauge of the oxidative activity of microflora and is regarded as a valuable soil quality indicator, as highlighted by (Saha *et al.,* 2008). Dehydrogenase activity (DHA) involves a combination of intracellular enzymes present in soil microorganisms. Across all treatments, DHA was observed to be highest, with a notable increase compared to the control. The significant enhancement of dehydrogenase activity in the potato crop, particularly with the treatment involving 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry) + bio-char 40% in both the 2017-18 and 2018-19 periods, is likely attributable to the introduction of organic matter through various organic manures. This organic input contributed to heightened microbial activity and increased microbial biomass. Similar findings were reported by (Prakash *et al.,* 2002, and Tejada and Gonzalez, 2009). Conversely, the control exhibited the lowest dehydrogenase activity, potentially attributed to imbalanced fertilization, leading to an inhibitory effect on microbial activity and limiting the availability of carbon (C).

Activity of acid and alkaline phosphatase:

Phosphates play a crucial role as a source of phosphorus for plant absorption by releasing PO_4 from immobile organic phosphorus. In our current investigation, it was observed that the activity of acid phosphatase exceeded that of alkaline phosphatase, potentially attributed to the soil's acidic nature. The heightened phosphatase activity signifies fluctuations in both the quantity and quality of soil phosphorylate substrates. Notably, the acid phosphatase activity exhibited an increase in potato crops (refer to Table 4.4.1 a & b) under treatment T_4 i.e. 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + 40% bio-char for both the 2017-18 and 2018-19 periods. This augmentation could be attributed to the addition of organic matter, resulting in increased organic carbon (OC) and nitrogen (N) content (Kavita *et al.,* 2021). Similarly, the alkaline phosphatase activity demonstrated a significant rise under treatment T_4 (Table 4.4.1 a and b). Bio-char, known to contain a substantial amount of phosphorus, contributed to the increased activity of both acid and alkaline phosphatases in the soil (Zamuner *et al.,* 2008).

The increased alkaline phosphatase activity corresponds with the findings of Jin (2010), proposing that the uptake of nitrogen (N) and phosphorus (P) by plants, coupled with the growth of fine roots and root hairs into bio-char pores, triggers the production of organic N and P mineralization enzymes. This observation aligns with the results reported by (Masto *et al.,* 2013 and Paz-Ferreiro *et al.,* 2012), who noted an enhanced alkaline phosphatase activity resulting from bio-char application.

Effect of bio-char based organic amendments on growth, yield and quality of potato:

Growth:

The tables presented in the results section, illustrating plant height, fresh weight, dry weight of the plant, and leaf area index (LAI), indicate a slight increase in growth, especially as the crop advances towards development during the season. This heightened growth rate is likely a result of favorable weather conditions. Importantly, the influence of different treatments becomes apparent not only in the vegetative stages but also becomes more pronounced during the later stages of crop development. Throughout the study year, the observed variations in growth parameters can be attributed to the cumulative effect of bio-char when combined with manures and fertilizers.

The synergy of these factors contributes to the overall enhancement of plant growth. The study's findings revealed improvements in growth parameters, including emergence percentage, plant height, leaf area index, fresh weight, dry weight of the plant, and the number of haulms in bio-char amended plots compared to the control. These growth parameters exhibited significant enhancement when bio-char was combined with manures and fertilizers. This suggests that the addition of some inorganic fertilizers, when combined with bio-char, can accelerate both growth and yield. This observation aligns with the results reported by (Gebremedhin *et al.,* 2015). The adsorption properties of bio-char and its content of mineral elements in soils may provide nutrients conducive to tuber germination. Agboola and Mosses (2015) observed that bio-char's sorptive capacity for allelochemicals could enhance plant germination, which aligns with the findings of the current study. Similarly, Upadhyay *et al.,* (2020) reported consistent results, stating that the application of bio-char, combined with manures and fertilizers, led to increased germination parameters of potato tubers (refer to Table 4.5.1 b). These findings collectively emphasize the positive impact of bio-char on the germination process and underscore the potential benefits of integrating bio-char into agricultural practices, particularly when combined with other organic inputs. In terms of plant height, significant effects were observed due to the incorporation of various doses of bio-char along with manures and fertilizers (refer to Table 4.5.2 a & b). The highest plant height at harvesting was recorded in the T_4 treatment, while the control exhibited the minimum plant height (PH). The application of bio-char significantly ($p<0.05$) increased plant height, a finding consistent with (Graber *et al.,* 2010), who highlighted the positive impact of bio-char on plant height. Additionally, the combination of bio-char with mineral fertilizers was found to significantly enhance plant growth, as emphasized by Schulz and Glaser (2012). Therefore, the synergistic application of bio-char with organic manures and fertilizers emerges as a promising strategy for optimizing agronomic performance.

