IMPACT OF MINERAL FERTILIZER, COMPOST AND BIOCHAR ON SOIL PROPERTIES, ROOT MORPHOLOGY AND CROP GROWTH OF MAIZE IN SANDY LOAM SOIL

by
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A Thesis submitted to
Faculty of Agriculture
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE IN AGRICULTURE

SOIL SCIENCE

Division of Soil Science and Agricultural Chemistry
Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu
Main Campus, Chatha, Jammu - 180009
2024

CERTIFICATE-I

This is to certify that the thesis entitled **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"** submitted in partial fulfillment of the requirements of the degree of **Master of Science in Agriculture (Soil Science)** to the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is original work and has similarities with published work not more than minor similarities as per UGC norms of 2018 adopted by the University. Further the level of minor similarities has been declared after checking the manuscript with **"DrillBit"** software provided by the University.

The work has been carried out by **Ms. Vani Mahindru**, under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.

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ACKNOWLEDGEMENTS

I bow with reverence to thank Mahadev, the supreme being, who has bestowed me with strength throughout the challenging moments of completing this dissertation. His wisdom and blessings have shaped every word and thought in this work.

I wish to express my deep and sincere gratitude to **Dr. Peeyush Sharma,** *Chief Scientist / Professor, Soil Science and Agricultural Chemistry, Udheywala, SKUAST-Jammu, Chatha and the chairman of the advisory committee for her guidance, unwavering support, constructive criticism and faith in me during the entire course of investigation and preparation of manuscript as well. I'am also thankful to Ma'am for providing me with all the necessary requirements needed in my research study.*

I extend my heartiest thanks to the other esteemed members of my advisory committee, **Dr. Vikas Abrol,** *Professor, Division of Soil Science and Agricultural Chemistry,* **Dr. Neetu Sharma,** *Professor, Division of Agronomy,* **Dr. Sachin Gupta,** *Professor, Division of Plant Pathology (Dean's Nominee) for their valuable suggestions and advice throughout the course.*

I 'am extremely grateful to **Dr. Vikas Sharma,** *Professor and Head, Division of Soil Science and Agricultural Chemistry, for providing me with all the facilities and his assistance throughout my work. It is through his intellect, support and guidance that helped me in my path of research.*

I owe my gratitude to the faculty members of the Division of Soil Science and Agricultural Chemistry, **Dr. Sarabdeep Kour** *(Professor),* **Dr. P.K. Rai,** *(Professor),* **Dr. Vivek M. Arya** *(Professor),* **Dr. Renu Gupta** *(Professor),* **Dr. Brinder Singh** *(Professor) and* **Dr. Veena Sharma** *(Technical officer) who have inspired my interest in the subject, guided me throughout my stay in the division and motivated me to work for my good.*

I acknowledge with appreciation my earnest thanks to the entire non-teaching staff, **Dr. Rohit Kumar Arora** *(Sr. Technician),* **Dr. Inderjit Sharma** *(Technical officer),* *Mrs. **Deepa** (Computer Assistant), **Mr. Sansar Chand** (LA), **Mr. Bishan Das** (Mali), **Mr. Chander Prakash**, **Mr. Pawan**, for rendering all possible help and support.*

*Words are not enough to express my feelings towards my family. I would like to thank my grandparents, **Late Mr. S.C. Mahindru, Late Mr. S.R. Malhotra, Late Mrs. Vimal Malhotra** and **Mrs. Asha Mahendru** who have always been my source of love, guidance and inspiration. I' am forever thankful to my three constant pillars of strength, my parents, **Mr. Atul Mahindru, Mrs. Pratibha Mahindru** and my elder brother **Mr. Vardhan Mahendru.***

*I would like to extend my sincere thanks to my respected seniors, **Owais Sir, Haziq Sir, Aabida Ma'am, Divya Ma'am, Reddy Sir, Stanzin Sir, Bhumika Ma'am** for their guidance, support and invaluable suggestions during my research work.*

*A special thanks to my dear friends and juniors **Vidushi, Aakash, Monu, Israr, Vaibhav, Gourav, Saraswati, Kajal, Shivali, Amandeep, Divyam, Yasmin, Harshita, Harnoor** for their help and support in one way or the other.*

In the end, I would like to thank all those who were directly or indirectly involved in my work.

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ABSTRACT

Title of the Thesis	:	**Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil**
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Degree to be awarded	:	Master of Science in Agriculture (Soil Science)
Year of award of degree	:	2024
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Abstract:

An investigation entitled, **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"** was conducted at the Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, during *kharif* season of 2023. The soil of the pot experiment was sandy loam in texture, neutral pH (6.7), low in organic carbon (0.26%), available nitrogen (164 kg ha^{-1}) and available potassium (91.5 kg ha^{-1}) but medium in available phosphorus (13.6 kg ha^{-1}). The pot experiment was laid out in factorial completely randomized design (two-factorial), wherein factor-1 was biochar which comprised 3 levels: B_1 (biochar @ 4t ha^{-1}), B_2 (biochar @8t ha^{-1}) and B_3 (biochar @ 12t ha^{-1}) and factor-2 was fertilizer amendments (both organic and inorganic) which comprised 4 levels: F_1 (100%N,P,K), F_2 (75%N,100%P,K,FYM @15t ha^{-1}), F_3 (50%N,100%P,K,FYM @15t ha^{-1}) and F_4 (FYM @15tha^{-1}). There were three replications which comprised of twelve treatments.

The results revealed that application of 12 t ha^{-1} biochar + 75% N + 100% P, K + FYM @15 t ha^{-1} (B_3F_2) increased soil organic carbon, available N, K, soil moisture and maximum water holding capacity over rest of the treatments. Reduction in soil bulk density, infiltration rate and hydraulic conductivity was recorded when soil was amended with biochar and mineral fertilizer (B_3F_2). Similarly improved plant height, nutrient uptake, root morphology and yield of rainfed maize in sandy loam soil under B_3F_2 treatment were recorded. Results showed that B_3F_2 treatment uplifted most of the soil physico-chemical properties, root growth and crop parameters when compared to sole application of recommended dose of mineral fertilizer.

Keywords: Mineral fertilizer, Biochar, Root morphology, Crop growth

Signature of Major Advisor

Signature of the Student

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LIST OF ABBREVIATIONS

MNRE	=	Indian Ministry of New and Renewable Energy
Mt	=	Million tonnes
GHGs	=	Greenhouse gases
PM	=	Particulate matter
IEA	=	International Energy Agency
BD	=	Bulk density
^{0}C	=	Degree celsius
mm	=	millimetre
K_{sat}	=	Saturated hydraulic conductivity
p	=	Probability
NO_3^--N	=	Nitrate-nitrogen
NH_4^+-N	=	Ammonium nitrogen
N	=	Nitrogen
P	=	Phosphorus
K	=	Potassium
Available N	=	Available nitrogen
Available P	=	Available phosphorus
AvailableK	=	Available potassium
CG	=	Coffee ground
CH	=	Coffee husk
KOH	=	Potassium hydroxide
pH	=	Potential of Hydrogen
EC	=	Electrical conductivity
OC	=	Organic carbon
SOC	=	Soil organic carbon
TOC	=	Total organic carbon
MWHC	=	Maximum water holding capacity
CEC	=	Cation exchange capacity
IR	=	Infiltration rate
HC	=	Hydraulic conductivity
AMF	=	Arbuscular mycorrhizal fungi
BC	=	Biochar

BC_v	=	Vineyard pruning biochar
BC	=	Woodchip biochar
FYM	=	Farmyard manure
VC	=	Vermicompost
&	=	And
Fig.	=	Figure
Max.	=	Maximum
Min.	=	Minimum
R.H.	=	Relative humidity
R.F.	=	Rainfall
Sci.	=	Science
Dept.	=	Department
Agri.	=	Agriculture
Univ.	=	University
pH	=	Puissance de hydrogen
EC	=	Electrical conductivity
OC	=	Organic carbon
Av.	=	Available
MBC	=	Microbial biomass carbon
NUE	=	Nutrient use efficiency
WUE	=	Water use efficiency
BD	=	Bulk density
SOM	=	Soil organic matter
SOC	=	Soil organic carbon
J&K	=	Jammu and Kashmir
µm	=	Micrometer
et al.	=	And others
viz.,	=	Namely
g cc^{-1}	=	Gram per cubic centimetre
DAP	=	Diammonium phosphate
ds m^{-1}	=	Decisiemen per meter
Mg m^{-3}	=	Mega gram per cubic meter
hr^{-1}	=	Per hour
@	=	At the rate of
CD	=	Critical difference
NS	=	Non-significant
ds m^{-1}	=	decisiemens per metre

%	=	Per cent
kg ha^{-1}	=	kilogram per hectare
g cm^{-3}	=	gram per centimetre cube
cm hr^{-1}	=	centimetre per hour
cm	=	centimetre
g pot^{-1}	=	gram pot^{-1}
g	=	gram
cm cm^{-3}	=	centimetre per centimetre cube
@	=	At the rate of

CHAPTER-1

INTRODUCTION

The industrial revolution (followed by the green revolution) fulfilled the food demands of the growing population. But this was done at the expense of increased use of synthetic fertilizers in agriculture. Reduced soil fertility is a major constraint in improving the agricultural production. In 1950, fertilizers comprised only a small percentage of the nutrients supplied to the crop and most of the supply was provided by the "natural fertility" of the soil and added manure. It was estimated that by 2020, more than 70% of the grain yield was dependent on fertilizers. This demand for plant nutrients continues to increase with the growing population.

Fertilizer costs and the mechanism underlying the effective utilisation of nutrients are prominent issues faced globally. Their overuse has resulted in deterioration of both soil and crops. In addition to adverse environmental effects caused by excess application of fertilizers, there is a looming global shortage of fertilizers. This is an unending vicious cycle of incorporating fertilizers at a pace which is exceeding the potential ability of soil or crop to withstand. Thus, ultimately making the soil "addict" for the same.

Lumps of surplus residue is another repercussion. The crop residue comprises the field residues and the residues generated post-harvest. On the contrary, the residues generated after processing the crop are the process residues. According to the Indian Ministry of New and Renewable Energy (MNRE), 500 million tonnes (Mt) of crop residue on average are generated annually.

The challenge comes with incinerating the crop residues in open areas that often lead to loss of nutrients, greenhouse gases emission (GHGs), leading to climate change. Enhanced particulate matter (PM) and other air pollutants, which cause health problems, thereby deteriorating soil fertility. Detrimental effects on soil fertility, lowering the total nutrients present in the soil can also be seen.

This marks up for an efficient management of field residues. Composting and biochar production are some of the sustainable strategies that resolves this limitation and simultaneously holds up for nutrients. This can be cut out by the conversion of organic waste to produce biochar using the pyrolysis process.

Biochar is the carbonaceous solid residue obtained after heating biomass under oxygen deficit conditions. It is made by pyrolysis (‘pyro’ in Greek means fire, while ‘lysis’ means breaking down into constituent parts). During pyrolysis, the organic matter is heated up to 300-600ºC in an oxygen deficit atmosphere. Biochar is a fine-grained, porous substance, sterile, odourless and a high carbon containing solid that may be produced from a variety of organic feedstock which can be made to suit the crop, soil type and management system to attain maximum benefit.

The term ‘biochar’ is a relatively new term and has only entered in usage in the 20th Century. However, it has been previously referred to as “black lands”, “black earth”, “dark earth”, “terra preta,” “terra preta de indio” (Indian black earth in Portuguese), or “Amazonian black earth”. It was initially linked with the study of deposits of enriched soils, known as “terra preta” (black carbon/earth) in the Amazon region of South America, in the early 20^{th} century. The research began to understand the permanently fertile soils in the Central Amazon. “This terra preta” is characterized by a sustainable enhanced fertility owing to enhanced SOM contents (Glaser, B. 2007).

Biochar incorporation alters soil physical properties such as pore size distribution, structure, thereby improving soil aeration and plant growth (Yadav *et al.* 2018). Owing to its porous nature, biochar reduces the soil bulk density which is favourable for plant growth (Chan 2008).

FYM is a source of organic matter that is used as an organic fertilizer in agriculture. FYM may be plant-derived or animal derived. It can be regarded as an animal manure that also contains plant material (often straw). Farm yard manure (FYM) application maintains the productivity of soil for a long duration (Kundu, 2007). Farm yard manure contains all the essential elements (both macro and micro) required for plant growth. Maintenance of organic matter in soil is important for the improving nutrient and structural status of soils, particularly under tropical conditions as in India (Manna *et al.,* 2003). FYM is not just a reservoir of plant nutrients, but also regulates the dynamics of all the nutrients (Katyal, 1977). Addition of farm yard manure in agricultural lands helps in build-up of the soil organic carbon and hence soil organic carbon is increased when FYM is applied. The high cation exchange capacity of soil is by virtue of exchange sites found in soil organic matter (SOM) (Laxminarayana 2001).

Despite, the positive impact biochar has on the soil and crops, it alone cannot be relied upon to feed the growing population. Mineral fertilizers cannot be completely terminated as it may lead to decline in the level of crop yields. Thus, a balance needs to be maintained in their application. Mineral fertilizers are the alternative for this. Mineral fertilizers are substances, either synthetic or natural, that provide nutrients necessary for plants to grow and develop normally. Nutrients from plants are food for the plants, some of which are utilized directly for human use, others as animal feed, natural fibre sources, or lumber producers. It is necessary to apply significant amounts of three plant nutrients: nitrogen, phosphorus, and potassium. Large amounts of calcium, magnesium, and sulphur are also needed. These nutrients are necessary for functions like energy transfer, internal pressure maintenance, and enzyme activity. They are components of numerous plant components, including proteins, nucleic acids and chlorophyll. Mineral fertilizers are mainly used in agriculture, for planting in crops to increase productivity. Therefore, great attention is paid to the production of fertilizers. The use of fertilizers allows increasing the yield of agricultural crops by 50-60%. For example, about a quarter of the food on the planet and about half of the cotton is obtained only from fertilizers. The nutrients in fertilizers, especially nitrogen, plays a dominant role in the mineral nutrition of plants.

Maize is also known as the “Queen of cereals” due to the maximum genetic yield potential. The term ‘maize’ is derived from the word ‘mahiz’ of Taino language which means ‘life giver’. It originated in Mexico and belongs to the family Poaceae. In India, it is known by different names as ‘Makka’ in Hindi, ‘Makkai’ in Punjabi and ‘Makk’ in Dogri language. It is also popularly known as ‘Corn’ in English-speaking countries. Maize, being the third most important food crop among cereals in India and contributes to nearly nine per cent of national food basket. In India, the cultivated area is about 19.06 million hectares, production and productivity of 28.77 million tonnes and 1.50 tonnes/hectare respectively. Erstwhile, in the Union Territory of J&K, the area, production and productivity stands up for about 220.06 thousand hectares, 412.205 thousand metric tonnes and 1.87 tonnes/hectare respectively. Out of 220.06 thousand hectares, maize cultivated over an area of about 17.77 thousand hectares in Jammu region with the production of 32.99 thousand metric tonnes and productivity of about 1.85 tonnes/hectare (FAOSTAT, 2021). It is an important rainfed crop of Jammu region.

However, the yield remains stagnant due to water stress, low rainfall and high evaporation.

Keeping in view, pot culture experiment was conducted to study **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"** with the following objectives:

Objectives

- To study the effects of mineral fertilizer, compost and biochar on root morphology and growth of maize plant.
- To investigate the effects of mineral fertilizer, compost and biochar on nutrient uptake and soil properties.

CHAPTER-2

REVIEW OF LITERATURE

Escalation in global demand for food, constrained resources and climate change necessitate our agricultural systems to be both more productive and resilient. Every year, world-wide carbon dioxide (CO_2) emissions from energy uses are increasing. According to the IEA's latest World Energy Outlook 2023 "CO_2 emissions to peak in the mid-2020s". An accompanying press release says this will happen "by 2025". Global fossil fuel use peaking in 2025, is two years earlier than expected last year. For the first time, coal, oil and gas each peaking before 2030 under current policies. Based on current national commitments, the gap to emissions consistent with limiting warming to 1.5°C in 2030 was estimated to be between 20.3 billion mt CO_2 and 23.9 billion mt CO_2.

Consequently, innovative tools are required to help deal with these complex challenges, which has fuelled interest in biochar as a soil amendment to improve soil quality and crop productivity. Production of biochar and its soil application primarily for waste management, soil amendment, carbon sequestration and greenhouse gas emission reduction from crop fields has emerged as an interesting field of study and research worldwide.

Biochar in combination with other organic and inorganic amendments will result in valuable outcomes. In this chapter, a brief review of the available literature regarding the current research has been offered under the labelled headings.

2.1 Biochar

2.1.1 Effect of biochar on physical properties of soil

2.1.2 Effect of biochar on chemical properties of soil

2.1.3 Effect of biochar on root morphology, plant growth and development

2.2 Mineral Fertilizers

2.2.1 Effect of biochar + mineral fertilizers on physical properties of soil

2.2.2 Effect of biochar + mineral fertilizers on chemical properties of soil

2.2.3 Effect of biochar + mineral fertilizers on root morphology, plant growth and development

2.3 Compost (FYM)

2.3.1 Effect of biochar + compost on physical properties of soil

2.3.2 Effect of biochar + compost on chemical properties of soil

2.3.3 Effect of biochar + compost on root morphology, plant growth and development

2.4 Combined application

2.4.1 Effect of biochar + mineral fertilizers + compost on physical properties of soil

2.4.2 Effect of biochar + mineral fertilizers + compost on chemical properties of soil

2.4.3 Effect of biochar + mineral fertilizers + compost on root morphology, plant growth and development

2.1 Biochar

Biochar is a charcoal-like material (carbon rich) that is produced from plant materials (such as grass, agricultural or forest residues) and is decomposed at high temperatures. It is the pyrolysis product which contains all non-combustible constituents of the feedstock (ash), and therefore is always present as a product of pyrolysis and gasification, regardless of process temperature and feedstock. From an agricultural perspective, biochar application immediately affects the physical, chemical and biological qualities of soil, such as its pH and EC, density, aeration and penetration resistance, all of which further directly or indirectly influences plant growth.

2.1.1 Effect of biochar on physical properties of soil

Rehman *et al*. (2020) made major observations of biochar on water holding capacity in different soil types. Pot experiment was conducted and it was deduced that biochar increased water holding capacity in sandy loamy soils. Basso *et al*. (2013) observed the similar trend. Also, woody biochar incorporation in soil led to increase in water holding capacity in loamy sand soil.

Verheijen *et al.* (2019) evaluated the effect of particle size of biochar and its concentration in sandy and sandy loam soil. Increasing biochar doses in soils resulted in lowered soil BD. This is attributed to measurement of bulk density as result of wetting and drying cycles due to undisturbed packed state of the soil. It was also observed that consistent results were observed even with single wetting and drying cycles.

Obia *et al*. (2016) examined the effects of biochar on soil porosity and the divided the same into two experiments. Experiment A consisted of crushed maize cob biochar applied in conservation farming, while experiment B consisted of corn cob and rice husk biochar. Biochar significantly ($p < 0.01$) increased soil total porosity in the planting basins by 2% biochar applied, but there was no difference between crops. In experiment B, there was an increase in total porosity for all biochar particle sizes in Kaoma soil ($p < 0.01$) and for the coarse 1–5 mm biochar fraction.

Burrell *et al.* (2016) studied the effect of a woodchip biochar on a Chernozem, Cambisol and a coarse-textured Planosol in a pot experiment. A comparative analysis was carried out to study the effect of different biochar on the Planosol, including woodchip biochar, straw biochar and two vineyard-pruning biochar produced at different pyrolysis temperatures. Soil aggregate stability was higher when compared to control in all biochar-amended Planosol treatments after three years, with 92%, 37%, 28% and 50% relative increase in the straw, 525^{o}C vineyard-pruning, 400 ^{o}C vineyard-pruning and woodchip biochar treatments, respectively. This effect was also observed in the woodchip biochar amended Chernozem with a 26% relative increase, but not in the Cambisol.

Githinji *et al.* (2014) documented the effect of biochar with different application rates on soil texture. It was examined that biochar addition modified the soil texture slightly from 'loamy sand' to 'sand'. This was due to the presence of many larger particles in the range of sand in the biochar. On the contrary, the increase in the concentration of clay particles provided for greater surface area, which further uplifted the physico-chemical soil properties.

Devereux *et al*. (2012) examined the effect of biochar on water retention in a pot trial using different concentrations of biochar @ 0%, 1.5%, 2.5% and 5% w/w. The increased biochar doses decreased the average pore size. Saturated hydraulic conductivity decreased on the addition of biochar. The decrease was attributed to large surface area and high number of pores in biochar, which needs to be retained with water.

2.1.2 Effect of biochar on chemical properties of soil

Feng *et al*. (2021) worked on corn and studied the effect of biochar application on available nitrogen. The available nutrients (NO_3^--N, NH_4^+-N) increased on the application of straw biochar. This was due to migration mechanism of nutrients in biochar.

Glaser *et al*. (2019) undertook a meta-analysis to study the effect of biochar on phosphorus availability in agricultural soils. Biochar application significantly increased available P. The overall mean response of biochar to plant-available P was significantly positive. There was a significant correlation between application amount and plant-available P in biochar-treated soil. Plant-available P positively responded to biochar application above 10 Mg ha^{-1}.

Wang *et al*. (2018) studied the effect of biochar application on potassium dynamics in the soil. A pot trial was conducted in soil types- alfisol and entisol. Potassium availability enhanced in both these soils. Alfisol soil showed increase in available K. This was mainly reflected in exchangeable-K. Entisol soil, on the other hand, showed a much greater improvement in non-exchangeable-K.

Lima *et al*. (2018) evaluated the effect of biochar made from coffee residues (both coffee ground (CG) and coffee husk (CH)) on the physicochemical characteristics of an entisol in maize. A greenhouse pot experiment, quantifying maize growth, with different rates of biochar amendments was conducted. The use of CH biochar had a significant incidence on soil pH as it contributed to a regular linear rise from 5.5 to 7 when biochar content increased from 4 to 16 Mg ha^{-1}. The use of CG biochar did not have the same effect on soil pH even for high biochar contents. Soil pH increased concomitantly with CH biochar content, but it did not evolve significantly with increasing CG biochar content. The presence of larger proportion of ash in CH biochar than in CG biochar, was the reason behind this. Generally, ash contains noticeable KOH amounts. This induces liming effect, thereby increased soil pH.