Dry matter accumulation was found to be higher under T_4, while it was recorded as the lowest under T_1 (refer to 4.4.3 a and b). These results align with previous investigations that have highlighted the positive role of bio-char and organic amendments in promoting plant growth and development (Graber *et al.,* 2010, Schulz and Glaser, 2012). Therefore, it can be suggested that the combination of bio-char with organic amendments emerges as a highly promising agricultural practice for optimizing agronomic performance. This synergistic approach capitalizes on the beneficial effects of both bio-char and organic inputs, potentially enhancing dry matter accumulation and overall plant productivity.

The co-application of manure, fertilizer, and bio-char has stimulated leaf growth, leading to an increased assimilation capacity driven by enhanced photosynthesis. Various bio-char-based amendments were found to exert a significant impact on leaf area, a phenomenon supported by Burke *et al.,* (2012), who attributed the increased leaf area to enhanced cell expansion. This discovery aligns with the outcomes reported by Njoku *et al.,* (2015) demonstrating that plots treated with bio-char exhibited a greater leaf area compared to control plots. In the context of the current study, the leaf area index (LAI) was notably affected by different combinations of treatments. Specifically, a substantial increase in LAI was observed under T_4 at both 30 days after sowing (DAS) and at harvest (refer to 4.5.4 a and b) throughout the growing season. This increase in LAI is crucial as leaf surfaces serve as primary boundaries for critical processes related to energy and mass exchange, including canopy interception, evapotranspiration, and gross photosynthesis. The significant impact on LAI across treatments may be attributed to bio-char-based organic amendments, as suggested by Camargo *et al.,* (2016). Overall, these results highlight the positive influence of bio-char in combination with organic amendments on leaf growth and area, contributing to the overall vitality and productivity of the plants.

The number of haulms per potato plant exhibited a substantial increase compared to the control (refer to 4.5.5 a and b), with the maximum number recorded in the T_4 treatment. Mollick *et al.*, (2020) similarly reported a significant increase in the number of stems with highest dose of bio-char application along with the fertilizers. The use of farm yard manure (FYM), pouyty manure (PM), vermicompost (VC), and bio-char, either individually or in combination with fertilizers, led to increased leaf chlorophyll content and a higher number of haulms compared to the use of inorganic fertilizers alone. This observation suggests that the enhanced availability of nutrients, coupled with vigorous plant growth and healthier plants, contributed to an overall increase in yield. Regarding developmental studies, the days to emergence were found to be the lowest under T_4, while the highest days to emergence were recorded under control conditions, indicating a positive response of potato seeds to the treatment. However, plants took more days to mature, specifically 115 days, under T_4 (refer to 4.5.6 a and b). These results underscore the complex interplay of various treatments on different stages of plant development, with T_4 showing a favorable impact on emergence but requiring more time for maturity.

Yield:

Several studies, including those conducted by Van Zwieten *et al.*, (2010 a and b) consistently emphasize the significant potential of bio-char to improve crop yields (Zhang *et al.*, 2012, and Nair *et al.*, 2014). However, the crop's response to bio-char application is highly variable and depends on factors such as the type of bio-char and the rate of application. In the present study, there was a notable increase in the number of tubers plant^{-1} with different rates of bio-char application, as outlined in Table 4.5.7a and 4.5.7b.