Lorenz *et al*. (2014) documented the effect of biochar on organic carbon. Biochar enhanced SOC sequestration. This is due to intrinsic stability of some biochar components in biochar.

Chintala *et al*. (2014) examined the effect of biochar on electrical conductivity of soil. Corn stover biochar significantly increased EC of soil. Biochar addition in acidic soil increased EC due to presence of weakly bound ions.

2.1.3 Effect of biochar on root morphology, plant growth and development

Wan *et al*. (2023) noted the alteration in root morphology in maize. It was observed that total root length, root area, root diameter, root volume of maize plants was significantly greater under biochar compared to non-biochar controls. Root length density was solely affected by biochar treatment. It was greater for biochar-amended plants than for non-biochar plants. All these effects of biochar on root morphological traits were more evident with wheat straw biochar.

Feng *et al*. (2021) undertook a field experiment to study the effects of biochar application on plant height and growth of corn. Excessive biochar application in shallow soil layers affected the water holding capacity of soil around the maize root system, and excessive soil loosening caused maize roots to concentrate near the soil surface.

Liu *et al*. (2021) carried out a study on maize to see the effect of biochar on root morphology in rainfed condition. Biochar amendment increased root size and the number of root tips significantly. Root length, root surface area, average root diameter, and root volume increased by 46.1%, 58.4%, 66.5%, and 73.0% respectively compared to control. The number of root tips increased by 88.2% compared to control.

Huang *et al*. (2018) studied the effect of biochar application on nitrogen uptake and utilization in rice. N uptake was determined by soil N availability and root system activity. Biochar increased total soil N content at the end of the experiment. The increase in total soil N content with biochar application was partly due to the biochar containing a certain amount of N.

Wang *et al*. (2018) studied the effects of biochar on soil potassium dynamics, mechanisms and crop uptake. K fixation occurred in entisol. This is attributed to higher content of 2:1 K-bearing minerals. During the maize period, crop K uptake was generally higher in entisol soil due to the release of non-exchangeable K. Moreover, biochar addition stimulated the growth of potassium dissolving bacteria.

Madiba *et al*. (2016) worked on a subterranean clover–wheat and studied the effect of biochar application on phosphorus availability. Biochar increased plant shoot P uptake. This is attributed to increased available P and microbial biomass P in soil. Biochar application also increased mycorrhizal colonisation in wheat roots which was higher (up to 70 %) at the P application rate of 25 kg ha^{-1}. Increase in soil pH and mycorrhizal colonisation from biochar application might have contributed to the increase in plant P uptake and shoot growth. The P uptake by plants was directly influenced by the extent of AMF colonisation and the proximity of P sources. Solaiman and Abbott (2008) demonstrated that the nearer the fungal hyphae was to the P source, the greater the P uptake. This holds true for biochar addition, if there was a close physical association between biochar, AMF hyphae and plant roots.

Xiao *et al*. (2016) examined the effect of biochar on root weight density in maize. The increase in root weight was observed post germination. This is because, biochar application greatly influenced root length density and root surface area density.

2.2 Mineral Fertilizers

Mineral fertilizers are materials which contain nutrients essential for crop growth and development. These plant nutrients are regarded as "food for plants". Three plant nutrients need to be applied in large quantities, nitrogen, phosphorus and potassium. Urea, DAP and MOP are the fertilizers for these nutrient elements respectively. Apart from providing essential plant nutrients, mineral fertilizers compensate for the nutrients lost by leaching or plant uptake.

2.2.1 Effect of biochar + mineral fertilizers on physical properties of soil

Adekiya *et al*. (2022) undertook two-year field experiment to study the combined application of biochar and K fertilizer on soil properties and performance of sweet potato. Four weeks after the application of treatments, bulk density, total porosity and gravimetric water content was determined. Application of K fertilizer alone did not improve soil's physical properties relative to control. The interactive effect of biochar and K fertilizer were significant for bulk density, porosity and moisture content of soil. The addition of biochar to K fertilizer improved soil physical properties relative to biochar or K fertilizer alone with 20 t ha^{-1} biochar + K fertilizer had the best values. Relative to control in 2020, 20 t ha^{-1} biochar + 120 kg ha^{-1} K fertilizers reduced soil bulk density by 30.4 % and increased porosity and moisture content by 28.5 % and 43.2

% respectively. In 2021, bulk density was reduced by 29.7% and porosity, and moisture content increased by 27.1 % and 39.9% respectively relative to control by the application @ 20 t ha^{-1} biochar + 120 kg ha^{-1} K fertilizers.

Rehman *et al*. (2021) worked on maize and applied manure-based biochar and mineral fertilizer to study the effect on water holding capacity in different types of soil. Water holding capacity of sandy loam soils increased. A similar effect was observed in sandy soils.

Fayole *et al*. (2019) conducted field experiment to study effect of biochar and mineral fertiliser on hydraulic conductivity in maize. Biochar altered the water holding capacity and improved the hydrological properties of the soil; i.e., hydraulic conductivity. Sandy soils normally had high infiltration rate and hydraulic conductivity. Biochar altered the downward movement of water and might hold the water against gravitation pull. The lower particle size of biochar enables it to fill-in larger sized pores and thereby modify water flux. The increase in water content was also significant at 0–60 cm soil depth where treatments comprised of biochar and fertiliser compared to soil treated with only fertiliser. This is attributed to biochar's ability to reduce soil water depletion caused by fertiliser application. Depletion of soil water (0–60 cm depth) by maize plant root was more in the unamended plot compared to soil treated with biochar. Addition of biochar reduced depletion in the rhizosphere of maize compared to the unamended plot, therefore making more water available for plant uptake.

Lusiba *et al*. (2017) evaluated the effect of biochar and P fertilizer on aggregate stability and bulk density. The effect of biochar and P fertilizer on aggregate stability was not significant at all soil depths. The effect of P fertilizer was significant at 10–15 cm. The interactive effect of biochar and P fertilizer on aggregate stability at 10–15 cm soil depth was significant ($P < 0.05$). Biochar and P fertilizer affected soil bulk density at 0–5 and 15–20 cm soil depth. At 0 and 5 t ha^{-1} biochar, P fertilizer application decreased soil bulk density, but at 10 and 20 t ha^{-1} biochar application, P fertilizer increased bulk density at 0–5 cm soil depth. Soil BD was higher at 0 and 5 t ha^{-1} and lower at 10 and 20 t ha^{-1} biochar application, without P fertilizer application. At 0 and 20 t ha^{-1} biochar, P fertilizer application increased soil bulk density. At 5 and 10 t ha^{-1} biochar, P fertilizer application decreased bulk density of soil at 15–20 cm.

2.2.2 Effect of biochar + mineral fertilizers on chemical properties of soil

Adekiya *et al*. (2022) examined the combined effect of biochar and K fertilizer on soil properties in sweet potato. Soil organic carbon (OC) was determined by Walkley and Black method using the dichromate wet oxidation method. Before experimentation, soil was low in organic carbon content. K fertilizer alone did not increase OC relative to biochar alone. This is because K fertilizer is not an organic material and so cannot increase soil organic carbon. Addition of biochar with K fertilizer increased pH, OC, N, P, K, Ca and Mg relative to their sole forms. This was because of the complementary effect of biochar and K fertilizer.

Cao *et al*. (2021) carried out a study in maize using fertilizers blended with biochar in soil to investigate P availability in soil. Phosphate bound with free cations, such as Al^{3+}, Fe^{3+} and Ca^{2+} in biochar can dissolve and release available P for plants to adsorb (Zhang *et al*., 2016). Biochar can also adsorb phosphate from soil solutions; thereby, retaining P and acting as a source of phosphorus (Peng *et al*. (2012); Streubel *et al*. (2012)). Therefore, the availability of soil P could be improved by directly releasing the available P from biochar (Gao *et al*., 2019). The total content of P in the soil is high, but its availability is relatively low. Here comes the role of mineral fertilizers. Thus, mineral fertilizers and biochar had a complementary effect on available P.

Useviˇciut¯ e *et al*. (2021) worked on Triticale to investigate the conjunctive effect of biochar and mineral fertilizer on soil chemical properties such as pH and EC. Soil pH was 11.8% higher after 24 months. The application of NPK fertilizers resulted in lower pH, which was 13.6% and 16.9% lower in the fertilized groups compared to unfertilized groups. A 5t ha^{-1} biochar dose increased soil pH by 1.72% and 15t ha^{-1} uplifted 6.84% in comparison to the treatments without biochar. On the addition of biochar @ 15 t ha^{-1}, soil pH increased by 12.5%, 5.88%, 5.75% and 3.98% after 3, 6, 12 and 24 months respectively. Biochar effect on soil pH was significant in all tillage-fertilization systems ($p < 0.05$). Soil electrical conductivity (EC) was 82.3% lower than after 24 months than after 3 months. The addition of NPK fertilizers resulted in higher soil EC. It resulted in 82.1% and 141% higher soil EC compared to unfertilized soil. The incorporation of biochar at different doses of 5t ha^{-1} and 15t ha^{-1} increased EC by 13% and 23.4%.

Feng *et al*. (2021) studied the impact of biochar and mineral fertilizer on available N and growth of corn. Traditional fertilization method was followed. The basal dose of fertilizer (N:P:K = 48:36:16) and topdressing (50 kg N fertilizer) was done. The topdressing was added three times before irrigation in the later maize growth stage at a ratio of 30:50:20, i.e., 15 kg was applied at the jointing stage, 25 kg at the tasselling stage, and 10 kg at the maturity stage. Biochar effectively increased the utilization rate of soil nitrogen fertilizer and the conversion rate of NO_3^--N to NH_4^+-N. Biochar application of ≥ 30 t ha^{-1} is likely to increase maize yield. Taghizadeh-Toosi *et al*. (2012) adopted a stable isotope tracer method and found that biochar had an adsorption effect on organic pollutants and can also store plant-available nitrogen in the soil. Thus, improving nitrogen utilization rate.

2.2.3 Effect of biochar + mineral fertilizers on root morphology, plant growth and development

Ahmed *et al*. (2021) carried out a pot experiment in maize to study the effect of biochar and P fertilizers in sandy clay loam soil. The integrated application of biochar and P doses significantly affected plant height, fresh and dry biomass. The longest plant height (127.67 cm) was observed for corn cob biochar (CCB) applied under 100% P supply and the lowest (88.72 cm) in control treatment. Biochar by P dose interaction improved plant fresh and dry biomass at vegetative and reproductive stages.

Kulczycki *et al*. (2020) performed a pot experiment in winter wheat to study the outcome of biochar of different doses mixed with mineral fertilizers on the growth and development of winter wheat. Significant results were seen in wheat germination. The sole or conjunctive application of NPK fertilizers with biochar enhanced yield (both fresh and dry) as compared to control. Better results were observed when NPK fertilizers were blended with biochar at high concentration. Significant results were observed when NPK fertilizers were blended with biochar @ 75% and more. In contrast, when the blending was done with biochar @ 50% significant results were not observed.

Ma *et al*. (2019) examined the effect of biochar, triple superphosphate fertilizer and irrigation in soybean growth, root nodulation, plant P uptake in sandy soil. Plant heights were measured from the tip of the apical meristem and number of pods were counted. Plant height increased significantly by irrigation from 85.4 to 94.9 cm by

11.1% and pod number significantly increased from 22.5 to 27.2 per plant, which was by 20.7%. Shoot competition might have effects on reproduction because the reproductive structures were found in the shoots. Meristem allocation was influenced by shoot competition. Plants normally increase their height at the cost of lateral growth when under adequate water conditions. As a result, the branch number would also be decreased, which might have decreased the potential of plants to produce meristems for reproduction. Biochar showed the potential to affect P uptake as shoot dry matter content and acid phosphomonoesterase (APM) activity had a strong correlation with shoot P, root P and shoot dry weight under the biochar treatment. It is likely that biochar affected the P uptake as biochar might increase organic P mineralization, facilitate the association between plants and mycorrhizal fungi, which might enhance P uptake and promote P-solubilizing microorganisms to release organic acid to solubilize ortho-P.

Sadaf *et al*. (2017) studied the mixed application of biochar and chemical fertilizers on N uptake, as accompanied by improvements in wheat productivity. Crop nitrogen uptake was significantly influenced by the application of biochar or chemical fertilizer. Biochar, when applied alone from all waste sources did not increase nitrogen uptake. Conversely, chemical fertilizers did increase the nitrogen uptake. When both biochar and chemical fertilizers were applied significant results were seen for crop uptake for both the individual and interactive effects. Apparent N recovery by wheat crop was significantly lower in biochar or biochar-chemical fertilizer treatments compared to chemical fertilizers treatment solely. This parameter ranged between 0.2 and 17% among all treatments.

2.3 Compost (FYM)

Farmyard manure is a simple byproduct of farmyard animal waste, i.e., cow dung, urine, waste straw and other dairy wastes. It is rich in nutrients. A small portion of N is directly available to the plants while a larger portion is made available as and when the FYM decomposes. This is attributed to increase in N mineralisation in the subsoil (on applying FYM) owing to the enhanced C demand by the microbial biomass. Availability of potassium and phosphorus from FYM is similar as that from inorganic sources. FYM has a tendency to increase the soil's ability to hold more water and minerals, thereby improving soil structure. It increases the assimilation of organic and inorganic N, thereby having a positive effect on microbial biomass and activity.

Enhanced microbial activity improves mineral delivery and plant nutrition. Eventually, improving soil fertility. FYM contains a high proportion of organic material, which feeds soil organisms and is necessary for maintaining active soil life, and it is high in nutrients.

2.3.1 Effect of biochar + compost on physical properties of soil

Pandey *et al*. (2023) examined the interaction between biochar and FYM soil health indicator under the salt affected soil. The water holding capacity of soil was significantly higher in soil when biochar was applied in large amount (@7.5 t ha^{-1}), but it was at par with the application of biochar @ 5.0 t ha^{-1} as compared to control and application of biochar @ 2.5 t ha^{-1}. The water holding capacity of soil was significantly higher in soil when FYM was applied @ 10.0 t ha^{-1}, but it was at par with application of FYM @ 5.0 t ha^{-1} as compared to control. Compost application improved soil physico-chemical characteristics, soil salinity and increased beneficial microbes (Omara *et al*. 2022). Biochar particles are fine grained with low density and they decrease the fraction of macro-pores but increase mesopores and micro pores contributed to overall increase in porosity. Thus, increase in capillary porosity marked as a precursor for increased water holding capacity.

Sharma *et al*. (2019) conducted a field experiment to determine the impact of biochar and organic manures on physical properties of soil. Biochar increased soil infiltration rate and decreased bulk density. This is attributed to high total porosity of biochar, it could retain water in small pores and support water to infiltrate into the soil surface (Asai *et al*., 2009). Eventually, increasing water retention capacity. Application of organic manures with biochar had a positive effect on soil bulk density. The bulk density of soil decreased with the application of compost, vermicompost and biochar. Application of 50% N through FYM + 50% N through vermicompost + 2t ha^{-1} biochar decreased soil compaction relative to control. The shrinking mechanism of puddled soils on drying and consequently becoming hard produced fissures. After rice, preparation of seed beds with fine tilth for wheat is difficult. Ploughing of puddled soil after rice resulted in the formation of large clods, which show high resistance against breaking. The 100% application of N through vermicompost + 2t ha^{-1} biochar decreased soil crack volume (1.82 times) followed by 50% N through FYM + 50% N through vermicompost + 2t ha^{-1} biochar (1.77 times) is recommended in rice under irrigated condition.

2.3.2 Effect of biochar + compost on chemical properties of soil

Nobile *et al*. (2022) studied the consequence of biochar and compost addition on organic carbon content. Compost alone significantly increased in the same. Increased organic matter inputs, such as compost, usually lead to higher quantity and change the quality of soil organic matter (Lima *et al*., 2009). Compost alone showed remarkable results with respect to the organic carbon content. The effect of compost alone on SOC content was not significant in the second year of study, probably because of its fast biodegradation and higher outputs of C than inputs, related to plant growth and previous harvest. When applied in mixture, compost mixed biochar increased SOC concentrations at the Indre site and all compost-biochar mixtures increased SOC at the Oise site, while no effect was observed at Haut-Rhin. More specifically, SOC increased at the Oise site with the application of rape, misc and ref compost-biochar mixtures. The increase of SOC in the presence of biochar was consistent with most of studies and is related to high content of stable C in biochar.

Manolikaki *et al*. (2019) conducted a pot experiment in maize to investigate the positive effects of biochar and compost for sandy loam soil texture. N availability was assessed. The C:N ratio is an important factor, which is widely used to assess N availability in soils. In this study, NH_4^+-N remained unaffected by the organic amendments except from rice husk biochar plus compost, for which NH_4^+ -N increased significantly. Positive effects were seen in grape pomace biochar. The other underlying mechanism is that biochar showed a beneficial effect on plant growth and improvement in physical properties.

Gautam *et al*. (2017) worked to study the outcome of biochar and FYM on soil parameters and growth attributes in the Himalayas. For topsoil, when the soil was incorporated with biochar and FYM, soil pH and exchangeable potassium (EK) increased.

Hairani *et al*. (2016) conducted a pot experiment to establish the effect of biochar application with FYM in soybean *(cv. Toyoharuka)* and sorghum *(Sorghum bicolor (L.) Moench cv. Hybrid Sorgo)*. There were four treatment combinations: cattle farmyard manure with/without biochar and rapeseed cake with/without biochar. It was observed that soils receiving cattle farmyard manure had higher soil pH. The addition of biochar resulted in significant increase in soil pH. The concentration of inorganic N (NH_4-N and NO_3-N) were not significantly different between the treatments. Soils receiving cattle farmyard manure, had higher concentration of available P. Despite the fact, that biochar is normally alkaline and has a potential to increase the soil pH, its effect on soil pH depends on the types of biochar (Yang *et al*., 2018). Besides this, microbial activities played a crucial role in affecting soil pH by phenomenon such as nitrification which produces H^+ (Yuan *et al*., 2013). The stronger positive correlation between soil pH and NH_4/NO_3 ratio observed in sorghum-grown soil supports the involvement of nitrification in different responses of soil pH to biochar application between soybean and sorghum. Together, some interactions between the sorghum rhizosphere and biochar might have affected soil pH; this may be the primary factor altering the microbial community structure in soils.

Schulz *et al*. (2012) carried out a greenhouse experiment to examine the effect of biochar with different treatments. The experiment comprised of six treatments. The treatments were control, biochar, compost, fertilizer alone, the collaborate application of biochar and fertilizer and biochar and compost. The assessment of organic carbon was made. It was observed that it was low in the growing phase. pH values were also analysed. Compost and control exhibited low soil pH values.

2.3.3 Effect of biochar + compost on root morphology, plant growth and development

Singh *et al*. (2020) worked on conjoint incorporation of biochar and FYM to study crop growth of wheat. Plant height (m) and ear length (cm) were measured at physiological maturity of crop and aboveground crop biomass (t ha^{-1}) was estimated just after the harvest. The growth attributes of the crop such as plant height and ear length were measured at physiological maturity. Ear length was high for chemical fertilizers, while it was lower for organic amendments, i.e., biochar and compost.

Gautam *et al*. (2017) carried out a field trial to study the effects of organic amendments together (biochar and farm yard manure) on crop growth. Crop yield (kg per plot/ton per hectare) of various crops such as soybean, garlic and radish were noted. It was found that the yield was high in organic amendments.

Schulz *et al*. (2012) performed a greenhouse experiment to visualise the effects of organics on soil quality. Plant height for both first and second year showed high results for organic treatments. But the yield gradually dropped in the second year.

2.4 Combined application

2.4.1 Effect of biochar + mineral fertilizers + compost on physical properties of soil

Laharia *et al*. (2020) in a field study of two consecutive seasons to evaluate the interactive effect of biochar, FYM and nitrogen on soil properties and yield of blackgram grown in vertisol. The study had nine treatments replicated three times. The treatments comprised of T_1- Control, T_2- FYM 5 t ha^{-1} + Nitrogen 10 kg ha^{-1} , T_3- FYM 5 t ha^{-1} + Nitrogen 20 kg ha^{-1} , T_4- FYM 10 t ha^{-1} + nitrogen 10 kg ha^{-1} , T_5- FYM 10 t ha^{-1} + Nitrogen 20 kg ha^{-1} , T_6- Biochar 5 t ha^{-1} + FYM 5 t ha^{-1} + Nitrogen 10 kg ha^{-1} , T_7- Biochar 5 t ha^{-1} + FYM 5 t ha^{-1} + Nitrogen 20 kg ha^{-1} , T_8- Biochar 10 t ha^{-1} + FYM 10 t ha^{-1} + Nitrogen 10 kg ha^{-1} , T_9- Biochar 10 t ha^{-1} + FYM 10 t ha^{-1} + Nitrogen 20 kg ha^{-1}. The recommended dose of fertilizer (RDF) was 20:20:0 kg N, P_2O_5 and K_2O. A numerical reduction in bulk density was observed in treatment T_8 and T_9. The decrease in bulk density due to biochar application has been associated with the high porosity, which when applied to soil increased the total pore volume reported by Mukherjee *et al.* (2013). Water holding capacity significantly increased with soil treated with biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} and nitrogen @ 20 kg ha^{-1} and it was found to be at par with the treatment biochar 10 t ha^{-1} + FYM 10 t ha^{-1} + Nitrogen 10 kg ha^{-1}. Lowest water holding capacity was recorded in control. Biochar having high specific surface area, extensive pore structure and more total porosity (micro and macro pores) increased the water holding capacity. Biochar application increased the water retention capacity of the soil because it increased soil porosity and due to adsorptive nature of biochar.

2.4.2 Effect of biochar + mineral fertilizers + compost on chemical properties of soil

Ahmad *et al*. (2021) conducted a two-year field experiment on biochar, poultry and farmyard manures in collaboration with synthetic fertilizers on soil properties in cotton. The conjunctive application of biochar and FYM showed synergistic effects on chemical, physical and yield attributes.

Rehman *et al*. (2021) conducted a pot experiment to evaluate the effects of biochar and farmyard manure under recommended fertilizer doses on tomato growth. Soil pH for corncob biochar was less compared to the cotton stick and rice straw biochar. When biochar and FYM were mixed, it reduced soil pH than the sole biochar at both rates. Soil EC under cotton stick biochar varied with biochar rate but not after addition of FYM. However, under corncob and rice straw biochar, biochar and FYM increased EC.

Laharia *et al*. (2020) studied the interactive effect of biochar, FYM and nitrogen on soil properties of blackgram grown in vertisol. The study had nine treatments replicated three times. The treatments comprised of T_1- Control, T_2- FYM 5 t ha^{-1} + Nitrogen 10 kg ha^{-1}, T_3- FYM 5 t ha^{-1} + Nitrogen 20 kg ha^{-1}, T_4- FYM 10 t ha^{-1} + nitrogen 10 kg ha^{-1}, T_5- FYM 10 t ha^{-1} + Nitrogen 20 kg ha^{-1}, T_6- Biochar 5 t ha^{-1} + FYM 5 t ha^{-1} + Nitrogen 10 kg ha^{-1}, T_7- Biochar 5 t ha^{-1} + FYM 5 t ha^{-1} + Nitrogen 20 kg ha^{-1}, T_8- Biochar 10 t ha^{-1} + FYM 10 t ha^{-1} + Nitrogen 10 kg ha^{-1}, T_9- Biochar 10 t ha^{-1} + FYM 10 t ha^{-1} + Nitrogen 20 kg ha^{-1}. The recommended dose of fertilizer (RDF) was 20:20:0 kg N, P_2O_5 and K_2O. The pH of soil ranged from 7.93 to 7.95 indicating that soil was slightly alkaline in reaction. The higher value of pH was recorded in control treatment T_1. The lowest pH was recorded with the soil application of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} and N @ 20 kg ha^{-1}. Biochar contains carbonate and soluble base cations, such as calcium and magnesium. The combination of cations and carbonate in the soil formed slightly soluble carbonates and restrict the hydrolyzation of carbonate, while decreasing content of hydroxyl in the soil. Thus, the soil pH was decreased to some extent after the addition of biochar reported by Yuan *et al*. (2011). The electrical conductivity (EC) ranged from 0.25 to 0.30 ds m^{-1} and highest value of EC were recorded in treatment T_8 and T_9. The increase in soil EC due to application of biochar might be attributed to ash accretion. The ash residues are generally dominated by carbonates of alkali and alkaline earth metals. The significantly highest organic carbon (4.95 g kg^{-1}) in soil after harvest of blackgram was observed with the soil application of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} and nitrogen @ 20 kg ha^{-1} and it was at par with treatment biochar 10 t ha^{-1} + FYM 10 t ha^{-1} + Nitrogen 10 kg ha^{-1}. The superiority of biochar for organic carbon content might be due to the huge surface area of biochar, which in turn provides micropores for beneficial microorganisms as a habitat thereby increasing a soil organic carbon content. Large amounts of organic carbon sequestered biochar might have resulted in increased organic carbon content of soil at harvest. This was similar with the finding of Nigussie *et al*. (2012). Similarly increase in the levels of organic carbon content in the surface soil was mainly due to the accumulation of organic residue over a certain time duration.

2.4.3 Effect of biochar + mineral fertilizers + compost on root morphology, plant growth and development

Rivelli *et al*. (2022) conducted an experiment to investigate the effect of biochar and inorganic fertilizer on plant growth in swiss chard. The treatments comprised of biochar from different feedstock (vineyard pruning and wood chips), two sources of fertilizers (ammonium nitrate as an inorganic source and vermicompost as an organic source) and the co-application of all these treatments. Two cuts were made and the considered experimental factors affected plant growth response differently. At the first cut, the ANOVA revealed that neither the two factors individually (biochar and fertilizer), nor their interaction (biochar × fertilizer) influenced leaf number. However, leaf length was affected by fertilizer ($p \leq 0.05$) and leaf fresh weight by both biochar and fertilizer ($p \leq 0.01$), as well as by their interaction ($p \leq 0.01$). Plants growing on the soil fertilized with organic fertilizer resulted in 17 and 45% higher leaf length and leaf fresh weight values, respectively, than the soil not fertilized (F_0), On the other hand, plants growing on soils amended with vineyard pruning biochar (B_v) showed a 20% lower leaf fresh weight value than the soil not amended (B_0), which in turn did not differ from the soil amended with woodchips biochar (B_w). More specifically, both the plants fertilized with organic fertilizer and plants fertilized with inorganic fertilizer respectively showed 75 and 90% higher leaf fresh weight (LFW) values than plants not fertilized (F_0).

Ahmad *et al*. (2021) carried out a two-year field experiment to study the effect of different organic amendments with chemical fertilizers. The interaction showed remarkable results for soil available nitrogen and potassium.

CHAPTER-3

MATERIALS AND METHODS

A pot research called **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"** was conducted at the Sher-e-Kashmir University of Agricultural Sciences & Technology in Jammu at the Division of Soil Science and Agricultural Chemistry. Soil was collected from Advanced Centre for Rainfed Agriculture, Dhiansar.

This chapter contains the experiment's specifics as well as the materials and techniques used.

3.1 General description

3.1.1 Details of study

The purpose of this study was to determine the effects of mineral fertilizers, biochar and compost and their combinations on the hydro-physical characteristics and maize performance in sandy loam soil under rainfed conditions. In comparison to other soils, maize grows and develops less overall in areas where the soil is often poor in aggregation and lacking in nutrients. This lowers the area's ability to retain moisture and nutrients.

3.1.2 Experimental location

Soil was collected from Advanced Centre for Rainfed Agriculture farm, Rakh-Dhiansar. The co-ordinates of the area from where soil was collected were 32^{o}37′ N latitude and 74^{o}55′ E longitude. The altitude was 334m above mean sea level.

3.1.3 Climate and weather

The university observatory in the campus provided for the weather data which included temperature, precipitation and relative humidity from July to November, which corresponds from 29th to 44th standard meteorological week. Maximum rainfall and relative humidity were observed in the 29th week. Maximum temperature was highest in the 36th week. Minimum temperature was highest in the 31st week.

Table 3.1: Weekly meteorological data recorded at university's meteorological observatory, SKUAST-J, Chatha during the crop growth period (2023)

Standard meteorological weeks	Dates and months	Mean maximum temperature (^{0}C)	Mean minimum temperature (^{0}C)	Mean RH morning (%)	Mean RH evening (%)	Rainfall total
29	16 Jul – 22 Jul	32.9	25.7	89.4	75.9	174.8
30	23 Jul – 29 Jul	33.7	25.7	92.0	67.7	86.4
31	30 Jul – 05 Aug	35.3	26.7	82.9	63.7	94.8
32	06 Aug– 12 Aug	34.8	25.4	85.9	67.7	69.4
33	13 Aug– 19 Aug	34.7	25.4	88.4	71.6	104.2
34	20 Aug – 26 Aug	34.7	24.9	88.7	65.3	86.4
35	27 Aug – 02 Sep	34.8	24.8	87.6	58.9	4.2
36	03 Sep – 09 Sep	35.6	23.7	82.9	55.4	19.4
37	10 Sep – 16 Sep	33.3	24.1	94.7	71.4	84.0
38	17 Sep – 23 Sep	32.9	23.8	88.0	60.9	11.2
39	24 Sep – 30 Sep	33.3	19.8	89.0	51.7	0.0
40	01 Oct – 07 Oct	33.6	19.1	89.4	45.3	0.0
41	08 Oct – 14 Oct	31.6	17.9	84.6	44.6	10.8
42	15 Oct – 21 Oct	26.5	14.6	89.4	63.4	89.2
43	22 Oct – 28 Oct	29.8	14.3	86.9	50.4	0.0
44	29 Oct – 04 Nov	29.9	14.2	92.6	46.6	0.0

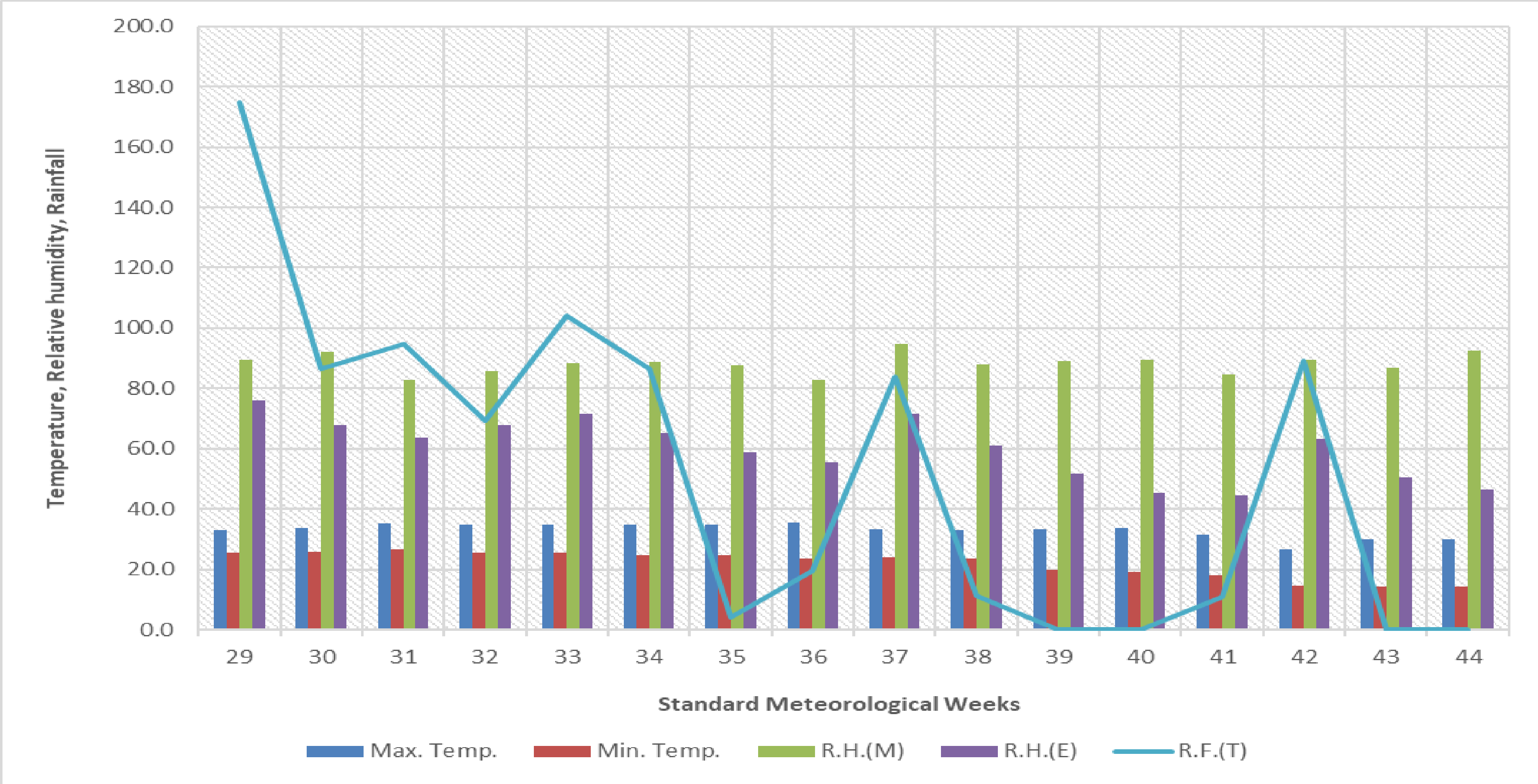

Fig. 3.1: Meteorological data during investigation

3.2 Pot experiment

In the Union Territory of Jammu and Kashmir, namely in the Kandi zones of the Western Himalayas, soil was collected from the Advanced Centre for Rainfed Agriculture, Rakh-Dhiansar. Initial physico-chemical data on the soil were recorded after sampling. The soil was sampled at a depth of 0 to 15 cm, and the bulk material was shade-dried for additional processing, primarily for the first chemical data of the soil.

The soil was subsequently filled into plastic pots that measured 30 cm in height, 30 cm in diameter at the top, and 16 cm at the base. However, to replicate the conditions, the bulk density of the soil had to be kept at a level that was comparable to the parent field condition. This was done by precisely placing the soil mass into the pot after the volume of the pot was known.

The incorporation rate was computed in advance to make the appropriate treatment combination. This was done by dividing the dosage per area by the area of the experimental pot in each treatment.

Before refilling, the precise amounts of soils were removed onto a plastic sheet and well mixed with biochar while bearing in mind the bulk density. The application rate (ton per hectare or kg per hectare) was divided by the pot area to determine the incorporation rate, which is the rate of application per pot for each treatment. For a cylindrical pot, the area ($A = \pi r^2$) is its circumference.

3.3.1 Physical and chemical properties

Random collection of samples was done to represent the whole area from a uniform depth of 0-15cm. Thereafter their physical and chemical properties were analysed.

The initial soil pH was neutral, EC was in the slight range, organic carbon and available nitrogen were low, available phosphorus was in the medium range, available potassium was low.

Plate 3.1: Collection of soil sample and laying of pot experiment

Table 3.2: Initial soil properties of the experimental soil

S. No.	Soil Properties	Values
A. Physical properties		
	Sand (%)	65.53
	Silt (%)	18.23
	Clay (%)	16.24
1	**Textural class**	**Sandy loam**
2	WHC (%)	34.14
3	BD (gcm^{-3})	1.47
4	Porosity (%)	44.52
B. Chemical properties		
1	pH	6.70
2	EC (ds m^{-1})	0.26
3	Organic Carbon (%)	0.26
4	Available N (kg ha^{-1})	164.00
5	Available P (kg ha^{-1})	13.60
6	Available K (kg ha^{-1})	91.50

3.4 Experimental details

3.4.1 Design and layout of the experiment

The experiment was carried out with twelve treatment combinations and three replications. The design employed in this investigation, was factorial completely randomised design (fCRD). The time span was roughly three months.

Name of crop : Maize (*Zea mays*)

Variety : Double DeKalb

Design of experiment : Factorial CRD

No. of treatments : 12

No. of replications : 03

Pot dimension radius : Radius:15 cm, Height: 30 cm (Area: 0.07m^2)

Table 3.3: Treatment combinations in detail

Factor-1 Biochar	B_1 = Biochar @ 4 t ha^{-1}
	B_2 = Biochar @ 8 t ha^{-1}
	B_3 = Biochar @ 12 t ha^{-1}
Factor-2 Fertilizer amendments (Organic and inorganic)	F_1 = 100% NPK
	F_2 = 75% N + 100% PK + FYM @ 15 t ha^{-1}
	F_3 = 50% N + 100% PK + FYM @ 15 t ha^{-1}
	F_4 = FYM @ 15 t ha^{-1}

RDF = 60:40:20

3.4.3(a) Characteristic of biochar

The feedstock used for biochar was rice husk that was produced using kiln method at main campus Chatha, SKUAST-Jammu. pH and EC of biochar was calculated by potentiometry and conductometry methods as given by Jackson (1973). Total carbon was analysed by CHNS analyzer. Nitrogen percentage in biochar was done by Kjeldahl digestion distillation method given by Jackson (1973). Phosphorus estimation was done by triacid digestion and vanadomolybdate method and is given by Jackson *et al*. (1973). Potassium estimation was done by triacid digestion and flame photometer method and is given by Jackson (1973). Core method was used in the estimation of bulk density. (Blake and Hartge, 1986).

Table 3.4: Properties of biochar

S. No.	**Property**	**Biochar**
1.	Colour	Black
2.	Odour	Smoky
3.	Total C (%)	45.08
4.	N (%)	0.69
5.	P (%)	0.15
6.	K (%)	1.33

Plate 3.2: Turning over of soil and weed removal

Plate 3.3: Biochar

3.4 FYM

FYM was taken from Chatha Organic Farming, SKUAST, Jammu.

Table 3.5: Properties of FYM

S. No.	Property	Biochar
1.	Colour	Blackish brown
2.	Odour	Earthy odour
3.	Total C (%)	30.00
4.	N (%)	0.50
5.	P (%)	0.36
6.	K (%)	0.70

Varietal characteristics

The maize variety used in the experiment was Double deKalb. It has yellow seeds.

Fertilizers

The inorganic fertilizers used were urea, DAP and MOP, which were bought from local market.

3.5 Observations recorded

3.5.1 Soil Characteristics

3.5.1.1 Soil Chemical Properties

3.5.1.1.1 Soil pH

Soil pH was governed with the help of a pH meter by combining soil and water suspensions (1:2.5) and using a glass and calomel electrode together. (Jackson, 1973).

3.5.1.1.2 Soil EC (ds m^{-1})

The EC was determined by measuring the conductivity bridge in the suspension and expressed in ds m^{-1} (Jackson, 1973).

3.5.1.1.3 Organic Carbon (%)

The wet digestion method (Walkley and Black, 1934) was used to measure organic carbon.

3.5.1.1.4 Available Nitrogen (kg ha^{-1})

Subbiah and Asija's 1956 description of the standard alkaline potassium permanganate method was used to calculate the available nitrogen content.

3.5.1.1.5 Available Phosphorus (kg ha^{-1})

The available phosphorus was calculated using the extractable P technique with 0.5M sodium bicarbonate. At 660 nm. stannous chloride provided for the colour intensity, which was measured with a spectrophotometer.

3.5.1.1.6 Available Potassium (kg ha^{-1})

Using 1N NH_4OAC (ammonium acetate) extractant, the amount of accessible potassium was calculated, and a corresponding intensity was detected through flame photometer to estimate the potassium concentration (Jackson, 1973).

3.5.1.2 Soil Physical Properties

3.5.1.2.1 Soil texture

The International Pipette Method was employed to ascertain the percentage of sand, silt, and clay in each sample (Kilmer and Alexander, 1949). The class of texture was determined using the USDA textural triangle diagram (Black, 1965)

3.5.1.2.2 Bulk density (g cm^{-3})

The core approach (Blake and Hartge 1986) was used to compute the bulk density. The core was inserted to the designated depth (0–15 cm) to collect soil samples.

The soil was then weighed. After two days of constant drying at 105 °C, it was weighed once more. The bulk density was computed as follows:

$$\text{Bulk density } (\text{g cm}^{-3}) = \frac{\text{X} - \text{Z}}{\text{v}} = \frac{\text{Oven dry weight of soil}}{\text{Volume of soil}}$$

Plate 3.4: Analysis of soil organic carbon

Plate 3.5: Analysis of soil available nitrogen

Plate 3.6: Analysis of soil available phosphorus

X= Weight of core with oven dry soil (g)

Z= Weight of core (g)

V= Volume of core (cm^3)

3.5.1.2.3 Porosity (%)

Particle density (PD) and bulk density (BD) were used to calculate porosity, or total porosity in general. Both volume and percentage can be used to express porosity. Porosity indices in our investigation are expressed as percentages.

$$\text{Porosity} = \left\{1 - \left(\frac{\text{BD}}{\text{PD}}\right)\right\} \times 100$$

3.5.1.2.4 Maximum water holding capacity (%)

The maximum water-holding capacity of soil can be estimated gravimetrically using the Keen Rackzowski box method (Keen and Raczkowski 1921). It can be estimated gravimetrically as follows:

$$\text{Maximum water holding capacity} = \frac{\text{Wet weight of soil} - \text{Oven dry weight of soil}}{\text{Oven dry weight of soil}} \times 100$$

3.5.1.2.5 Soil moisture (%)

Soil moisture data was collected using digital soil moisture meter probe from Lutron Electronic enterprise co.103 Taipei, Taiwan (model PMS-714).

$$\text{Soil moisture (\%)} = \left(\frac{\text{Net weight of wet soil} - \text{Net weight of oven dry soil}}{\text{Net weight of oven dry soil}}\right) \times 100$$

3.5.1.2.6 Aggregate stability (%)

The Eijkelkamp wet sieving equipment was utilized to assess a soil's aggregate stability. The theory behind this is that, when submerged in dispersing solution, the weaker aggregates disintegrate readily than the stable ones, and the different sieves aid in determining the ratio of disintegrating sizes. In this method, unprocessed soil sample aggregates (4g) from each treatment were taken four times. Samples were placed in four different sized sieves- 0.125mm, 0.250mm, 0.5mm and 2mm. These sieves were set inside an aluminium container filled with water and allowed to move up and down for three minutes. Sieves with samples were completely filled with water. The soil particles were collected in second set of aluminium cans that were half filled with water and all aggregates are destroyed with finger or forceps. These soil aggregates were dried in oven and their weights were taken.

$$MWD = \Sigma X_i Y_i$$

Where,

X_i = MWD of aggregate of soil

Y_i = Mass of aggregates as fraction of total dry mass of analyzed sample.

The aggregate stability was calculated as follows:

$$\text{Aggregate stability} = \frac{\text{Stable aggregates}}{\text{Stable aggregate} + \text{unstable aggregate}}$$

3.5.1.2.7 Infiltration rate (cm hr^{-1})

Determination of infiltration rate was done with mini disc infiltrometer from Decagon Devices, Pullman, WA, USA (model M12) after harvest. Both the chambers were filled with water. Thereafter, suction was set at 2cm. Before placing the infiltrometer, the surface is cleared from stones, plant debris or any uneven hindrances. Bubble formation must be avoided from the porous side that is in contact with the soil, to eliminate chances of error. Stopwatch was started, which was in sync with the placement of the infiltrometer. At consecutive intervals of 30 seconds, volume was noted.

The cumulative infiltration is calculated using the Philip's equation:

$$I = C_2 t\ 0.5 + C_1 t \quad \ldots \text{(i)}$$

Where,

I = Cumulative Infiltration (cm)

C_2 = Sorptivity (cm min0.5)

C_1= Ks constant

t = time (minutes)

Equation (i) can be represented mathematically by plotting CI against the square root of time (SRT). The infiltration rate was calculated using the first derivative of the CI by using the following formula:

$$i = 0.5C_2t^{-0.5} + C_1 \quad \dots \text{(ii)}$$

Plotting the infiltration rate versus 1/ (2 t 0.5) and fitting a linear equation to the collected data allowed us to derive a mathematical representation for Equation (ii).

3.5.1.2.8 Hydraulic conductivity (cm hr^{-1})

The hydraulic conductivity was estimated by the method proposed by Zhang (1997), wherein cumulative infiltration rate is measured vs time.

The hydraulic conductivity of the soil is computed as follows:

$$K = \frac{C_1}{A}$$

Where,

K = Hydraulic conductivity of the soil.

C_1 = Slope of the curve (cumulative infiltration vs square root of time),

A = Value relating to van Genuchten parameters, which depends on soil type, radius of the disc of infiltrometer and suction rate.