The treatment T_4 showed the maximum number of tubers plant^{-1}, while the control treatment yielded the minimum. Youssef *et al.*, (2017) similarly reported a positive increase in the number of tubers with bio-char fertilization. Furthermore, the tuber yield of potatoes saw a significant increase due to the use of bio-char in along with fertilizers (Table 4.5.8 a & b). The highest tuber yield was obtained from the T_4 treatment, while the lowest tuber yield (14.51 tone ha^{-1}) was observed in the T_1 (control) treatment. It's worth noting that while many studies, such as those by (Van Zwieten *et al.*, 2010; Zhang *et al.*, 2012, and Nair *et al.*, 2014), support the positive impact of bio-char on crop yields, others, like (Deenik *et al.*, 2010; Gaskin *et al.*, 2010, and Van Zwieten *et al.*, 2010), have reported small improvements or even reductions in yield with the use of bio-char in nutrient-rich soils. The variability in crop responses highlights the importance of considering bio-char type and application rates for optimal outcomes in agricultural practices (Gaskin *et al.*, 2010).

Quality:

Bio-char plays a pivotal role in influencing both the quality and yield attributes of potatoes, impacting parameters such as reducing sugar, starch content, Vitamin C content, specific gravity, and shelf life. In the study, starch content was observed to be the highest under treatment T_4 (refer to 4.5.9 a and b). This aligns with findings from Das (2018), who similarly reported an increase in starch content with bio-char application. The enhancement in starch content in bio-char and fertilizer-treated plots can be attributed to improved growth and increased accumulation of carbohydrates. It's important to note that an increase in starch content often correlates with a reduction in the protein content of potato tubers. In addition to starch content, the analysis of potato tuber grading revealed a higher yield of large-sized tubers under treatment T_4. This result is attributed to improved crop nutrition, facilitated by the abundant provision of nutrients through the utilization of bio-char, manures, and fertilizers under treatment T_4 (refer to Table 4.5.9 a and b). This enhanced nutrient availability likely contributed to increased tuber bulking compared to other treatments, further emphasizing the positive impact of bio-char on both the quantitative and qualitative aspects of potato yield.

CHAPTER-V

SUMMARY AND CONCLUSION

The study, titled "**Effect of bio-char-based organic amendments on soil biological & biochemical indicators in relation to increase soil nutrient release potential and yield of potato**" was carried out during the Rabi seasons of 2017-18 and 2018-19 in the village of Kalloh, Mansa, located in Punjab. The experiment utilized a Randomized Block design with three replications, incorporating a total of thirteen combinations of bio-char-based organic treatments. For the details of the treatment and its combinations implemented during the period of research refer (Table-3.3a and 3.3b).

It's noteworthy that, based on the recommendation of the research advisory committee, RDF was increased from 25% to 50% in all treatment combinations for the 2018-19 season, except for the control. Throughout the study, the recommended packages and practices for potato crops were uniformly applied to the entire research trial field in both years. These recommendations were consistently followed for the entire duration of the research work. In addition to these standardized practices, various cultural operations such as irrigation, weeding, and plant protection measures were executed concurrently. This synchronized approach aimed to accurately assess the true impact of the treatments on the soil and the overall growth of the potato crop. Observations related to soil conditions, seedling growth, and biochemical analysis of soil, yield, and yield attributes were recorded in accordance with the recommended days after sowing. Carefully collected soil samples from the 0-15 cm depth were obtained using standard procedures, ensuring the systematic and accurate assessment of soil characteristics throughout the research period.

The study was undertaken with the primary objective of determining the impact of bio-char-based organic amendments on soil biological and biochemical indicators, with a specific focus on increasing soil nutrient release potential and potato yield. To achieve reliable results, the following objectives were considered:

1- To study the potential of bio-char-based organic amendment in relation to increase soil nutrient release potential.

2- To identify the combination of organic amendment to be mixed in different proportions with bio-char.

3- To study the impact of organic amendment on soil biological and biochemical indicators.

4- To evaluate the carbon and nitrogen sequestration of soil amended with different proportions of organic amendments.

5- To correlate the soil enzymes, soil nutrient status, and soil physical status with the growth parameters

By addressing these objectives, the study aimed to provide comprehensive insights into how bio-char-based organic amendments affect both soil health and potato crop performance, with a specific emphasis on nutrient dynamics and yield outcomes.