3.5.1.3 Plant Parameters

3.5.1.3.1 Plant height (cm)

The plant height was taken after an interval of 30, 60 and 90 days. After 30 days of sowing, the plant height was taken from the base of the pot to the uppermost fully opened leaf. After 60 and 90 days from sowing, tassel emergence was achieved, wherein measurement was done from the base up to the tassel.

3.5.1.3.2 Root shoot ratio

Fresh weight measurements of root and shoot were made on the same day they were harvested because any delay, even exposure to heat, could cause the moisture content to decrease. Using an electronic weighing equipment, it was done.

3.5.1.3.3 Uptake studies (NPK uptake)

Following harvest, samples of the treatment-marked plants were cleaned and oven dried at a temperature of 65^0 C after the dried samples were ground using an electronic sample grinder equipped with stainless steel blades, they were sealed in paper bags to prevent contamination and spoilage. The nutrient analysis was performed on these samples.

Digestion

The digestion of nitrogen was done in KELPLUS block digester (model KES 08L RTS) with concentrated H_2SO_4 in the presence of tri-catalysts mixture comprising of potassium sulphate, ferrous sulphate and cupric sulphate in the ratio of 20:2:1 (K_2SO_4: $FeSO_4$: $CuSO_4$).

The digestion of phosphorus and potassium was also done in the same apparatus, wherein dried samples were digested overnight with concentrated nitric acid, perchloric acid and sulphuric acid in the ratio of 10:4:1 (HNO_3: $HClO_4$: H_2SO_4). Multiple analysis along with blank was performed for accuracy. The result came in % and was converted to kg ha^{-1} using the following formula:

$$\text{Nutrient uptake of maize (kg ha}^{-1}) = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1})}{100}$$

Plate 3.7: Analysis of soil available potassium

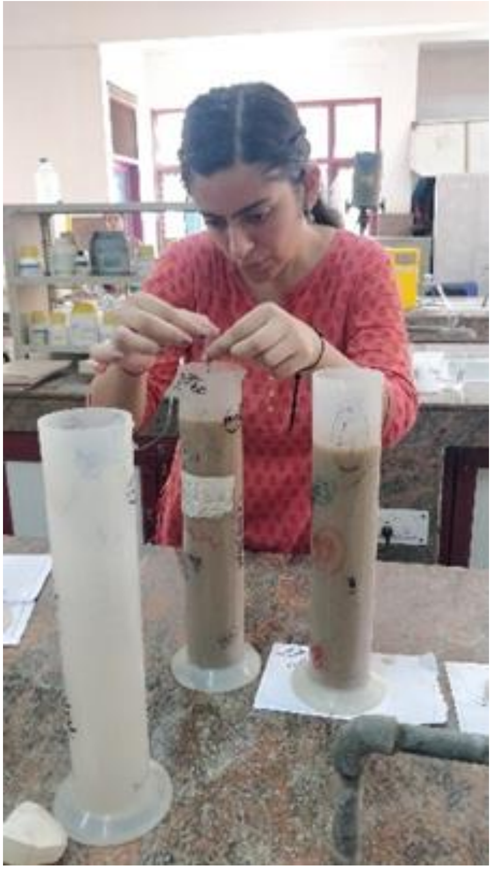

Plate 3.8: Estimation of soil texture

Plate 3.9: Estimation of maximum water holding capacity

Plate 3.10: Estimation of soil infiltration rate

Nitrogen uptake (kg ha^{-1})

Following the process of digestion, the distillation was carried out using a semi-automatic Kjeldahl apparatus from KELPLUS (model ELITE-EX VA). The standard titration procedure, as outlined by Bullock *et al*., (1992) was then employed to conclude the process.

Phosphorus uptake (kg ha^{-1})

Phosphorus estimation was done by the Vanado-molybdate phosphoric acid method, wherein colour intensity is proportional to the concentration (Jackson 1973). The same was undertaken using spectrophotometer.

Potassium uptake (kg ha^{-1})

Potassium content was directly calculated after diluting the digested solution concentration to 10 times in flame photometer (Jackson, 1973).

3.5.1.4 Root Parameters

3.5.1.4.1 Root volume (cm^3)

Root volume was calculated by placing the entire root in a measuring cylinder filled with water up to a certain marked volume. The change in net volume was observed. The result came in ml which is equal to cm^3.

3.5.1.4.2 Root weight (g)

Roots were collected, washed, shade and oven dried (65^{o}C) to remove moisture. Thereafter, their weight was measured using weighing balance.

3.5.1.4.3 Root weight density (g cm^{-3})

The root weight density was calculated by the formula given by Tennant, which is as follows:

$$\mathrm{RWD} = \frac{\mathrm{RW}}{\mathrm{RV}}$$

Where,

RWD = Root weight density (g cm^{-3})

RW = Root weight (g), RV = Root volume (cm^3)

3.5.1.4.4 Root length density (cm cm^{-3})

The root weight density was calculated by the formula given by Tennant, which is as follows:

Where,

RLD = Root length density (cm cm^{-3}),

RL = Root length (cm), RV = Root volume (cm^3)

3.5.1.4.5 Root length (cm)

The root length was measured from internode with the longest hair of main root.

Plate 3.11: Measurement of plant height

Plate 3.12: Analysis of nitrogen uptake

Plate 3.13: Analysis of phosphorus uptake

CHAPTER-4

RESULTS

The goal of the pot experiment was to determine the **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"** under Rainfed Condition in the Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences & Technology, Chatha campus, Jammu. This chapter has covered the findings of several parameters related to soil and plant analysis under the following headings:

(A) Soil studies

4.1 Soil Chemical Properties

4.1.1 pH

4.1.2 Electrical conductivity (ds m^{-1})

4.1.3 Organic carbon (%)

4.1.4 Available nitrogen (kg ha^{-1})

4.1.5 Available phosphorus (kg ha^{-1})

4.1.6 Available potassium (kg ha^{-1})

4.2 Soil Physical Properties

4.2.1 Bulk density (g cm^{-3})

4.2.2 Porosity (%)

4.2.3 Maximum water holding capacity (%)

4.2.4 Soil moisture (%)

4.2.5 Aggregate stability (%)

4.2.6 Infiltration rate (cm hr^{-1})

4.2.7 Hydraulic conductivity (cm hr^{-1})

(B) Crop studies

4.3 Plant parameters

4.3.1 Plant height (cm)

4.3.2 Root-shoot ratio

4.3.3 Yield (kg ha^{-1} and g pot^{-1})

4.3.4 Nitrogen uptake (kg ha^{-1} and g pot^{-1})

4.3.5 Phosphorus uptake (kg ha^{-1} and g pot^{-1})

4.3.6 Potassium uptake (kg ha^{-1} and g pot^{-1})

4.4 Root parameters

4.4.1 Root volume (cm^3)

4.4.2 Root weight (g)

4.4.3 Root weight density (g cm^{-3})

4.4.4 Root length density (cm cm^{-3})

4.4.5 Root length (cm)

4.1 Chemical properties

4.1.1 pH

The data pertaining to the effect of biochar and fertilizer amendments (organic and inorganic) on soil pH are presented in Table No 4.1 and Fig. No. 4.1. Among the three biochar levels, B_3 showed highest pH (6.67), while B_1 showed lowest pH (6.63). B_1 and B_2 were statistically at par and B_2 and B_3 were statistically at par. The fertilizer amendments and the interaction effect on soil pH was found non-significant.

Soil pH increased in the order:

$B_1F_2 = B_1F_4 < B_1F_3 < B_1F_1 < B_2F_2 = B_2F_4 < B_2F_3 < B_2F_1 < B_3F_2 < B_3F_4 < B_3F_3 < B_3F_1$

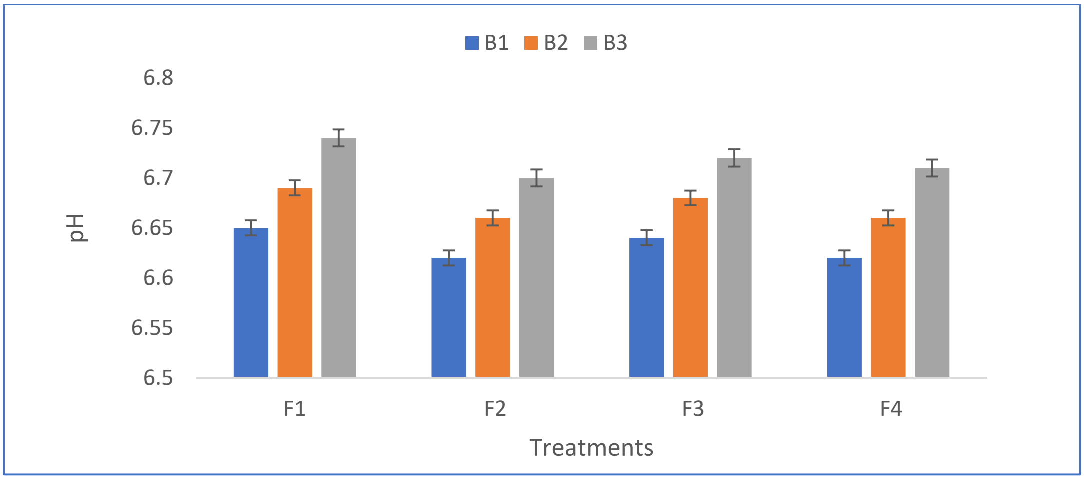

Fig. 4.1: Effect of biochar, mineral fertilizer and compost on soil pH

4.1.2 Electrical conductivity (ds m^{-1})

The effect of biochar and fertilizer amendments (organic and inorganic) was significant on electrical conductivity of soil (Table 4.1). Soil EC was highest in B_3 (0.31) and was lowest in B_1 (0.26). B_1 and B_2 were statistically at par. In fertilizer amendments, highest soil EC was found in F_1 and lowest in F_2 (0.26). F_2 and F_3 were statistically at par. The interaction effect was non-significant.

Soil electrical conductivity increased in the order:

$B_1F_2 = B_2F_3 < B_1F_3 = B_2F_2 < B_1F_1 = B_1F_4 = B_3F_2 < B_2F_4 < B_2F_1 = B_3F_3 < B_3F_4 < B_3F_1$

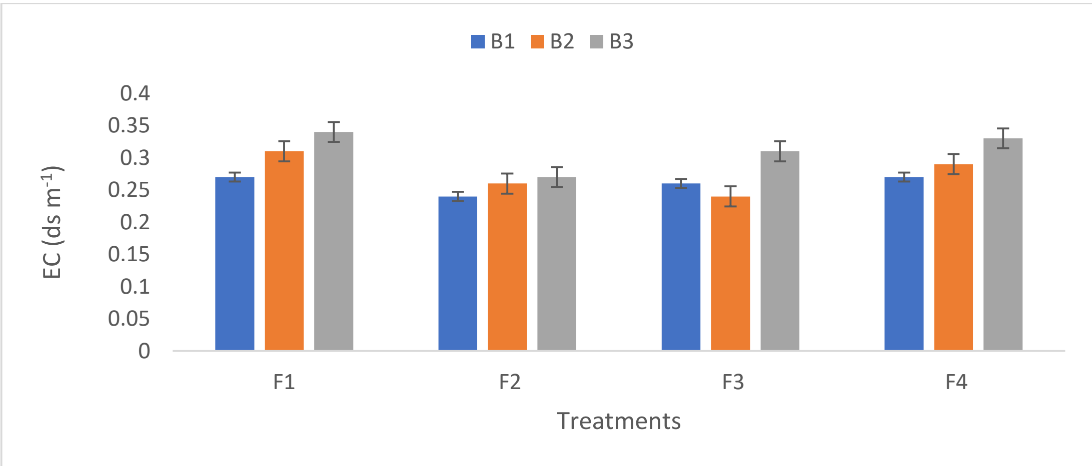

Fig. 4.2: Effect of biochar, mineral fertilizer and compost on soil EC

4.1.3 Organic carbon (%)

The effect of biochar, fertilizer amendments and their interaction was found significant. The results presented in Table No. 4.1 confirmed that B_3 had highest organic carbon (0.27) and was lowest in B_1 (0.24). B_2 and B_3 were statistically at par. The significantly higher soil organic carbon (in fertilizer amendments) was noticed in F_2 (0.32). On the contrary, lowest soil organic carbon was seen in F_1(0.20). In case of interaction, B_3F_2 (0.34) was superior among all other treatments. Treatment with lowest organic carbon was B_1F_1 (0.19).

Soil organic carbon increased in the order:

$B_1F_1 < B_2F_1 = B_3F_1 < B_1F_4 < B_2F_4 < B_3F_4 < B_1F_3 < B_2F_3 < B_3F_3 < B_1F_2 < B_2F_2 < B_3F_2$

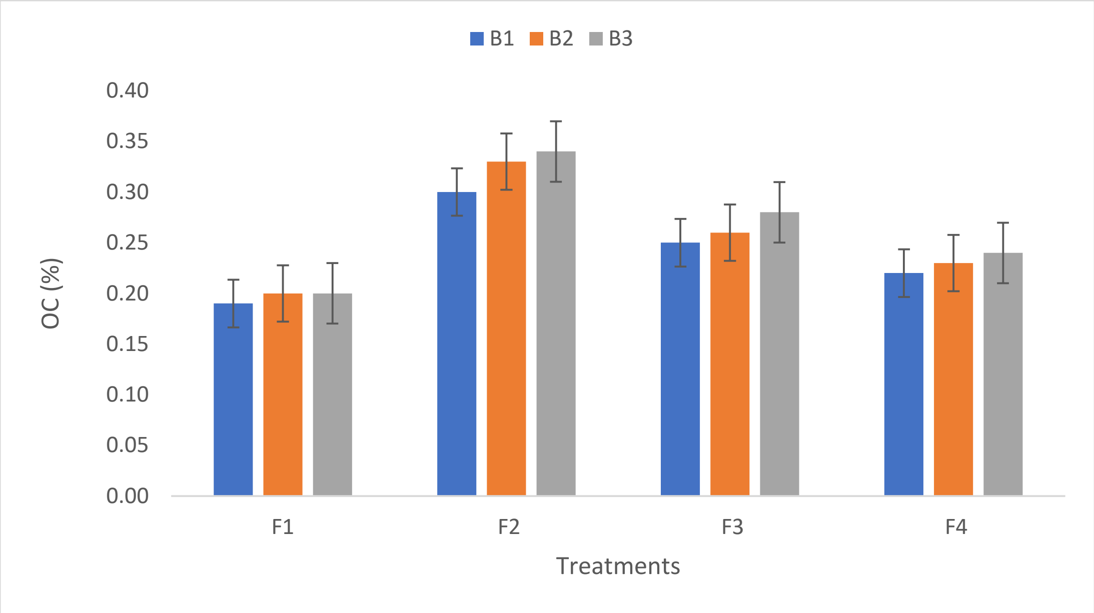

Fig. 4.3: Effect of biochar, mineral fertilizer and FYM on soil OC

Table 4.1: Effect of biochar, mineral fertilizer and FYM on soil pH, EC and OC

Treatments	**pH**	**EC (ds m^{-1})**	**OC (%)**
B_1 (Biochar @ 4 t ha^{-1})	6.63	0.26	0.24
B_2 (Biochar @ 8 t ha^{-1})	6.67	0.28	0.26
B_3 (Biochar @ 12 t ha^{-1})	6.72	0.31	0.27
Mean	6.66	0.28	0.26
*CD Factor (B) (5%)	0.05	0.03	0.01
F_1 (100% NPK)	6.69	0.31	0.20
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	6.66	0.26	0.32
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	6.68	0.27	0.26
F_4 (FYM @ 15 t ha^{-1})	6.66	0.30	0.23
Mean	6.67	0.28	0.25
*CD Factor (F) (5%)	NS	0.04	0.01
*CD Interaction (BXF) (5%)	NS	NS	0.01

* = significant at $p \leq 0.05$

4.1.4 Available nitrogen (kg ha^{-1})

Both the individual (biochar and fertilizer) and interaction effects (biochar x fertilizer) were found significant for soil available nitrogen. Higher the biochar dose, i.e., B_3 (197.77) resulted in high available N and lower dose in B_1 (168.59) showed lowest available N (Table No. 4.2). Fertilizer amendments, which were the direct source of nitrogen showed highest results of available N in F_2 (195.40). Lowest available nitrogen was found in F_4 (165.15). The highest increase in soil available nitrogen was found in treatment B_3F_2 (213.82) over B_1F_4 (154.05) which was by 27.95%.

Soil available nitrogen increased in the order:

$B_1F_4 < B_2F_4 < B_1F_3 < B_2F_3 < B_1F_1 < B_2F_1 < B_3F_4 < B_1F_2 < B_2F_2 < B_3F_3 < B_3F_1 < B_3F_2$

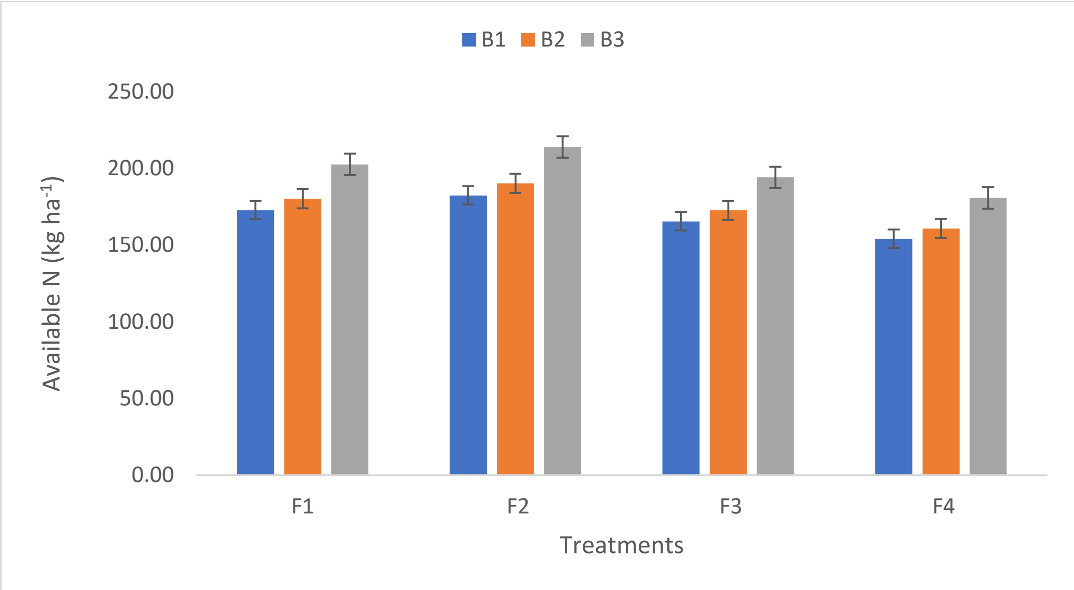

Fig. 4.4: Effect of biochar, mineral fertilizer and compost on soil available N

4.1.5 Available phosphorus (kg ha^{-1})

The effect on available phosphorus was completely non-significant. As perceived from Table No. 4.2, B_3 (13.65) recorded highest available P, which was non-significant. Lowest value was in case of B_1 (12.63). Among the fertilizer amendments, F_2 (14.43) marked for the highest value and lowest was in F_4 (11.57). Lowest value was in F_4 (11.57).

Soil available phosphorus increased in the order:

$B_1F_4 < B_2F_3 < B_3F_4 < B_1F_1 < B_2F_1 = B_1F_3 < B_3F_1 < B_1F_2 < B_3F_3 < B_2F_3 < B_2F_2 < B_3F_2$

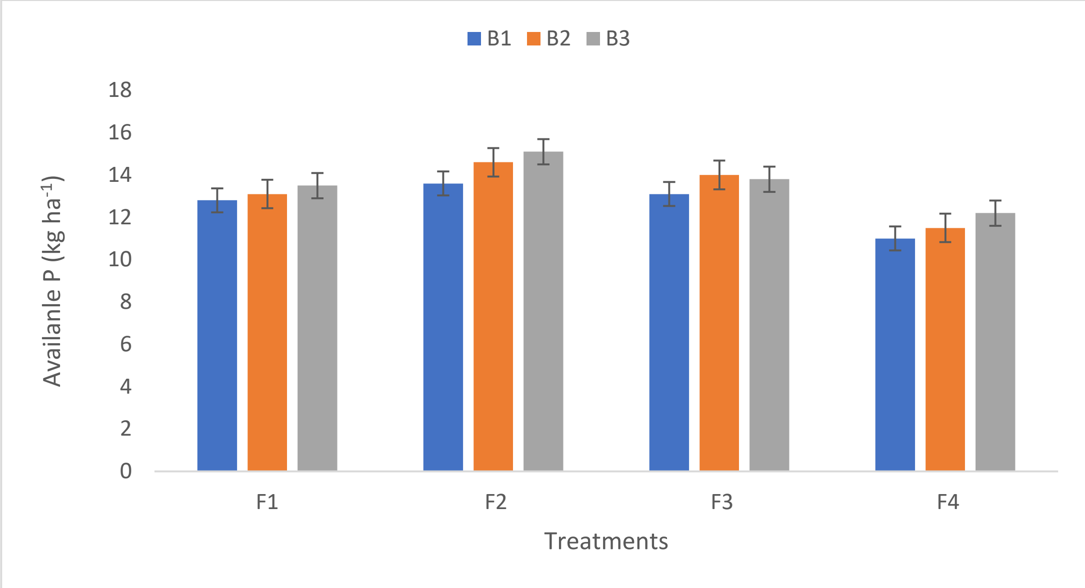

Fig. 4.5: Effect of biochar, mineral fertilizer and compost on soil available P

4.1.6 Available potassium (kg ha^{-1})

Both the individual (biochar and fertilizer) and interaction effects (biochar x fertilizer) were found significant for soil available potassium (Table No. 4.2). B_3 (106.69) and B_1 (91.51) had highest and lowest available K respectively. F_2 (105.35) showed highest results, while F_4 (87.78) showed lowest results. Highest available potassium was observed in treatment B_3F_2 (128.55) and the lowest was observed in treatment B_1F_4 (92.20).

Soil available potassium increased in the order:

$B_3F_4 < B_1F_1 < B_1F_3 < B_1F_4 < B_1F_2 < B_2F_4 < B_2F_1 < B_2F_3 < B_2F_2 < B_3F_1 < B_3F_3 < B_3F_2$

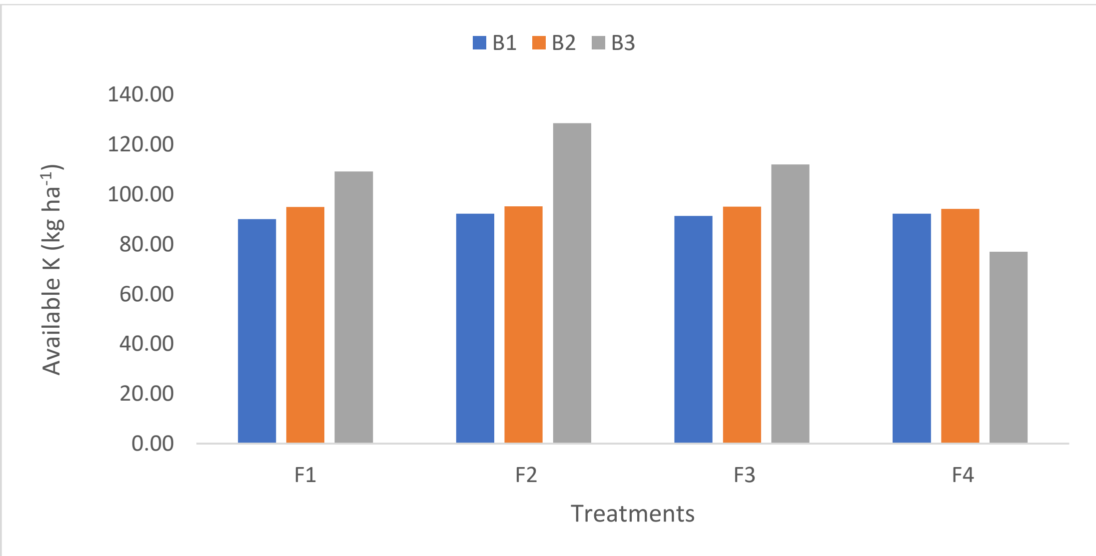

Fig. 4.6: Effect of biochar, mineral fertilizer and compost on soil available K

Table 4.2: Effect of biochar, mineral fertilizer and FYM on soil available nitrogen, available phosphorus and available potassium

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
B_1 (Biochar @ 4 t ha^{-1})	168.59	12.63	91.51
B_2 (Biochar @ 8 t ha^{-1})	175.85	13.30	94.86
B_3 (Biochar @ 12 t ha^{-1})	197.77	13.65	106.69
Mean	180.73	13.19	97.69
*CD Factor (B) (5%)	8.98	NS	6.72
F_1 (100% NPK)	185.08	13.13	98.09
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	195.40	14.43	105.35
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	177.31	13.63	99.52
F_4 (FYM @ 15 t ha^{-1})	165.15	11.57	87.78
Mean	180.73	13.19	97.69
*CD Factor (F) (5%)	10.37	NS	7.762
*CD Interaction (BXF) (5%)	17.97	NS	13.44

* = significant at $p \leq 0.05$

4.2.1 Bulk density (g cm^{-3})

The individual and interaction was significant for bulk density of soil. Lowest bulk density was observed in B_1 (1.46). F_2 and F_3 showed lowest bulk density (1.44 each) and were statistically at par. Lowest bulk density was seen in treatment B_3F_3 (1.43), which was statistically at par with B_3F_2 (1.43) and B_2F_3 (1.43).

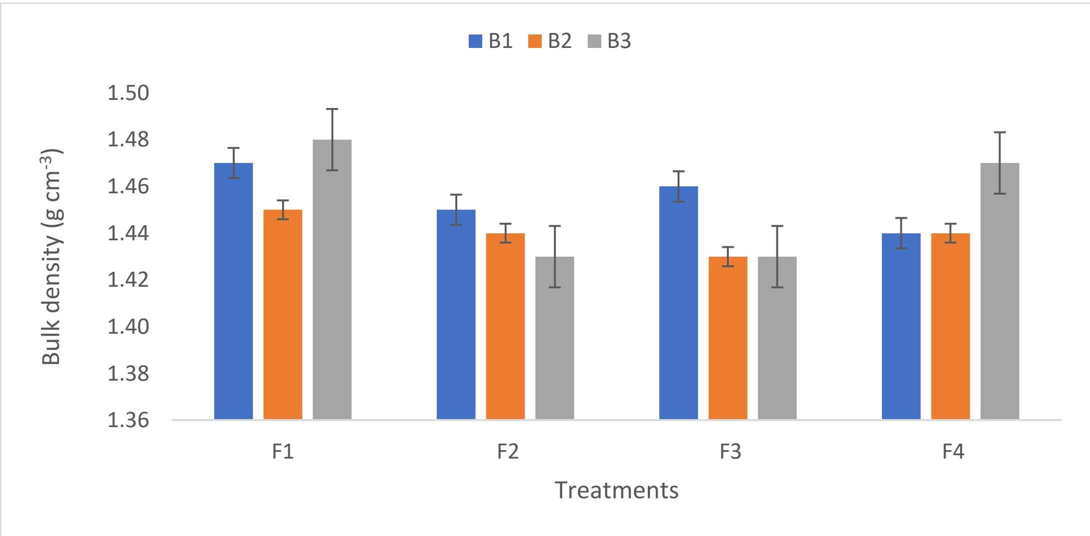

Fig. 4.7: Effect of biochar, mineral fertilizer and compost on soil bulk density

4.2.2 Porosity (%)

Significant results were noted for both the individual and interaction in case of porosity. Lowest porosity was in B_1 (45.21) and F_1 (44.20) individually. F_2 (45.78) and F_3 (46.40) were statistically at par. Lowest porosity was observed in B_1F_1 (43.52).

Soil porosity increased in the order:

$B_1F_1 < B_2F_1 < B_1F_4 < B_3F_4 < B_2F_4 < B_3F_1 < B_1F_2 < B_3F_2 < B_2F_2 < B_1F_3 < B_3F_3 < B_2F_3$

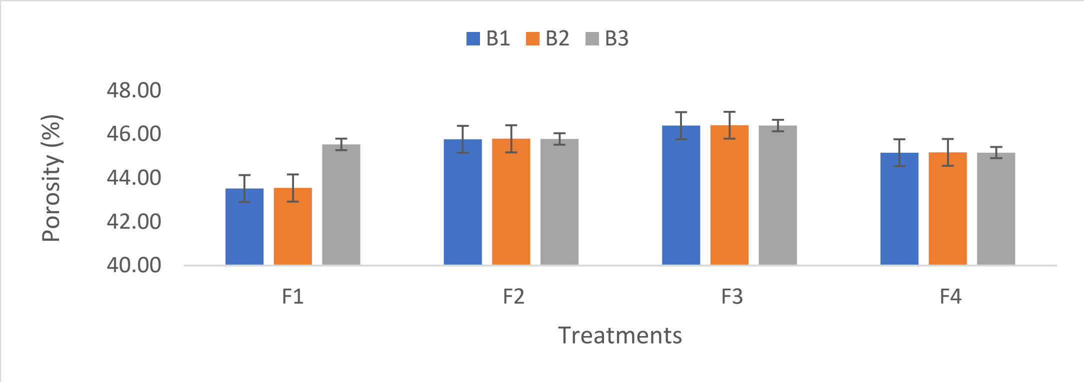

Fig. 4.8: Effect of biochar, mineral fertilizer and compost on soil porosity

4.2.3 Maximum water holding capacity (%)

The individual and interactive effects were found significant for maximum water holding capacity of the soil. The highest dose of biochar, i.e., B_3 (35.61) showed highest maximum water holding capacity. For fertilizer amendments, F_3 (37.09) showed the highest results. Highest maximum water holding capacity was observed in B_3F_3 (38.60).

Maximum water holding capacity of the soil increased in the order:

$B_2F_1 < B_1F_1 < B_3F_1 < B_1F_4 < B_2F_4 < B_3F_4 < B_1F_3 < B_1F_2 < B_2F_2 < B_2F_2 < B_3F_2 < B_2F_3 < B_3F_3$

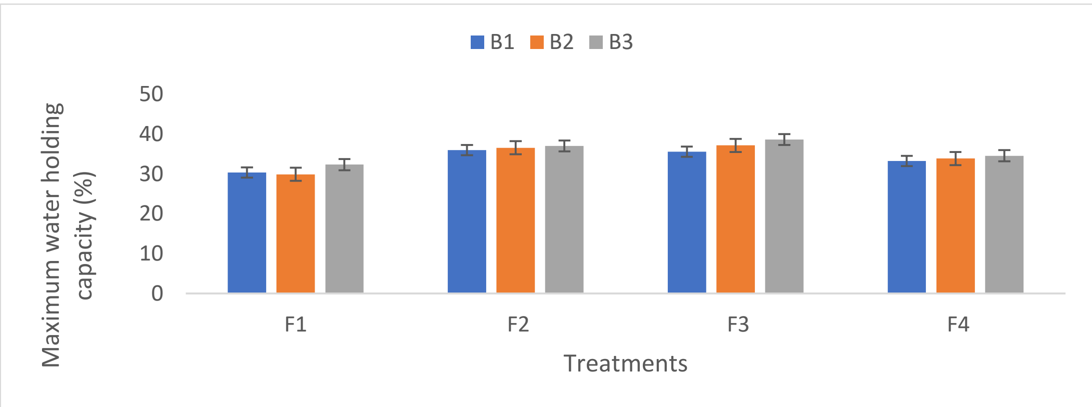

Fig. 4.9: Effect of biochar, mineral fertilizer and compost on soil maximum water holding capacity

Table 4.3: Effect of biochar, mineral fertilizer and FYM on soil bulk density, porosity and maximum water holding capacity

Treatments	Bulk density (g cm^{-3})	Porosity (%)	Maximum water holding capacity (%)
B_1 (Biochar @ 4 t ha^{-1})	1.46	45.21	33.74
B_2 (Biochar @ 8 t ha^{-1})	1.45	45.23	34.34
B_3 (Biochar @ 12 t ha^{-1})	1.44	45.72	35.61
Mean	1.45	45.39	34.56
*CD Factor (B) (5%)	0.01	0.44	0.51
F_1 (100% NPK)	1.47	44.20	30.83
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	1.44	45.78	36.49
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	1.44	46.40	37.09
F_4 (FYM @ 15 t ha^{-1})	1.45	45.16	33.85
Mean	1.45	45.39	34.57
*CD Factor (F) (5%)	0.01	0.51	0.583
*CD Interaction (BXF) (5%)	0.02	0.88	1.01

* = significant at $p \leq 0.05$

4.2.4 Soil moisture (%)

The soil moisture content at various intervals of 30 DAS, 60 DAS and 90 DAS was found significant for both the individual and interactive effects. B_3 showed highest soil moisture at all the intervals (30 DAS, 60 DAS, 90 DAS; 20.73 for 30 DAS, 14.43 for 60 DAS, 12.47 for 90 DAS). F_2 showed highest soil moisture at every time interval (22.57 for 30 DAS, 16.40 for 60 DAS, 12.24 for 90 DAS).

Soil moisture 30 DAS increased in the order:

$B_1F_1 < B_2F_1 < B_1F_4 < B_2F_4 < B_3F_1 < B_3F_4 < B_1F_3 < B_2F_3 < B_1F_2 < B_3F_3 < B_2F_2 < B_3F_2$

Soil moisture 60 DAS increased in the order:

$B_1F_1 < B_2F_1 < B_3F_1 < B_1F_4 < B_2F_4 < B_3F_4 = B_1F_3 < B_2F_3 < B_1F_2 < B_2F_2 < B_3F_2$

Soil moisture 90 DAS increased in the order:

$B_1F_2 < B_2F_1 < B_1F_1 < B_3F_1 = B_1F_4 < B_1F_3 < B_2F_3 < B_3F_4 < B_2F_4 < B_2F_2 < B_3F_2 < B_3F_3$

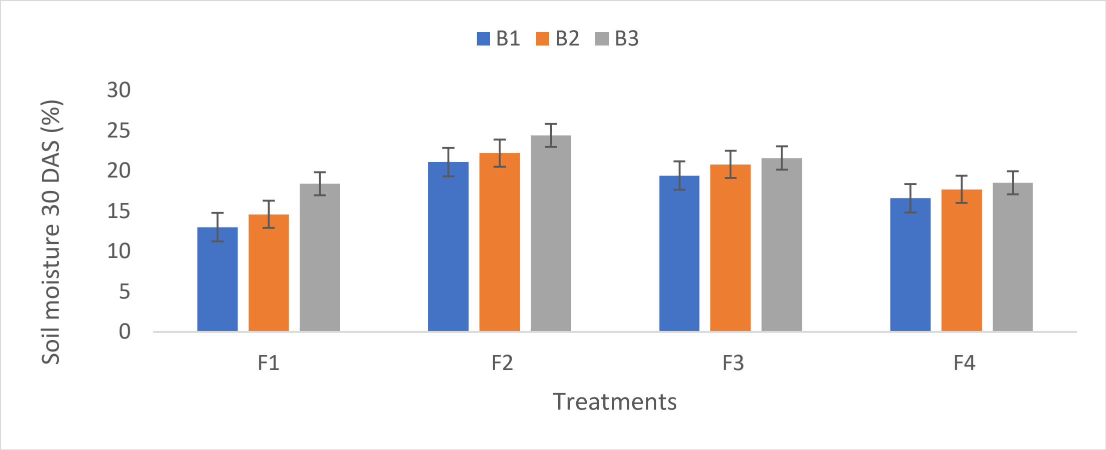

Fig. 4.10: Effect of biochar, mineral fertilizer and compost on soil moisture 30 DAS

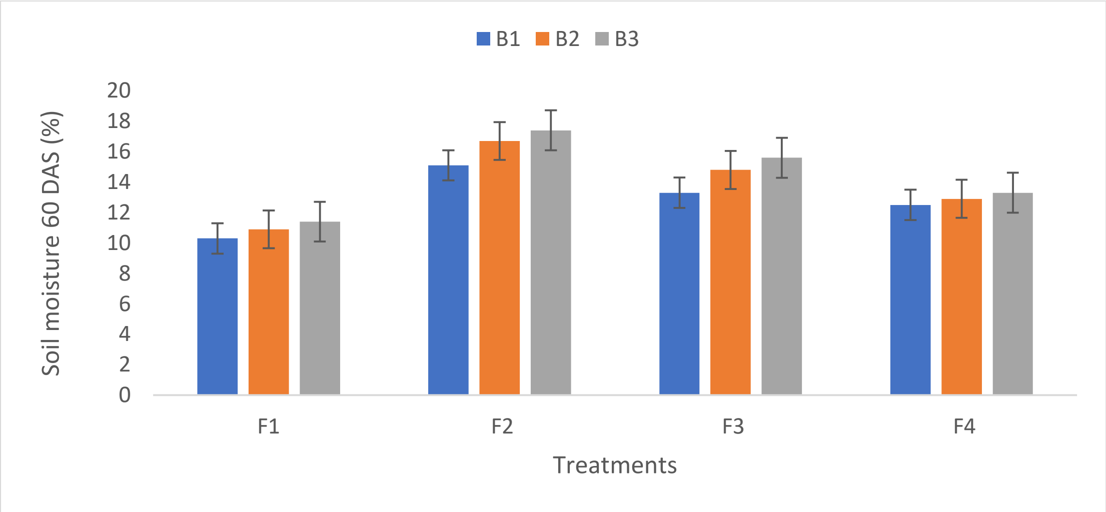

Fig. 4.11: Effect of biochar, mineral fertilizer and compost on soil moisture 60 DAS

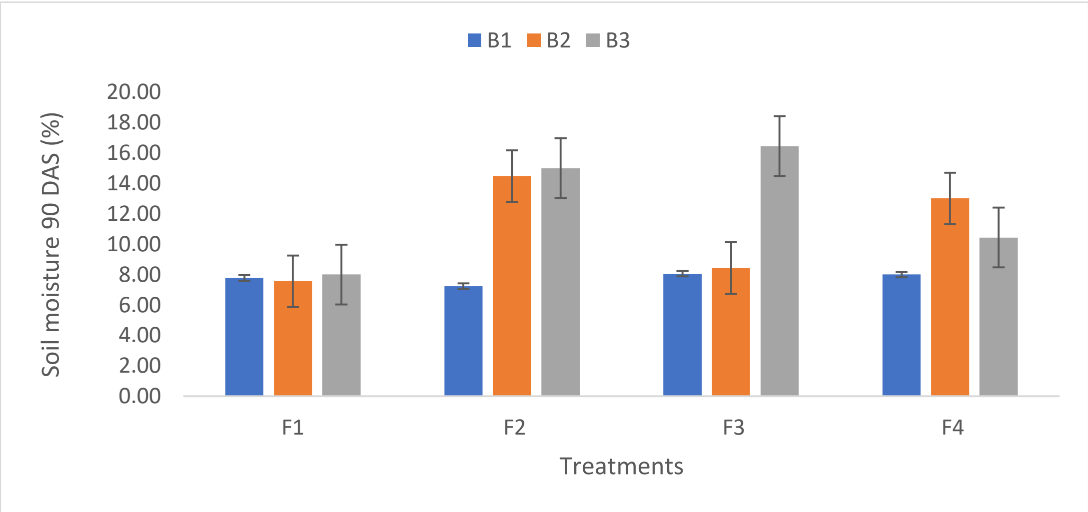

Fig. 4.12: Effect of biochar, mineral fertilizer and compost on soil moisture 90 DAS

Table 4.4: Effect of biochar, mineral fertilizer and FYM on soil moisture at various intervals

Treatments	Soil moisture 30 DAS (%)	Soil moisture 60 DAS (%)	Soil moisture 90 DAS (%)
B_1 (Biochar @ 4 t ha^{-1})	17.53	12.80	7.77
B_2 (Biochar @ 8 t ha^{-1})	18.83	13.83	10.87
B_3 (Biochar @ 12 t ha^{-1})	20.73	14.43	12.47
Mean	19.03	13.69	10.37
*CD Factor(B) (5%)	0.76	0.32	1.76
F_1 (100% NPK)	15.33	10.87	7.78
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	22.57	16.4	12.24
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	20.60	14.57	10.98
F_4 (FYM @ 15 t ha^{-1})	17.60	12.90	10.48
Mean	19.02	13.69	10.37
*CD Factor (F) (5%)	0.88	0.37	2.04
*CD Interaction (BXF) (5%)	1.52	0.64	3.53

* = significant at $p \leq 0.05$

4.2.5 Aggregate stability (%)

Mean weight diameter

The results of biochar and fertilizer amendments (organic and inorganic) were significant on mean weight diameter. When biochar and fertilizer amendments were compared individually, highest mean weight diameter was in B_3 (0.70) and F_2 (0.76) respectively. The interaction was found non-significant. The lowest mean weight diameter was observed in B_1F_4 (0.58).

Mean weight diameter increased in the order:

$B_1F_4 < B_2F_4 < B_1F_1 < B_2F_1 < B_3F_4 < B_3F_1 < B_1F_3 < B_2F_3 < B_1F_2 < B_3F_3 < B_2F_2 < B_3F_2$

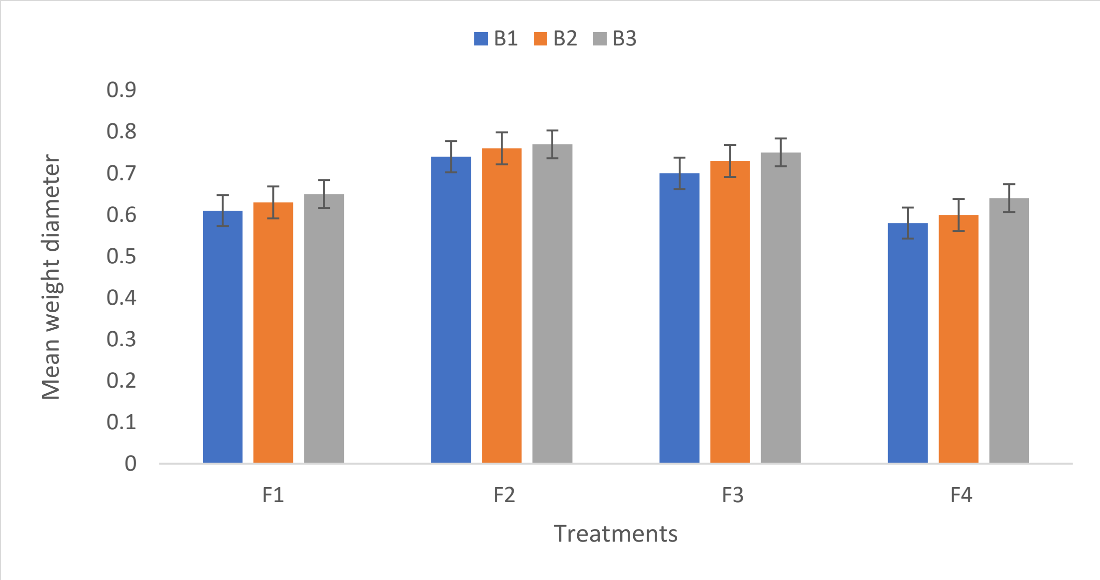

Fig. 4.13: Effect of biochar, mineral fertilizer and compost on mean weight diameter of soil

4.2.6 Infiltration rate (cm hr^{-1})

All the individual and interactive effects were found significant for infiltration rate of soil. Higher is the application of organics (here biochar FYM), less is the infiltration rate in sandy loam soil. The lowest infiltration rate was in B_3 (0.89). F_4 showed lowest infiltration rate (0.76). The lowest infiltration rate was observed in B_3F_4 (0.73).