1- The outcomes of this work suggest that the use of bio-char-based organic amendments had a substantial impact on the liberation of nitrogen, phosphorus, and potassium in both years. Notably, the second year exhibited a more pronounced effect, particularly in terms of nitrogen and phosphorus release. Specifically, the highest release of nitrogen was observed in treatment T_4, while treatment T_3 consistently recorded the highest liberation of phosphorus and potassium in both years of soil samples whereas both the treatments were statistically significant for the release of nitrogen, phosphorous, and potassium in the soil compared with a control set of treatment at (p 0.05%). This implies that certain combinations of bio-char-based treatments, represented by T_4 for nitrogen and T_3 for phosphorus and potassium, were particularly effective in enhancing the release of these essential nutrients from the soil. The results underscore the potential of bio-char-based amendments to influence nutrient dynamics in the soil, contributing to improved nutrient availability for plant growth and development.

2- The application of treatments in the soil had an impact on the ammonical and nitrate forms of nitrogen (NH_4^+N and NO_3^-N in mg kg^{-1}). Results from the study showed that bio-char-based organic treatments had a nonsignificant influence on the release of both the form of nitrogen i.e. ammonical and nitrate forms at (p 0.05%) in 2017-18. However, the same treatments played a significant impact in subsequent years of the trial in 2018-19, with the highest amounts recorded in T_1 (positive amendments - 100% NPK) for both parameters, followed by T_4.

3- In both years of the study, the application of the above-mentioned treatments had a notable impact on the levels of organic carbon (%) and soil microbial biomass carbon (SMBC in µg g^{-1}) in the soil. T_4 consistently recorded the highest values for both organic carbon percentage and soil microbial biomass carbon in both years. Additionally, in the second year, the amounts of organic carbon percentage and SMBC particulate organic carbon (g kg^{-1}) were found to be higher than those in the first year. These results indicate that the bio-char-based organic amendments, particularly represented by T_4, had a statistically significant influence on enhancing soil organic carbon content and microbial biomass carbon compared with control at (p 0.05%) in both the years (2017-18 and 2018-19. The observed increase in these parameters in the second year suggests a potential cumulative effect of the amendments over time. The findings highlight the positive impact of bio-char-based treatments on soil carbon dynamics and microbial biomass, contributing to overall soil health and fertility.

4- The treatments also had a significant impact on the levels of organic carbon (%) and soil microbial biomass carbon (SMBC µg g^{-1}) during both years of the study. In both years, T_4 consistently recorded the highest values for both organic carbon percentage and soil microbial biomass carbon. Furthermore, in the second year, the amounts of organic carbon percentage and SMBC and particulate organic carbon (POC g kg^{-1}) were found to be higher than those in the first year.

5- The soil pH and electrical conductivity (EC) levels were consistently and significantly higher in the years, 2017-18 and 2018-19. Notably, T_4 recorded the highest values compared to the rest of the treatments including control was showing statistically significant difference at (p 0.05%). This higher pH and EC levels can be attributed to the application of the bio-char-based organic amendment to the soil in both years.

6- The applied treatments also had a substantial influence on the levels of labile carbon and particulate organic carbon (g kg^{-1}) in the soil during both years of the study. Notably, there was a significant difference between T_4 and T_5 in the amount of labile carbon and particulate organic carbon in both years at (p 0.05%). Additionally, the second-year soil contained marginally more labile carbon than the first-year soil. These findings indicate that the specific bio-char-based treatments, particularly T_4, had a notable influence on increasing the levels of labile carbon and particulate organic carbon in the soil.

7- The study demonstrated that bio-char-based organic amendments had a significant and positive impact on soil enzyme activities, including dehydrogenase activity, acid phosphatase activity, and alkaline phosphatase activity, in both years. Across all soil enzyme studies, T_4 consistently emerged as the most effective treatment among all the options whereas it showed the highest significant difference with control at (p 0.05%). However, it was observed that the activity of these enzymes was marginally higher in the second year compared to the first year. These findings indicate that the application of bio-char-based amendments, particularly represented by T_4, positively influenced the soil enzyme activities, contributing to enhanced microbial activity and nutrient cycling in the soil.