Infiltration rate increased in the order:

$B_3F_4 < B_2F_4 < B_1F_4 < B_3F_3 < B_2F_3 < B_1F_3 < B_3F_2 < B_2F_2 < B_1F_2 = B_3F_1 < B_2F_1 < B_1F_1$

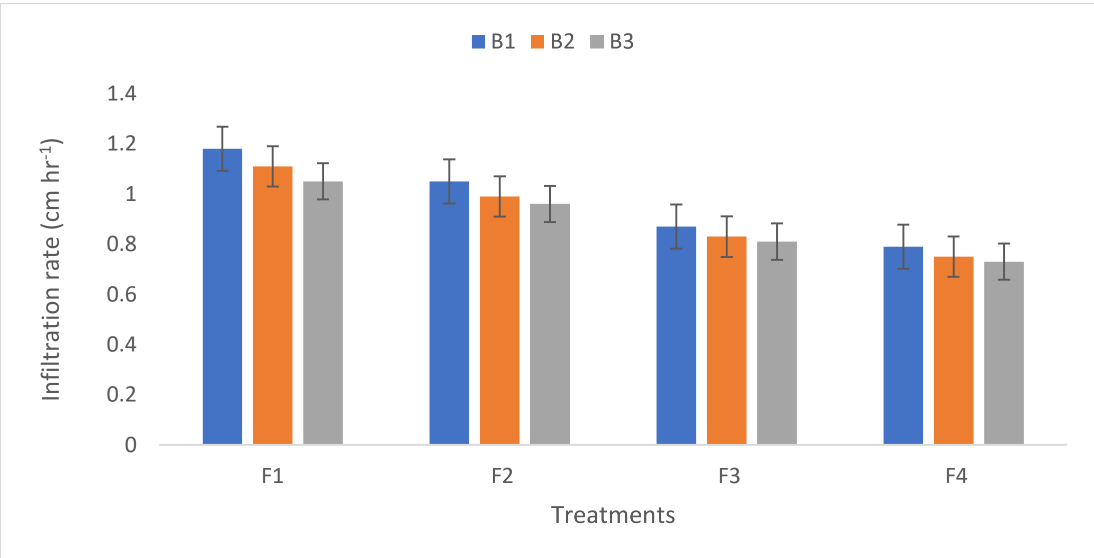

Fig. 4.14: Effect of biochar, mineral fertilizer and compost on soil infiltration rate

4.2.7 Hydraulic conductivity (cm hr^{-1})

Significant results were noted for the sole and interactive effects in hydraulic conductivity. The pattern of individual effects was similar as that of infiltration rate. The lowest hydraulic conductivity was observed in B_3 (0.75), F_4 (0.68), B_3F_4 (0.60).

Hydraulic conductivity increased in the order:

$B_3F_4 < B_2F_4 < B_1F_4 < B_3F_3 < B_2F_3 < B_3F_2 < B_1F_3 < B_2F_2 = B_3F_1 < B_1F_2 < B_2F_1 < B_1F_1$

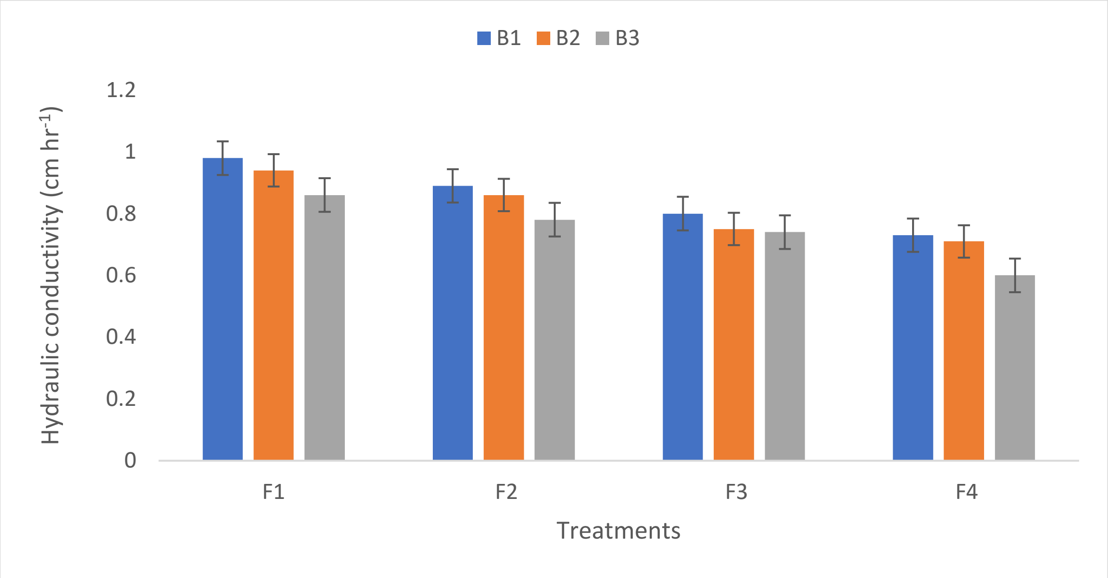

Fig. 4.15: Effect of biochar, mineral fertilizer and compost on soil hydraulic conductivity

Table 4.5: Effect of biochar, mineral fertilizer and FYM on mean weight diameter, infiltration rate, hydraulic conductivity

Treatments	Mean weight diameter	Infiltration rate (cm hr^{-1})	Hydraulic conductivity (cm hr^{-1})
B_1 (Biochar @ 4 t ha^{-1})	0.66	0.97	0.85
B_2 (Biochar @ 8 t ha^{-1})	0.68	0.92	0.82
B_3 (Biochar @ 12 t ha^{-1})	0.70	0.89	0.75
Mean	0.68	0.93	0.81
*CD Factor(B) (5%)	0.02	0.01	0.02
F_1 (100% NPK)	0.63	1.11	0.93
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	0.76	1.00	0.84
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	0.73	0.84	0.76
F_4 (FYM @ 15 t ha^{-1})	0.61	0.76	0.68
Mean	0.68	0.93	0.80
*CD Factor (F) (5%)	0.02	0.01	0.02
*CD Interaction (BXF) (5%)	NS	0.02	0.03

* = significant at $p \leq 0.05$

4.3.1 Plant height (cm)

Plant height at various intervals of 30 DAS, 60 DAS and 90 DAS was found significant for both the individual and interactive effects. Both the sources (organic and inorganic) being the source of nourishment (in terms of nutrients) for the plants, higher the dosage, better the growth attributes, i.e., plant height. Therefore, highest plant height was marked in B_3 (68.85 for 30 DAS, 105.88 for 60 DAS, 125.47 for 90 DAS) and F_2 (73.57 for 30 DAS, 116.43 for 60 DAS, 136.20 for 90 DAS) respectively and individually. In case of interaction, highest plant height was seen in B_3F_2 (75.1 for 30 DAS, 119.37 for 60 DAS, 139.77 for 90 DAS).

Plant height 30 DAS increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_2F_1 < B_1F_1 < B_3F_1 < B_1F_3 < B_3F_3 < B_2F_3 < B_1F_2 < B_2F_2 < B_3F_2$

Plant height 60 DAS increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_1 < B_2F_1 < B_3F_1 < B_1F_3 < B_2F_3 < B_3F_3 < B_1F_2 < B_2F_2 < B_3F_2$

Plant height 90 DAS increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_1 < B_2F_1 < B_3F_1 < B_1F_3 < B_2F_3 < B_3F_3 < B_1F_2 < B_2F_2 < B_3F_2$

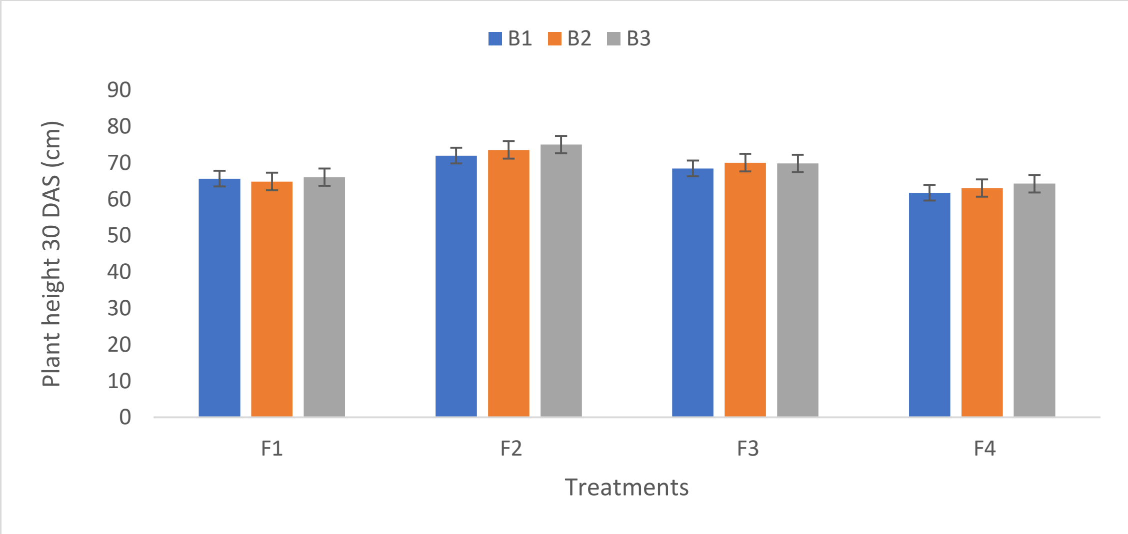

Fig. 4.16: Effect of biochar, mineral fertilizer and compost on plant height 30 DAS

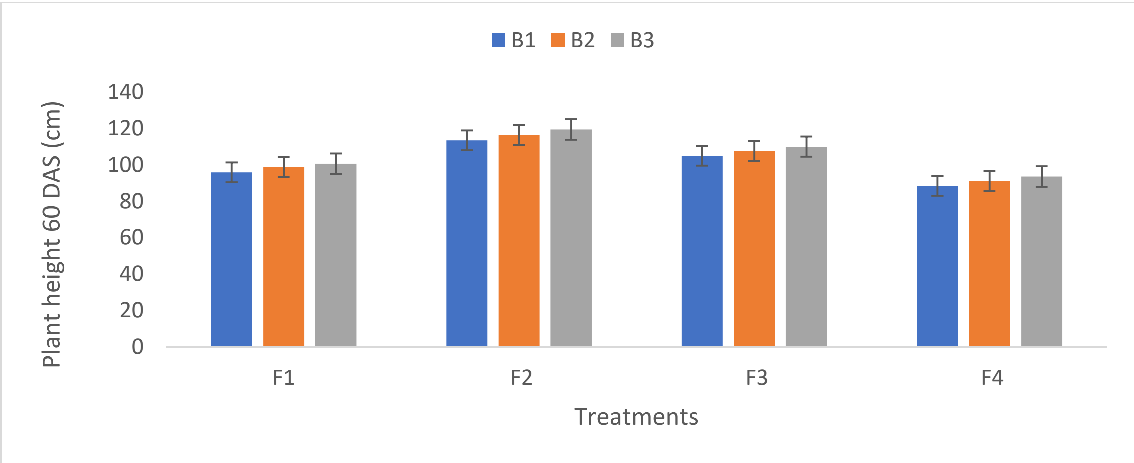

Fig. 4.17: Effect of biochar, mineral fertilizer and FYM on plant height 60 DAS

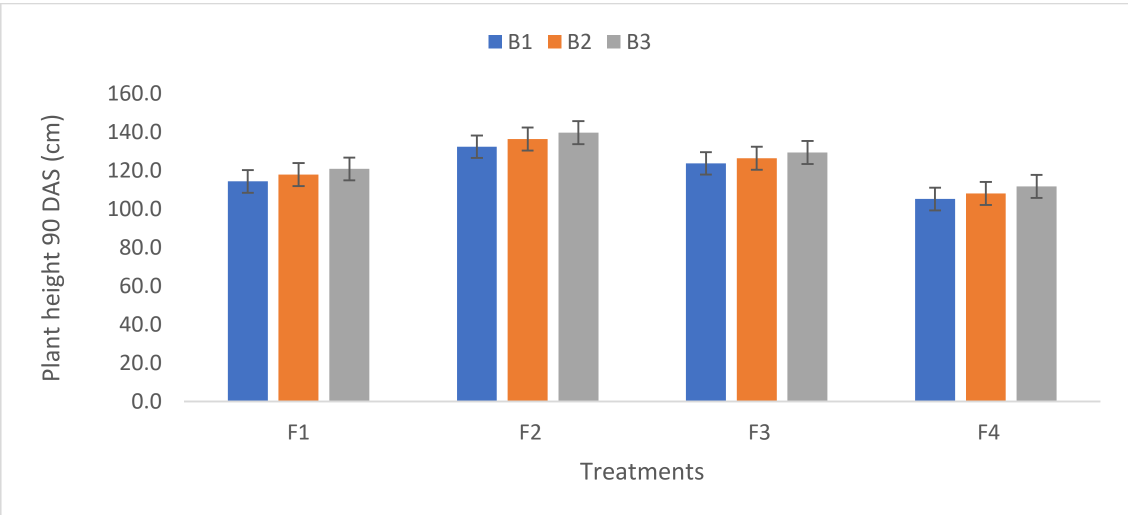

Fig. 4.18: Effect of biochar, mineral fertilizer and FYM on plant height 90 DAS

Table 4.6: Effect of biochar, mineral fertilizer and FYM on plant height at various intervals

Treatments	Plant height (30 DAS)	Plant height (60 DAS)	Plant height (90 DAS)
B_1 (Biochar @ 4 t ha^{-1})	67.00	100.66	118.97
B_2 (Biochar @ 8 t ha^{-1})	67.93	103.47	122.23
B_3 (Biochar @ 12 t ha^{-1})	68.85	105.88	125.47
Mean	67.92	103.33	122.14
*CD Factor(B) (5%)	0.45	0.26	0.30
F_1 (100% NPK)	65.57	98.35	117.73
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	73.57	116.43	136.20
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	69.50	107.50	126.56
F_4 (FYM @ 15 t ha^{-1})	63.07	91.04	108.39
Mean	67.92	103.33	122.22
*CD Factor (F) (5%)	0.52	0.30	0.34
*CD Interaction (BXF) (5%)	0.91	0.52	0.59

* = significant at $p \leq 0.05$

4.3.2 Root-shoot ratio

The effect of biochar, mineral fertilizers and FYM was completely non-significant for root-shoot ratio. Although, the effect of root-shoot ratio was non-significant, doses wherein biochar was applied the highest (i.e., B_3, 0.49) showed highest root-shoot ratio outcomes, when compared to B_2 (0.47) and B_1 (0.46). Similar trend was in case of fertilizer amendments, wherein the highest values were for F_2 (0.49).

Root-shoot ratio increased in the order:

$B_1F_4 < B_3F_4 = B_2F_4 < B_1F_1 < B_2F_1 = B_3F_1 = B_1F_3 < B_3F_1 = B_2F_2 < B_1F_2 < B_3F_3 < B_3F_2$

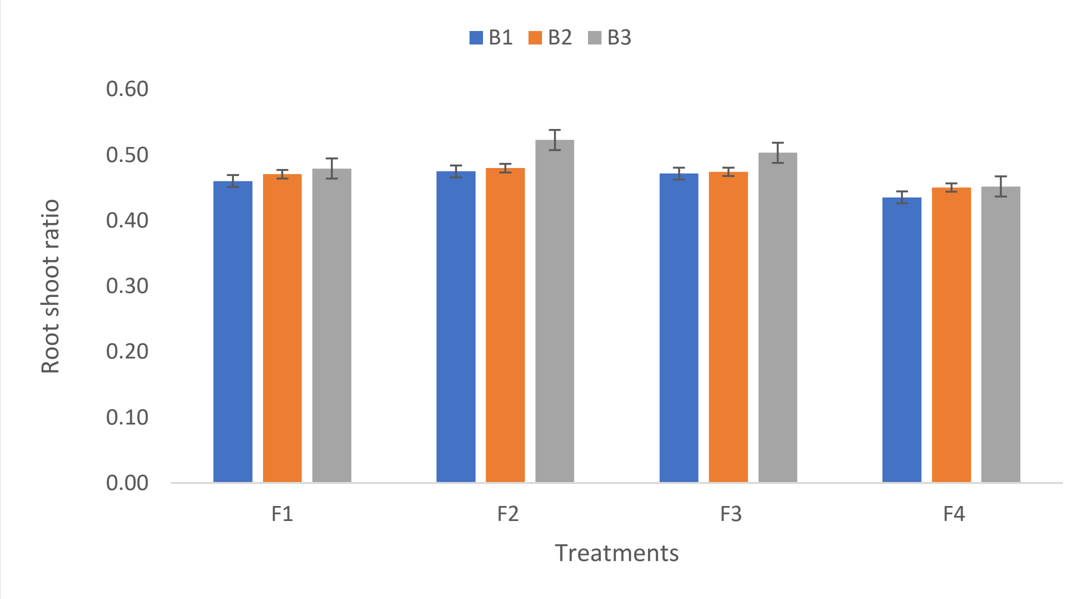

Fig. 4.19: Effect of biochar, mineral fertilizer and compost on root-shoot ratio

4.3.3 Grain Yield (kg ha^{-1} and g pot^{-1})

Grain yield was found significant for both individual and interactive effects. The highest grain yield was observed in B_3 (2939.25 kg ha^{-1}), F_2 (3308.67 kg ha^{-1}) and B_3F_2 (3507 kg ha^{-1}).

Grain yield increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_1 < B_2F_1 < B_3F_1 < B_1F_3 < B_2F_3 < B_3F_3 < B_1F_2 < B_2F_2 < B_3F_2$

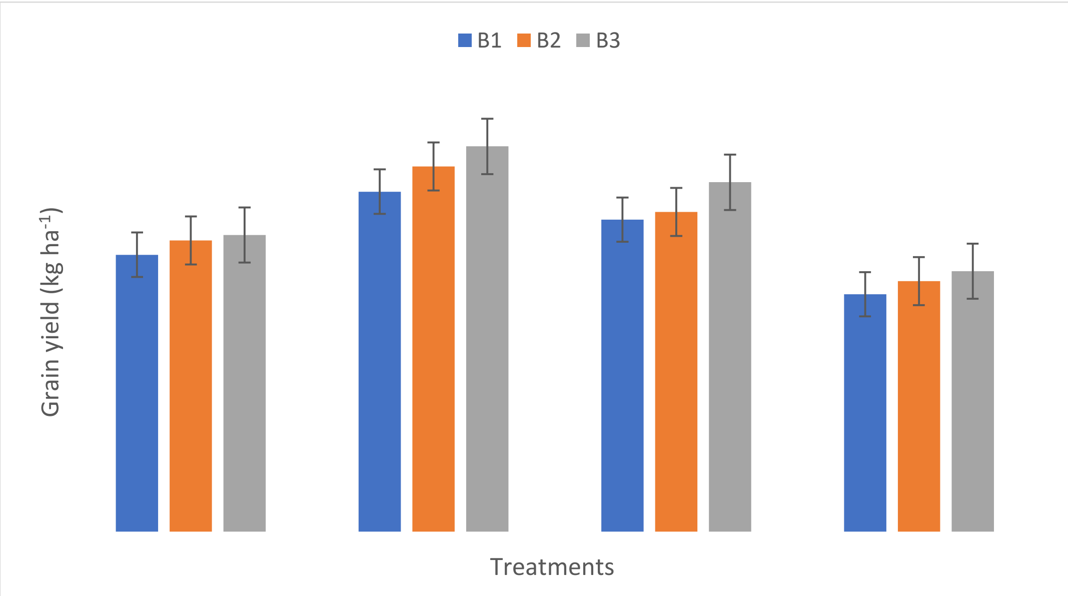

Fig. 4.20: Effect of biochar, mineral fertilizer and compost on grain yield

Table 4.7: Effect of biochar, mineral fertilizer and FYM on root-shoot ratio and grain yield

Treatments	Root-shoot ratio	Grain yield (g pot^{-1})	Grain yield (kg ha^{-1})
B_1 (Biochar @ 4 t ha^{-1})	0.46	18.58	2653.75
B_2 (Biochar @ 8 t ha^{-1})	0.47	19.54	2791.00
B_3 (Biochar @ 12 t ha^{-1})	0.49	20.57	2939.25
Mean	0.47	19.56	2794.67
*CD Factor(B) (5%)	NS	0.30	43.205
F_1 (100% NPK)	0.47	18.36	2623.33
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	0.49	23.16	3308.67
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	0.48	20.84	2976.67
F_4 (FYM @ 15 t ha^{-1})	0.45	15.89	2270.00
Mean	0.47	19.56	2794.67
*CD Factor(F) (5%)	NS	0.35	49.89
*CD Interaction (BXF) (5%)	NS	0.61	86.41

* = significant at $p \leq 0.05$

4.3.4 Nitrogen uptake (kg ha^{-1} and g pot^{-1})

The effect of biochar, fertilizer amendments and the interactive effects were significant for nitrogen uptake. Table No. 4.8 suggests that the individual effects were highest in B_3 (45.36 kg ha^{-1}) for biochar and F_2 (45.24) for fertilizer amendments. B_2F_2 (45.71 kg ha^{-1}) recorded the highest N uptake value.

Nitrogen uptake increased in the order:

$B_2F_2 < B_3F_2 < B_1F_2 < B_3F_3 = B_2F_3 < B_3F_1 < B_1F_3 < B_2F_3 < B_3F_3 < B_1F_2 < B_2F_2 < B_3F_2$

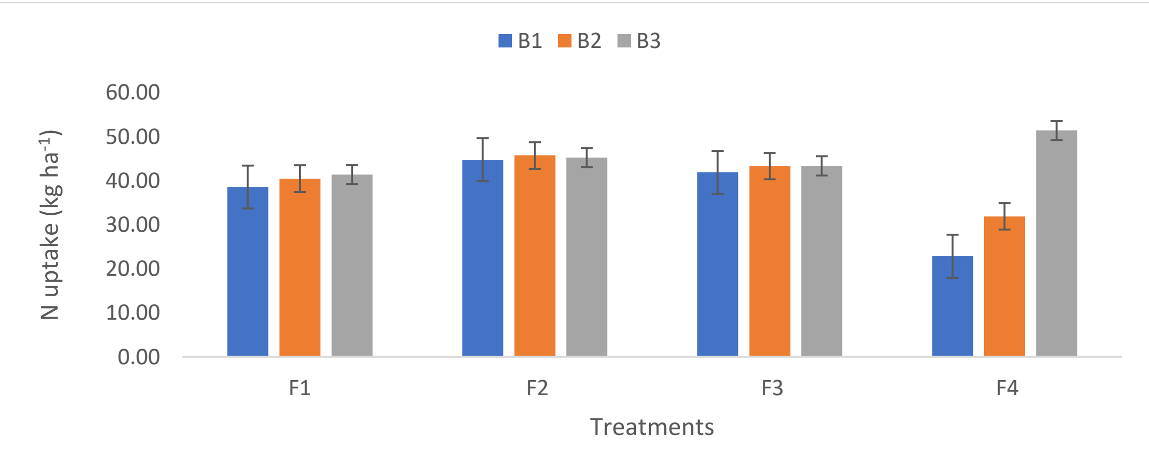

Fig. 4.21: Effect of biochar, mineral fertilizer and compost on N uptake

Table 4.8: Effect of biochar, mineral fertilizer and FYM on nitrogen uptake

Treatments	N uptake (g pot^{-1})	N uptake (kg ha^{-1})
B_1 (Biochar @ 4 t ha^{-1})	0.26	37.02
B_2 (Biochar @ 8 t ha^{-1})	0.28	40.36
B_3 (Biochar @ 12 t ha^{-1})	0.32	45.36
Mean	0.29	40.91
*CD Factor(B) (5%)	0.02	3.36
F_1 (100% NPK)	0.28	40.16
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	0.32	45.24
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	0.30	42.86
F_4 (FYM @ 15 t ha^{-1})	0.25	35.40
Mean	0.29	40.92
*CD Factor (F) (5%)	0.03	3.88
*CD Interaction (BXF) (5%)	0.05	6.71

* = significant at $p \leq 0.05$

4.3.5 Phosphorus uptake (kg ha^{-1} and g pot^{-1})

The effect of biochar, fertilizer amendments and their interaction was completely non-significant for phosphorus uptake. As observed in Table No. 4.9 the highest P uptake values were obtained in B_3 (11.4 kg ha^{-1}) and F_2 (12.40 kg ha^{-1}) individually for biochar factor and fertilizer factor respectively and in B_3F_2 (13.20 kg ha^{-1}) in interaction.