8- The study demonstrated that bio-char-based organic amendments had a significant and positive impact on soil enzyme activities, including dehydrogenase activity, acid phosphatase activity, and alkaline phosphatase activity, in both years. Throughout all soil enzyme studies, T_4 consistently emerged as the most effective treatment among all options. However, it was observed that the activity of these enzymes was marginally higher in the second year compared to the first year.

9- In the first year of the experiment, it was observed that biochar-based organic amendments had no statistically significant effect on the plant's emergence percentage. However, in the second year, there was a significant impact on the plant's emergence percentage, and T_4 was distinguished as significantly highest impactful for the emergence of the plant compared to the rest of the treatments by showing a significant difference at (p=0.05%).

10- As a result of applying bio-char and organic resources to the soil during both the years of 2017-18 and 2018-19, there was a significant difference in plant height at all the days following sowing, namely 30, 60 days, as well as at harvest time. It was found that the maximum height of all treatments was observed in T_4, where the second trial was marginally superior to the first year in terms of height.

11- Due to the application of treatments to the soil, a significant jump in the dry matter accumulation (%) was observed. In both years, the maximum amount of dry matter accumulation was reported in T_4, while the marginal difference in dry matter accumulation percentage was observed in 2018-18 in comparison to 2017-18.

12- Different combinations of treatments were employed throughout the growing season with the aim of progressively enhancing the leaf area index (LAI). In both the years 2017-18 and 2018-19, the highest LAI was consistently recorded in T_4. Notably, the expanded LAI was observed to be at its maximum in the second year compared to the first year.

13- The number of haulms plant^{-1} in both years was significantly influenced by the application of bio-char-based organic amendments, leading to a notable increase in haulms plant^{-1}. Among the treatments, T_4 demonstrated a higher effectiveness compared to the other treatments. Additionally, T_3 showed a similar level of effectiveness to T_4 in both years.

14- Developmental studies, including days to emergence and days to maturity, exhibited significant responses to the use of the bio-char and organic resources. The treatment combination of 25% recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40 % in 2017-18 and 50 % recommended dose of fertilizers + 75% (bone meal + vermicompost + poultry manure) + bio-char 40 % in 2018-19 was identified as one of the most effective. In these treatments, days to emergence were minimized, indicating a quicker emergence of plants. However, days to maturity took a longer duration compared to the remaning all the treatments in during the study period.

15- The application of bio-char-based organic amendments did not have a significant effect on the number of plants per meter row length in both years. However, significant responses were observed for yield attributes, including the average number of tubers, the average weight of tubers, the average weight of tubers plant^{-1}, and tuber ha^{-1}. The maximum increase in these yield attributes was observed under the treatment 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 40 % in 2017-18 and 50% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 40% in 2018-19.

16- The starch content in tubers exhibited a significant increase under the application of bio-char-based organic amendments. The highest increase of starch content was recorded with the treatment T_4 in both the years of study 2017-18 and 2018- 19 while the T_3 was recorded very close to T_4. The starch content (%) was recorded as marginally superior in 2nd year compared to 1st year.

Conclusions:

Certainly, the findings of the present study strongly suggest a correlation between the application of bio-char-based organic amendments and an increase in potato yield. This correlation is likely attributed to the manipulation and improvement of soil physicochemical properties, soil enzyme activity, as well as the growth, development, and yield-related properties of the potato plants. The positive outcomes observed in these aspects indicate that the bio-char-based amendments had a beneficial impact on multiple factors influencing potato cultivation, ultimately contributing to enhanced yield.

As compared to a control treatment, the improvement of the soil's physico-chemical properties as well as the enzymes within the soil is beneficial to the release of nutrients in appropriate amounts throughout the growing season. Additionally, it also contributes to the preservation of the biological properties of soil, thereby providing you with an additional benefit in this regard as well.

Among the bio-char-based organic amendments, T_4 i.e. 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + b io-char 40%) and 50% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 40% and T_3 25% recommended dose of fertilizer+75% (bone meal + vermicompost + poultry manure) + bio-char 30%) and 50% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + bio-char 30%) (2017-18 and 2018-19) were found the most appropriate treatment combination while the improvement was in the second set of treatments compared to the first set of treatments for the entire parameters including soil physical and biological properties, soil enzyme activity, growth, development, yield and yield attributes.

Suggestions for the future research

As per the outcomes received from the research that includes field experiments followed by laboratory testing of various parameters of the soil as well as the plant, it can be concluded that bio-char alone is not known to have a significant impact on crops and soil because they are plant and site-specific. As nutrient boosters for soil and crops, vermicompost, poultry manure, and bone meal have all been proven to be effective. There is therefore a need to conduct further study in order to gain a better understanding of the effect of bio-char on crop growth, development yield, and biochemical and molecular changes in growing crops. In the future, a study should also take into account the type of bio-char, the method of preparation, and the amount of bio-char to the soil.

Based on the findings the following suggestion can be given to the farmers.

- The bio-char-based organic amendments demonstrated a apparent impact on improving the soil nutrient release status in both sets of treatment combinations. While positive results were observed in combinations with 50% recommended dose of fertilizer compared to those with 25% recommended dose of fertilizer, the best combination was consistently recorded in T_4 in both years. T_4 represented the treatment with 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + 40% bio-char and 50% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + 40% bio-char. Following T_4, T_3 exhibited favorable outcomes as well.
- The bio-char-based organic amendments also exerted a apparent impact on the improvement of the growth, development, yield, and yield attributes of the potato crop in both sets of treatment combinations. Better results were observed in combinations with 50% recommended dose of fertilizer compared to those with 25% recommended dose of fertilizer. The best combination was consistently recorded in T_4 in both years, representing 25% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + 40% bio-char, and 50% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + 40% bio-char. Following T_4, T_3 exhibited favorable outcomes as well.

- Based on the findings of this study, it is recommended that farmers consider the combination of T_4, specifically 50% recommended dose of fertilizer + 75% (bone meal + vermicompost + poultry manure) + 40% bio-char, for achieving better soil health and maximizing the yield of potato crops. This combination has demonstrated positive effects on soil health, including nutrient release status, as well as on the growth, development, and yield attributes of the potato crop. By adopting this recommended combination, farmers may enhance both the sustainability of soil conditions and the overall productivity of potato cultivation.

CHAPTER-6

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Appendix – I

Fixd cost of potato cultivation (ha^{-1}) (2017-18)

Particulars	Operational input ha^{-1}	Rate (Rs.)	Units	Total cost (Rs. ha^{-1})
Seed	3000 kg	16	3000	48000
Ploughing	5 hr	850	5	4250
Labourers	-	-	-	-
Plot preparation	8-man days	300	8	2400
Sowing	25-man days	300	25	7500
Irrigation	10-man days	300	10	3000
Harvesting	25-man days	300	25	7500
Spray	-	-	-	-
Paraquat	2.0L	350	2	700
Dithane	1.8 l	400	1.8	720
Ridomill	1.8 l	1100	1.8	1980
Cypermethrin	750 ml	400	.75	300
Fipronil (Soil application)	10 kg	90	10	900
Spray Labourers	4-man days	300	4	1200
Cost of cultivation (Rs ha^{-1})				78450

Appendix – II

Treatment wise cost of cultivation (Rs ha^{-1}) (2017-18)

Treatments	Fixed Cost	Variable Cost	Total cost of cultivation	Gross returns	Net returns	B:C ratio
T1	78450	6100	84550	266000	181450	2.15
T2	78450	17650	96100	363670	267570	2.78
T3	78450	18650	97100	365100	268000	2.76
T4	78450	19650	98100	366170	268070	2.73
T5	78450	24150	102600	303330	200730	1.96
T6	78450	10275	88725	298670	209945	2.37
T7	78450	18525	96975	300300	203325	2.10
T8	78450	25150	103600	343400	239800	2.31
T9	78450	11275	89725	338120	248395	2.77
T10	78450	19525	97975	341700	243725	2.49
T11	78450	26150	104600	347330	242730	2.32
T12	78450	12275	90725	340700	249975	2.76
T13	78450	20525	98975	346660	247685	2.50