Phosphorus uptake increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_3 < B_3F_1 < B_2F_1 < B_1F_1 < B_1F_2 < B_2F_3 < B_2F_2 < B_3F_3 < B_3F_2$

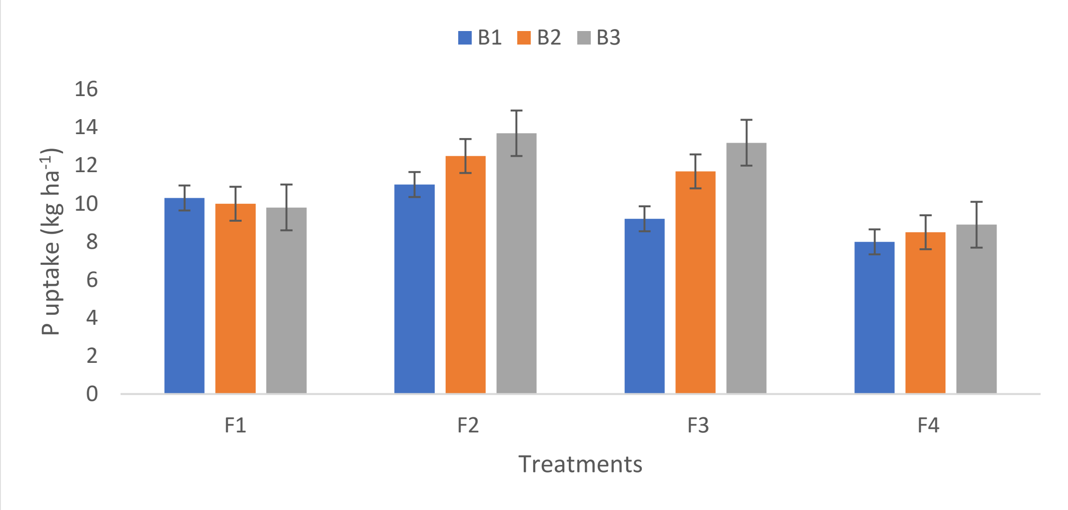

Fig. 4.22: Effect of biochar, mineral fertilizer and compost on P uptake

Table 4.9: Effect of biochar, mineral fertilizer and FYM on phosphorus uptake

Treatments	**P uptake ($g\ pot^{-1}$)**	**P uptake ($kg\ ha^{-1}$)**
B_1 (Biochar @ 4 t ha^{-1})	0.07	9.63
B_2 (Biochar @ 8 t ha^{-1})	0.07	10.68
B_3 (Biochar @ 12 t ha^{-1})	0.08	11.40
Mean	0.07	10.57
*CD Factor(B) (5%)	NS	NS
F_1 (100% NPK)	0.07	10.03
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	0.09	12.40
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	0.08	11.37
F_4 (FYM @ 15 t ha^{-1})	0.06	8.47
Mean	0.07	10.57
*CD Factor (F) (5%)	NS	NS
*CD Interaction (BXF) (5%)	NS	NS

* = significant at $p \leq 0.05$

4.3.6 Potassium uptake (kg ha^{-1} and g pot^{-1})

The effect of biochar, fertilizer amendments and their interaction was significant for potassium uptake. As evident from Table No. 4.10, F_2 (35.56 kg ha^{-1}) marked for the highest K uptake values among fertilizer amendments and B_3 (39.52 kg ha^{-1}) among biochar treatments. In interaction B_3F_3 (40.95 kg ha^{-1}) was highest.

Potassium uptake increased in the order:

$B_2F_4 < B_1F_4 < B_1F_3 < B_1F_1 < B_2F_1 < B_3F_1 < B_3F_2 < B_1F_2 < B_2F_2 < B_2F_3 < B_3F_3 < B_3F_4$

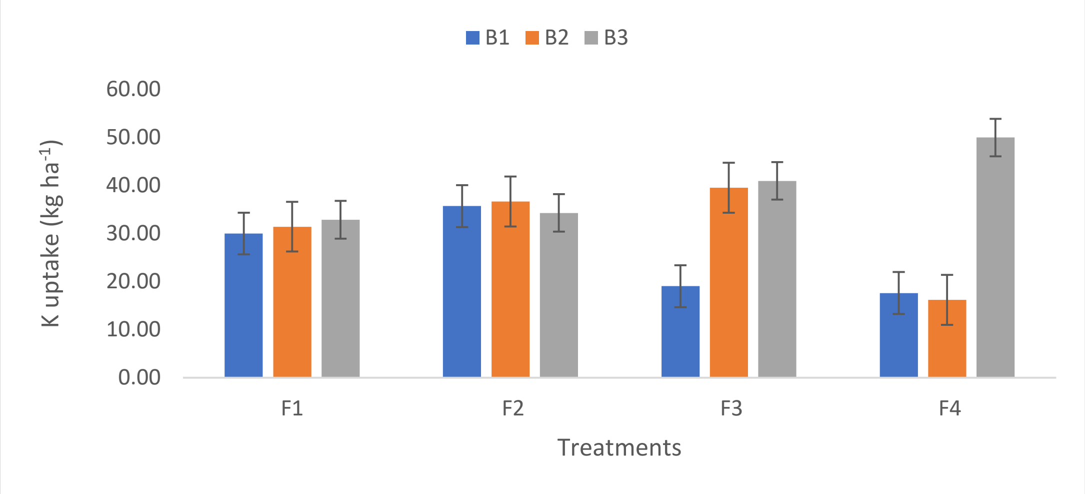

Fig. 4.23: Effect of biochar, mineral fertilizer and compost on K uptake

Table 4.10: Effect of biochar, mineral fertilizer and FYM on potassium uptake

Treatments	**K uptake ($g\ pot^{-1}$)**	**K uptake ($kg\ ha^{-1}$)**
B_1 (Biochar @ 4 t ha^{-1})	0.18	25.60
B_2 (Biochar @ 8 t ha^{-1})	0.22	30.95
B_3 (Biochar @ 12 t ha^{-1})	0.28	39.52
Mean	0.23	32.02
*CD Factor(B) (5%)	0.02	3.22
F_1 (100% NPK)	0.22	31.43
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	0.25	35.56
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	0.23	33.17
F_4 (FYM @ 15 t ha^{-1})	0.19	27.94
Mean	0.22	32.02
*CD Factor (F) (5%)	0.03	3.72
*CD Interaction (BXF) (5%)	0.05	6.45

* = significant at $p \leq 0.05$

4.4.1 Root volume

The effect of biochar, fertilizer amendments and their interaction showed positive and significant results for root volume. Higher the incorporation of inorganic and organics, higher is the root growth and its spread. Considering individual factors, B_3 (31.88 cm^3) had highest root volume and F_2 (33.37 cm^3) for fertilizer amendments. Table No. 4.11 illustrates that the highest root volume was observed in B_3F_2 (38.4 cm^3).

Root volume increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_1 < B_2F_1 < B_1F_3 < B_2F_3 < B_1F_2 < B_3F_1 < B_2F_2 < B_3F_3 < B_3F_2$

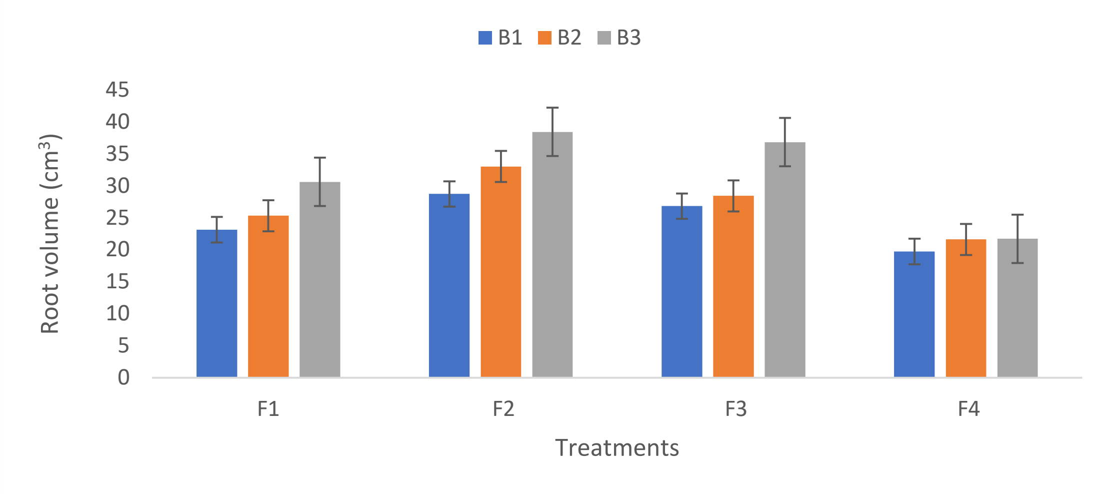

Fig. 4.24: Effect of biochar, mineral fertilizer and compost on root volume

4.4.2 Root weight

Significant results were observed for root volume in biochar, fertilizer amendments and their interaction. B_3 (31.28 g) and F_2 (33 g) were significantly superior among their respective other treatments of biochar and fertilizer amendments respectively. The highest root weight was observed in B_3F_2 (38.9 g).

Root weight increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_1 < B_2F_1 < B_1F_3 < B_2F_3 < B_1F_2 < B_3F_1 < B_2F_2 < B_3F_3 < B_3F_2$

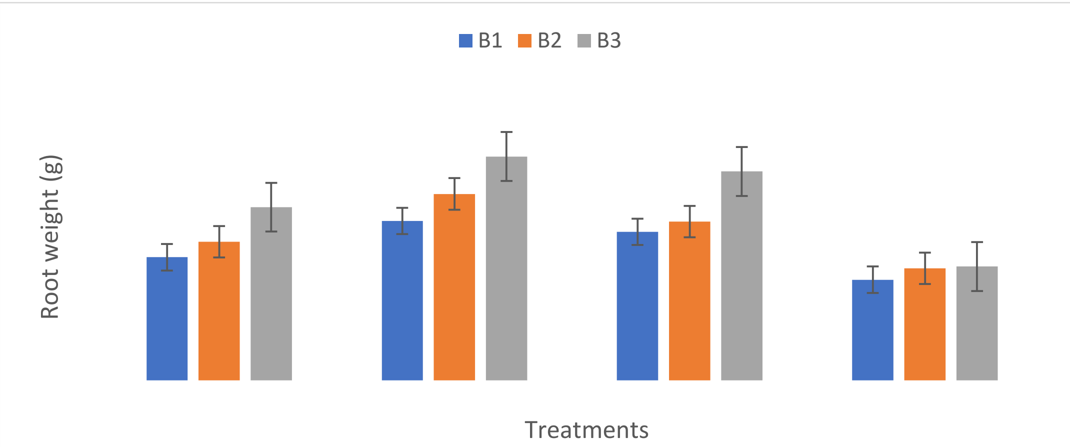

Fig. 4.25: Effect of biochar, mineral fertilizer and compost on root weight

4.4.3 Root weight density

Root weight density was completely non-significant for root weight density. Factor-1, Factor-2 and their interaction were highest in B_3 (0.97 g cm^{-3}), F_2 (0.99 g cm^{-3}) and B_3F_2

(1.01 g cm^{-3}) respectively (Table No. 4.11).

Root weight increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_1 < B_2F_1 < B_1F_3 < B_2F_3 = B_1F_2 < B_3F_1 = B_2F_2 < B_3F_3 < B_3F_2$

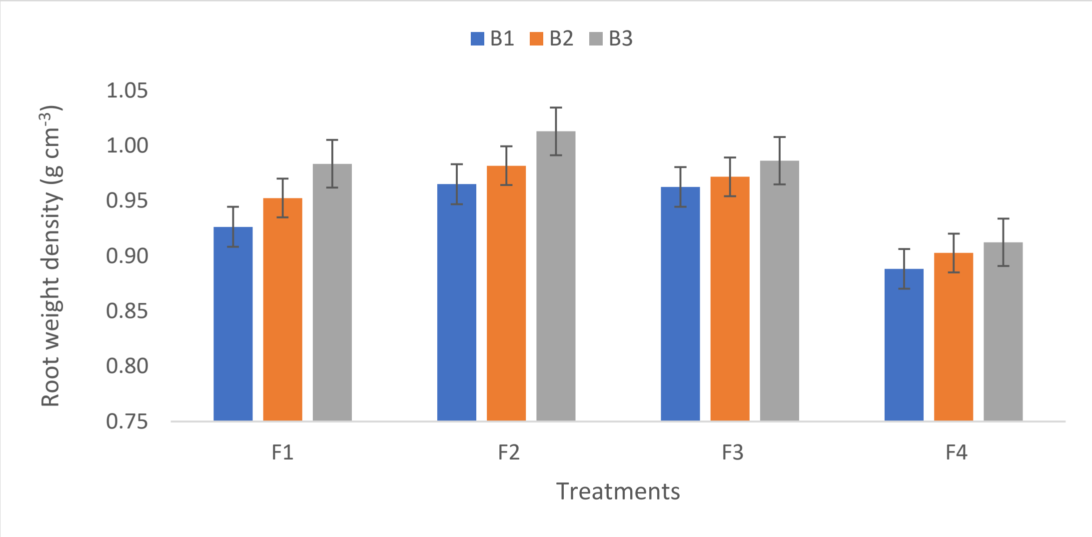

Fig. 4.26: Effect of biochar, mineral fertilizer and compost on root weight density

Table 4.11: Effect of biochar, mineral fertilizer and FYM on root volume, root weight, root weight density

Treatments	Root volume (cm^3)	Root weight (g)	Root weight density (g cm^{-3})
B_1 (Biochar @ 4 t ha^{-1})	24.58	23.10	0.94
B_2 (Biochar @ 8 t ha^{-1})	27.08	25.90	0.95
B_3 (Biochar @ 12 t ha^{-1})	31.88	31.28	0.97
Mean	27.85	26.76	0.95
*CD Factor(B) (5%)	1.65	2.05	NS
F_1 (100% NPK)	26.33	25.20	0.95
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	33.37	33.00	0.99
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	30.67	29.90	0.97
F_4 (FYM @ 15 t ha^{-1})	21.00	18.93	0.90
Mean	27.84	28.36	0.95
*CD Factor (F) (5%)	1.91	2.37	NS
*CD Interaction (BXF) (5%)	3.31	4.10	NS

* = significant at $p \leq 0.05$

4.4.4 Root length density

The individual and interactive effects of biochar and fertilizer amendments (organic and inorganic) was found non-significant for root length density. Highest results were for B_1 (0.66 cm cm^{-3}), F_4 (0.70 cm cm^{-3}), B_1F_4 (0.71 cm cm^{-3}).

Root length density increased in the order:

$B_3F_2 < B_3F_3 < B_2F_2 < B_3F_1 < B_2F_3 < B_1F_2 = B_1F_3 < B_1F_2 < B_2F_1 < B_2F_4 = B_1F_1 < B_3F_4 < B_1F_4$

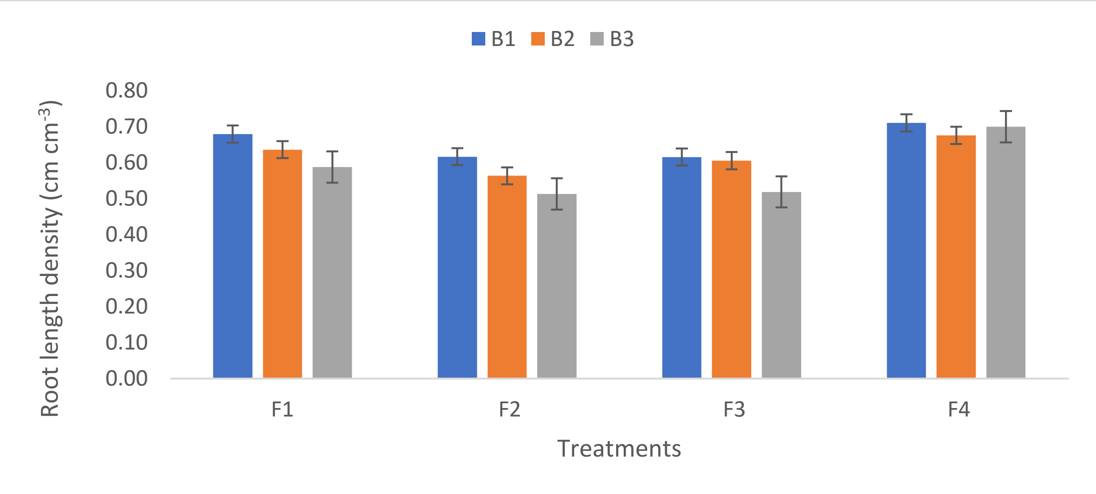

Fig. 4.27: Effect of biochar, mineral fertilizer and compost on root length density

4.4.5 Root length

The individual and interactive effects of biochar and fertilizer amendments (organic and inorganic) was found significant for root length. As shown in Table No. 4.12, highest result was seen in B_3 (18 cm), F_2 (18.67 cm) and B_3F_2 (19.7 cm).

Root length increased in the order:

$B_1F_4 < B_2F_4 < B_3F_4 < B_1F_1 < B_2F_1 < B_1F_3 < B_2F_3 < B_1F_2 < B_3F_1 < B_2F_2 < B_3F_3 < B_3F_2$

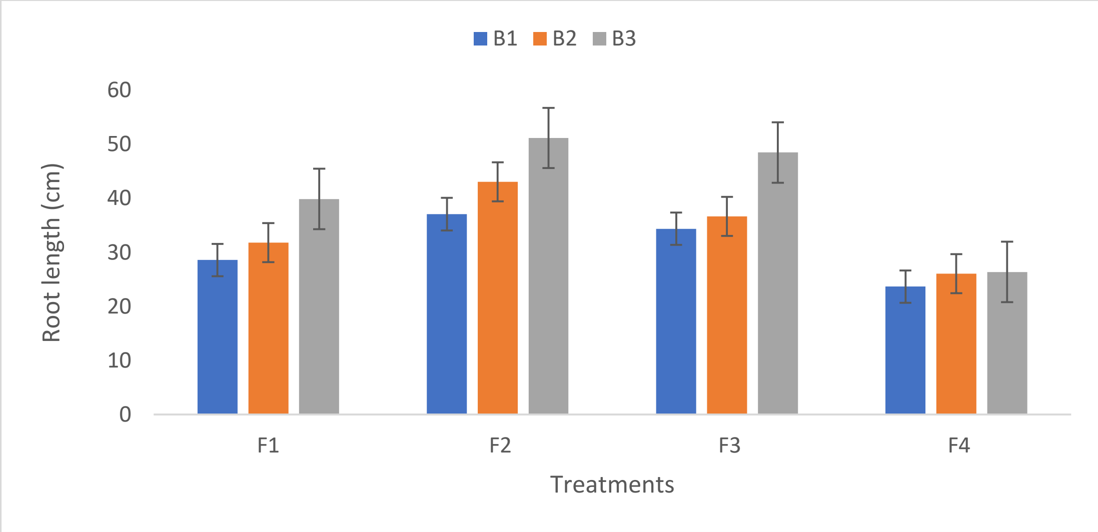

Fig. 4.28: Effect of biochar, mineral fertilizer and compost on root length

Table 4.12: Effect of biochar, mineral fertilizer and FYM on root length density, root length

Treatments	Root length (cm)	Root length density (cm cm^{-3})
B_1 (Biochar @ 4 t ha^{-1})	15.98	0.66
B_2 (Biochar @ 8 t ha^{-1})	16.63	0.62
B_3 (Biochar @ 12 t ha^{-1})	18.00	0.58
Mean	16.87	0.62
*CD Factor(B) (5%)	2.11	NS
F_1 (100% NPK)	16.60	0.63
F_2 (75% N + 100% PK +FYM @ 15 t ha^{-1})	18.67	0.56
F_3 (50% N + 100% PK +FYM @ 15 t ha^{-1})	17.60	0.58
F_4 (FYM @ 15 t ha^{-1})	14.60	0.70
Mean	16.87	0.62
*CD Factor (F) (5%)	2.43	NS
*CD Interaction (BXF) (5%)	4.21	NS

* = significant at $p \leq 0.05$

(C) Interaction tables of the significant parameters

Table 4.13: Interactive effect of biochar, mineral fertilizer and FYM on soil organic carbon

Organic carbon (%)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	0.19	0.20	0.20	**0.20**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	0.30	0.33	0.34	**0.32**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	0.25	0.26	0.28	**0.26**
F_4 (FYM @ 15 t ha^{-1})	0.22	0.23	0.24	**0.23**
Mean	**0.24**	**0.26**	**0.27**	
	CD (5%)			
Factor (B)	0.01			
Factor (F)	0.01			
Factor (BXF)	0.02			

Table 4.14: Interactive effect of biochar, mineral fertilizer and FYM on soil available nitrogen

Available nitrogen (kg ha^{-1})				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	172.64	180.08	202.53	**185.08**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	182.27	190.12	213.82	**195.40**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	165.40	172.52	194.02	**177.31**
F_4 (FYM @ 15 t ha^{-1})	154.05	160.68	180.71	**165.15**
Mean	**168.59**	**175.85**	**197.77**	
	CD (5%)			
Factor (B)	8.98			
Factor (F)	10.37			
Factor (BXF)	17.97			