Appendix – III

Fixd cost of potato cultivation (ha^{-1}) (2018-19)

Particulars	Operational input ha^{-1}	Rate (Rs.)	Units	Total cost (Rs. ha^{-1})
Seed	3000 kg	16	3000	48000
Ploughing	5 hr	850	5	4250
Labourers	-	-	-	-
Plot preparation	8-man days	300	8	2400
Sowing	25 man days	300	25	7500
Irrigation	10 man days	300	10	3000
Harvesting	25 man days	300	25	7500
Spray	-	-	-	-
Paraquat	2.0L	350	2	700
Dithane	1.8 l	400	1.8	720
Ridomill	1.8 l	1100	1.8	1980
Cypermethrin	750 ml	400	.75	300
Fipronil (Soil application)	10 kg	90	10	900
Spray Labourers	4 man days	300	4	1200
Cost of cultivation (Rs ha^{-1})				78450

Appendix – IV

Treatment-wise cost of cultivation (Rs ha^{-1}) (2018-19)

Treatments	Fixed Cost	Variable Cost	Total cost of cultivation	Gross returns	Net returns	B:C ratio
T1	78450	6100	84550	278000	193450	2.29
T2	78450	19175	97625	375670	278045	2.85
T3	78450	20175	98625	377100	278475	2.82
T4	78450	21175	99625	378170	278545	2.80
T5	78450	25675	104125	315330	211205	2.03
T6	78450	11800	90250	310670	220420	2.44
T7	78450	20050	98500	312300	213800	2.17
T8	78450	26675	105125	355400	250275	2.38
T9	78450	12800	91250	350120	258870	2.84
T10	78450	21050	99500	353700	254200	2.55
T11	78450	27675	106125	359300	253175	2.39
T12	78450	13800	92250	356700	264450	2.87
T13	78450	22050	100500	358660	258160	2.57

Appendix – V

Effect of biochar-based organic amendments on graded yield (q ha^{-1}) of potato tubers (2017-18)

Treatments details	Grade A (>75 g)	Grade B (50-75 g)	Grade C (<50 g)
T1	81.00	97.00	88.00
T2	150.50	145.10	68.07
T3	151.81	146.41	66.88
T4	153.69	147.50	65.00
T5	110.10	100.14	93.09
T6	103.25	98.31	97.11
T7	106.18	99.89	94.23
T8	138.55	120.29	84.56
T9	130.54	118.31	89.27
T10	133.11	121.57	87.02
T11	148.32	128.67	70.34
T12	145.34	124.79	74.57
T13	147.22	128.33	71.11
C.D.	**5.43**	**5.59**	**3.25**

Appendix – VI

Effect of biochar-based organic amendments on graded yield (q ha^{-1}) of potato tubers (2018-19)

Treatments details	Grade A (>75 g)	Grade B (50-75 g)	Grade C (<50 g)
T1	84.00	101.00	93.00
T2	154.50	148.10	73.07
T3	155.81	150.40	70.95
T4	158.60	152.41	67.18
T5	115.10	103.14	97.09
T6	107.10	102.20	101.37
T7	109.18	105.24	97.88
T8	141.65	125.45	88.30
T9	134.12	122.22	93.78
T10	136.11	127.45	90.14
T11	152.32	131.67	75.34
T12	149.34	127.79	79.57
T13	151.22	131.33	76.11
C.D.	**6.25**	**5.05**	**2.81**

LIST OF PUBLICATIONS

Singh, J., Kumar, P. and Siddique, A. (2023). Biochar-based organic amendments on soil health, nutrient status and quality of potato (*Solanum tuberosum*). *Plant science today*, https://doi.org/10.14719/pst.2706

LIST OF CONFERENCES

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2. National Seminar on "Sustainable Rural Livelihood - Opportunities and Challenges" held at G.G.D.S.D. COLLEGE, HARIANA (HOSHIARPUR)