Table 4.15: Interactive effect of biochar, mineral fertilizer and FYM on soil porosity

Porosity (%)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	43.52	43.54	45.53	**44.20**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	45.77	45.79	45.78	**45.78**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	46.39	46.41	46.40	**46.40**
F_4 (FYM @ 15 t ha^{-1})	45.15	45.17	45.16	**45.16**
Mean	**45.21**	**45.23**	**45.72**	
	CD (5%)			
Factor (B)	0.44			
Factor (F)	0.51			
Factor (BXF)	0.88			

Table 4.16: Interactive effect of biochar, mineral fertilizer and FYM on soil maximum water holding capacity

Maximum water holding capacity (%)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	30.31	29.87	32.30	**30.83**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	35.93	36.53	37.00	**36.49**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	35.53	37.13	38.60	**37.09**
F_4 (FYM @ 15 t ha^{-1})	33.20	33.83	34.53	**33.85**
Mean	**33.74**	**34.34**	**35.61**	
	CD (5%)			
Factor (B)	0.51			
Factor (F)	0.58			
Factor (BXF)	1.01			

Table 4.17: Interactive effect of biochar, mineral fertilizer and FYM on soil moisture 30 DAS

Soil moisture 30 DAS (cm)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	13.00	14.60	18.40	**15.33**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	21.10	22.20	24.40	**22.57**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	19.40	20.80	21.60	**20.60**
F_4 (FYM @ 15 t ha^{-1})	16.60	17.70	18.50	**17.60**
Mean	**17.53**	**18.83**	**20.73**	
	CD (5%)			
Factor (B)	0.76			
Factor (F)	0.88			
Factor (BXF)	1.52			

Table 4.18: Interactive effect of biochar, mineral fertilizer and FYM on soil moisture 60 DAS

Soil moisture 60 DAS (cm)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	10.30	10.90	11.40	**10.87**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	15.10	16.70	17.40	**16.40**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	13.30	14.80	15.60	**14.57**
F_4 (FYM @ 15 t ha^{-1})	12.50	12.90	13.30	**12.90**
Mean	**12.80**	**13.83**	**14.43**	
	CD (5%)			
Factor (B)	0.32			
Factor (F)	0.37			
Factor (BXF)	0.64			

Table 4.19: Interactive effect of biochar, mineral fertilizer and FYM on soil moisture 90 DAS

Soil moisture 90 DAS (cm)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	7.78	7.56	8.00	**7.78**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	7.24	14.48	15.00	**12.24**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	8.06	8.43	16.45	**10.98**
F_4 (FYM @ 15 t ha^{-1})	8.00	13.01	10.43	**10.48**
Mean	**7.77**	**10.87**	**12.47**	
	CD (5%)			
Factor (B)	1.76			
Factor (F)	2.04			
Factor (BXF)	3.53			

Table 4.20: Interactive effect of biochar, mineral fertilizer and FYM on soil infiltration rate

Infiltration rate (cm hr^{-1})				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	1.18	1.11	1.05	**1.11**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	1.05	0.99	0.96	**1.00**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	0.87	0.83	0.81	**0.84**
F_4 (FYM @ 15 t ha^{-1})	0.79	0.75	0.73	**0.76**
Mean	**0.97**	**0.92**	**0.89**	
	CD (5%)			
Factor (B)	0.01			
Factor (F)	0.01			
Factor (BXF)	0.02			

Table 4.21: Interactive effect of biochar, mineral fertilizer and FYM on soil hydraulic conductivity

Hydraulic conductivity (cm hr^{-1})				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	0.98	0.94	0.86	**0.93**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	0.89	0.86	0.78	**0.84**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	0.80	0.75	0.74	**0.76**
F_4 (FYM @ 15 t ha^{-1})	0.73	0.71	0.60	**0.68**
Mean	**0.85**	**0.82**	**0.75**	
	CD (5%)			
Factor (B)	0.01			
Factor (F)	0.01			
Factor (BXF)	0.02			

Table 4.22: Interactive effect of biochar, mineral fertilizer and FYM on plant height 30 DAS

Plant height 30 DAS (cm)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	65.70	64.90	66.10	**65.57**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	72.00	73.60	75.10	**73.57**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	68.50	70.10	69.90	**69.50**
F_4 (FYM @ 15 t ha^{-1})	61.80	63.10	64.30	**63.07**
Mean	**67.00**	**67.93**	**68.85**	
	CD (5%)			
Factor (B)	0.45			
Factor (F)	0.52			
Factor (BXF)	0.91			

Table 4.23: Interactive effect of biochar, mineral fertilizer and FYM on plant height 60 DAS

Plant height 60 DAS (cm)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	95.80	98.73	100.53	**98.35**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	113.50	116.43	119.37	**116.43**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	104.90	107.60	110.00	**107.50**
F_4 (FYM @ 15 t ha^{-1})	88.43	91.10	93.60	**91.04**
Mean	**100.66**	**103.47**	**105.88**	
	CD (5%)			
Factor (B)	0.26			
Factor (F)	0.30			
Factor (BXF)	0.52			

Table 4.24: Interactive effect of biochar, mineral fertilizer and FYM on plant height 90 DAS

Plant height 90 DAS (cm)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	114.40	117.93	120.87	**117.73**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	132.40	136.40	139.77	**136.19**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	123.80	126.47	129.40	**126.56**
F_4 (FYM @ 15 t ha^{-1})	105.20	108.10	111.83	**108.38**
Mean	**118.95**	**122.23**	**125.47**	
	CD (5%)			
Factor (B)	0.30			
Factor (F)	0.34			
Factor (BXF)	0.59			

Table 4.25(a): Interactive effect of biochar, mineral fertilizer and FYM on grain yield (g pot^{-1})

Grain yield (g pot^{-1})				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	17.64	18.55	18.90	**18.36**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	21.67	23.27	24.55	**23.16**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	19.88	20.37	22.26	**20.84**
F_4 (FYM @ 15 t ha^{-1})	15.12	15.96	16.59	**15.89**
Mean	**18.58**	**19.54**	**20.58**	
	CD (5%)			
Factor (B)	0.30			
Factor (F)	0.35			
Factor (BXF)	0.61			

Table 4.25(b): Interactive effect of biochar, mineral fertilizer and FYM on grain yield (kg ha^{-1})

Grain yield (kg ha^{-1})				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	2520.00	2650.00	2700.00	**2623.33**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	3095.00	3324.00	3507.00	**3308.67**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	2840.00	2910.00	3180.00	**2976.67**
F_4 (FYM @ 15 t ha^{-1})	2160.00	2280.00	2370.00	**2270.00**
Mean	**2653.75**	**2791.00**	**2939.25**	
	CD (5%)			
Factor (B)	43.21			
Factor (F)	49.89			
Factor (BXF)	86.41			

Table 4.26(a): Interactive effect of biochar, mineral fertilizer and FYM on nitrogen uptake (g pot^{-1})

Nitrogen uptake (g pot^{-1})				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	0.27	0.28	0.29	**0.28**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	0.31	0.32	0.32	**0.32**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	0.29	0.30	0.30	**0.30**
F_4 (FYM @ 15 t ha^{-1})	0.16	0.22	0.36	**0.25**
Mean	**0.26**	**0.28**	**0.32**	
	CD (5%)			
Factor (B)	0.02			
Factor (F)	0.03			
Factor (BXF)	0.05			

Table 4.26(b): Interactive effect of biochar, mineral fertilizer and FYM on nitrogen uptake (kg ha^{-1})

Nitrogen uptake (kg ha^{-1})				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	38.57	40.48	41.43	**40.16**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	44.76	45.71	45.24	**45.24**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	41.90	43.33	43.33	**42.86**
F_4 (FYM @ 15 t ha^{-1})	22.86	31.90	51.43	**35.40**
Mean	**37.02**	**40.36**	**45.36**	
	CD (5%)			
Factor (B)	3.36			
Factor (F)	3.88			
Factor (BXF)	6.72			

Table 4.27: Interactive effect of biochar, mineral fertilizer and FYM on root volume

Root volume				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	23.10	25.30	30.60	**26.33**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	28.70	33.00	38.40	**33.37**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	26.80	28.40	36.80	**30.67**
F_4 (FYM @ 15 t ha^{-1})	19.70	21.60	21.70	**21.00**
Mean	**24.58**	**27.08**	**31.88**	
	CD (5%)			
Factor (B)	1.65			
Factor (F)	1.91			
Factor (BXF)	3.31			

Table 4.28: Interactive effect of biochar, mineral fertilizer and FYM on root weight

Root weight (g)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	21.40	24.10	30.10	**25.20**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	27.70	32.40	38.90	**33.00**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	25.80	27.60	36.30	**29.90**
F_4 (FYM @ 15 t ha^{-1})	17.50	19.50	19.80	**18.93**
Mean	**23.10**	**25.90**	**31.28**	
	CD (5%)			
Factor (B)	2.05			
Factor (F)	2.37			
Factor (BXF)	4.10			

Table 4.29: Interactive effect of biochar, mineral fertilizer and FYM on root length

Root length (cm)				
	Factor-1 Biochar			
Factor-2 Fertilizer amendments (organic and inorganic)	B_1 (Biochar @ 4 t ha^{-1})	B_2 (Biochar @ 8 t ha^{-1})	B_3 (Biochar @ 12 t ha^{-1})	**Mean**
F_1 (100% NPK)	15.70	16.10	18.00	**16.60**
F_2 (75% N +100% PK + FYM @ 15 t ha^{-1})	17.70	18.60	19.70	**18.67**
F_3 (50% N +100% PK + FYM @ 15 t ha^{-1})	16.50	17.20	19.10	**17.60**
F_4 (FYM @ 15 t ha^{-1})	14.00	14.60	15.20	**14.60**
Mean	**15.98**	**16.63**	**18.00**	
	CD (5%)			
Factor (B)	2.11			
Factor (F)	2.43			
Factor (BXF)	4.21			

CHAPTER-5

DISCUSSION

The experimental results emanating from the investigation entitled **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"** conducted at Division of Soil Science and Agricultural Chemistry, SKUAST-Jammu, Chatha during the *kharif* season of 2023 have been described in the previous chapter. The results emanated from the trial pertaining to various aspects have been presented, discussed and supported with relevant literature under the following broad headings:

5.1 Effect of biochar, mineral fertilizer and compost on soil chemical properties

5.1.1 pH

5.1.2 EC

5.1.3 Organic carbon

5.1.4 Available N

5.1.5 Available P

5.1.6 Available K

5.2 Effect of biochar, mineral fertilizer and compost on soil physical properties

5.2.1 Bulk density

5.2.2 Porosity

5.2.3 Maximum water holding capacity

5.2.4 Soil moisture

5.2.5 Aggregate stability

5.2.6 Infiltration rate

5.2.7 Hydraulic conductivity

5.3 Effect of biochar, mineral fertilizer and compost on plant parameters in Double DeKalb maize

5.3.1 Plant height

5.3.2 Root-shoot ratio

5.3.3 N uptake

5.3.4 P uptake

5.3.5 K uptake

5.4 Effect of biochar, mineral fertilizer and compost on root parameters in Double DeKalb maize

5.4.1 Root volume

5.4.2 Root weight

5.4.3 Root weight density

5.4.4 Root length density

5.4.5 Root length

5.1 Effect of biochar, mineral fertilizer and compost on soil chemical properties

5.1.1 pH

Biochar and mineral fertilizers increased soil pH. The highest increase in soil pH was seen in B_3F_1 with application of biochar @ 12 t ha^{-1} and mineral fertilizers @ 100% N, P, K respectively. Higher pyrolysis temperature contributed to the alkaline nature of biochar, that led to the removal of formyl, carboxyl or other organic chemicals and increased inorganic compounds, thereby increasing pH (Singh *et al*. 2020). Moreover, the presence of salts in biochar facilitated for increased soil pH. The findings of Wang *et al*. (2012) suggested that the addition of rice husk biochar increased the pH of garden soil (acidic soil) by 1 unit.

Though mineral fertilizer decreased soil pH, the effect was non-significant. This decrease is because urea stimulates nitrification and accelerates soil acidification (Tong *et al*., 2011). Moreover, the enhancement of nitrification is observed in subtropical areas due to the input of NH_4^+ ions, which also led to release of H^+ ions.

FYM decreases soil pH due to the production of organic acids. But, the effect was non-significant. The decrease is because FYM addition is accompanied with the addition of organic matter in soil, which results in the liberation of organic acid (Khan *et al*. 2010).

5.1.2 Electrical Conductivity

Biochar increased the electrical conductivity in soil. Since biochar constitutes various elements, such as Mg, S and Zn and increased the availability of macro-elements / micro-elements (Lucchini *et al.*, 2017). Biochar holds the potential to adsorb exchangeable cations than other forms of soil organic matter (SOM), due to its porous structure, negative surface charges and greater surface area (Igalavithana *et al*., 2017), which enhanced the electrical conductivity of the soil.

The effect of mineral fertilizers and FYM on the electrical conductivity of soil was non-significant.

5.1.3 Organic carbon

The mixed application of biochar, mineral fertilizer and FYM increased soil organic carbon relative to combined application of biochar with FYM and biochar with mineral fertilizer. The use of 12 t ha^{-1} biochar + 75% N, 100% P, 100% K + 15 t ha^{-1} FYM (B_3F_2) showed significantly higher OC concentration. This is because rice husk biochar used in our study was a rich source of carbon. It contained 45.10% total carbon. Moreover, a very striking phenomenon “negative priming effect” (Lu *et al*., 2014) exists in biochar, wherein organic carbon gets increased due to suppression in the decomposition of organic carbon caused by biochar in sandy loam soil. Since, biochar is organic in source (Shenbagavalli and Mahimairaja, 2012), the increased soil OC could also be due to the direct addition of carbon from the biochar.

Mineral fertilizers might have contributed to the enhanced soil organic carbon in the soil by favouring the proliferation of plant biomass. Another reason for the increased soil organic carbon could be the addition of mineral fertilizers. This is because, mineral fertilizers affect organic carbon by increasing the above ground and root biomass due to immediate supply of plant nutrients in sufficient quantities (Geisseler *et al*., 2014)

FYM increased soil OC in soil due to the addition of carbon source through FYM, root biomass and crop residues. Another reason is that FYM contains microbes which helps in building soil organic matter (Brar *et al.,* 2015).

Combined application of mineral fertilizers and organic amendments (biochar and FYM) increased soil organic carbon. This is because organic fertilizers supply the substratum for microbial activities. A higher rate of mineral fertilizers rich in nitrogen stimulates the decomposition processes and determines a progressive depletion of the soil organic matter (Allam *et al*., 2022).

5.1.4 Available nitrogen

Biochar application increased available nitrogen in soil. This is because the biochar used in our experiment had 0.69% nitrogen. Moreover, the large surface area and a highly porous structure of biochar improves the physical properties of soil, thereby providing nitrogen retention to biochar (Glaser *et al*., 2001).

Mineral fertilizers increased the available nitrogen in soil. This is because urea is the direct source of nitrogen, as it contains 46% nitrogen (Selvarajh *et al*., 2021).

FYM increased available nitrogen in soil. This is because, FYM decomposition takes place which leads to mineralisation and accessibility of nitrogen.

Balanced application of the inorganic and organic amendments improved available N. The highest available N was observed in B_3F_2 (12 t ha^{-1} biochar + 75% N, 100% PK + 15 t ha^{-1} FYM). Biochar increased the available N in soil. Biochar includes carbon, which may directly raise soil nitrogen (Luo *et al*. 2011). Nitrogen is increased because carbon is lowered in mineralization. Thereby, it increased the N in C:N ratio. Lowering nitrogen loss also improves availability by changing the nitrogen cycle in the soil (Huang *et al*. 2014). Moreover, biochar is an efficient absorber and binder of ammonia (NH_3) in soil. This lowers ammonia volatilization from soil surfaces, thereby increased nitrogen availability.

5.1.5 Available phosphorus

Although, biochar, mineral fertilizers and FYM increased soil available phosphorus, the increase was non-significant.

Biochar contains a mixture of metal-P consortia, such as $FePO_4$, $AlPO_4$ and $CaPO_4$ (Sun *et al*. 2018). Phosphate binds with free cations, such as Al^{3+}, Fe^{3+} and Ca^{2+} in biochar and can dissolve and release available phosphorus for plants to adsorb (Zhang *et al*., 2016).

FYM increased the available P in soil. FYM, being an organic manure might have been the reason behind this increase. This is because, manure helps in the production of intermediate compounds that interact with phosphorus-fixing cations (aluminium, iron) which lead to the reduction in P adsorption capacity and increased its availability (Behera *et al*., 2023).

Mineral fertilizers, particularly DAP is a source of phosphorus. It readily dissolves in soil and releases available phosphorus.

5.1.6 Available potassium

Biochar increased available potassium content in soil. This is because, the biochar used in our study was a rich source of potassium. It contained 1.33% potassium. This might be due to the large concentration of potassium found in biochar itself (Chan *et al*., 2008; Abrol *et al*., 2016; Mahindru *et al*., 2024)

Mineral fertilizers increased available potassium in soil. This is because, MOP fertilizer directly contributes to potassium in soil. MOP contains 60% potassium.

FYM increased the availability of potassium in soil. This is attributed to mineralisation. Moreover, the application of FYM (organic amendment) caused reduction in potassium fixation and consequently increased available potassium content (Tiwari *et al*., 2024).

5.2 Effect of biochar, mineral fertilizer and compost on soil physical properties

5.2.1 Bulk density

The integrated use of biochar, mineral fertilizer and FYM decreased soil bulk density relative to sole application of biochar and mineral fertilizers (control). The use of 12 t ha^{-1} biochar + 50% N, 100% PK + 15 t ha^{-1} FYM (B_3F_3) showed lower BD value, which was at par with B_3F_2 (Biochar @ 12 t ha^{-1} + 75% N + 100% PK + FYM @ 15 t ha^{-1}) and B_2F_3 (Biochar @ 8 t ha^{-1} + 50% N + 100% PK + FYM @ 15 t ha^{-1}).

Bulk density reduced with increase in biochar addition due to porous nature (Adekiya *et al*., 2020). The reduction in bulk density with biochar treated soils was a result of formation of macropores and rearrangement of soil particles (Hseu *et al*. 2014).

Organic materials have a low bulk density and consequently higher porosity (Martin *et al*., 2001 and Bronick *et al*., 2005). Organic components (biochar and FYM) had a dilution effect in lowering bulk density. The mixing of organic materials with more dense mineral fractions of soil caused a decrease in bulk density. Increased organic matter content resulted in greater total porosity and lowered soil bulk density (Tejada *et al*., 2008).

Mineral fertilizers slightly increased bulk density. This is because, mineral fertilizers slightly deteriorate the soil structure (Celik *et al*., 2010).

5.2.2 Porosity

Biochar, mineral fertilizer and FYM when combined increased porosity relative to combined application of biochar and mineral fertilizers.

Biochar has high specific surface area, extensive pore structure, which facilitates more total porosity (micro and macro pores) (Laharia *et al*., 2020). The application of biochar to soil increased the total pore volume, which increased porosity (Mukherjee *et al*., 2013).

Soil incorporation of organic materials with synthetic fertilizers reduced nutrients losses especially nitrogen and phosphorus and improved the fertilizers use efficiency through improved microbial activity. This led to lowered bulk density and increased total porosity of soil (Brooks *et al*., 2018; Foster *et al*., 2016; Yadav *et al*., 2019).

5.2.3 Maximum water holding capacity

Biochar increased the maximum water holding capacity of the soil. This is because, soil holds water by two phenomenon- adsorption and capillarity. Moreover, biochar is an effective medium for increasing irrigation effectiveness and runoff mitigation. This is because, when biochar is added in the soil, it reduces sealing. This is attributed to increase in calcium in soil solution, leading to decrease in sodium; i.e. decreased sodium adsorption ratio (Abrol *et al*., 2016)

Mineral fertilizers and FYM increased the maximum water holding capacity of the soil by promoting rapid root growth which led to increased water holding capacity of the soil (Wang *et al*., 2023).

FYM increased maximum water holding capacity of the soil. This is because FYM incorporation in the soil is accompanied with the addition of organic matter in soil. Organic matter being charged on the surface attracts water (which is dipole) and increased the water holding capacity of the soil.

5.2.4 Soil moisture

Biochar application enhanced soil moisture. This is attributed to the fact that biochar reduces soil evaporation and prolongs the time required for the surface vapour to escape into the atmosphere. This is because biochar shifts the water retention curve towards more positive water potential values at a given volumetric soil moisture level (Fischer et al. 2018). This helps in lowering the evapotranspiration rates. Another reason is that biochar can hold soil moisture by increasing the plant available water (Basso *et al*., 2013; Jeffery *et al*., 2011; Masiello *et al*., 2015).

Mineral fertilizers when applied in combination with organics (biochar and FYM) increased soil moisture. This is because, urea is hygroscopic; thereby it has the tendency to hold water (Wang *et al*., 2023).

Organic amendments (biochar and FYM) increased soil moisture. This is attributed to the fact that these amendments provide organic matter to the soil. And organic matter holds water since it is charged from surface (Basso *et al*., 2013).

5.2.5 Aggregate stability

Biochar increased the aggregate stability of the soil. This is because, it combines the soil particles by virtue of the activated carbon present in it. This leads to increasing the aggregate stability of the soil (Abrol *et al*., 2016). Moreover, biochar increased the mean weight diameter of the soil due to increase in the amount of oxidised functional groups after mineralisation of biochar (Njoku *et al*., 2015).

FYM and mineral fertilizers increased aggregate stability of the soil. This is by virtue of two phenomenon. The main event occurring in soil (sandy loam) is that FYM provides the soil with organic matter, which increased the stability of macroaggregates.

This organic matter helps in binding of mineral fractions with polysaccharides (Ibrahim *et al*., 2020). The other event, which is not the main factor responsible in our soil, but must have happened to some extent, is that organic matter forms strong bonds between clay domains and clay particles. However, our soil has less proportion of clay, the contribution of this event stands secondary.

5.2.6 Infiltration rate

Biochar decreased the infiltration rate in sandy loam soil. This is because, size of the soil particles is big (sand). When, biochar is added in the soil, it provides with micropores and mesopores. These small sized pores possess the ability to retain water, thereby restricting the water to infilter (Githinji *et al*., 2014). Moreover, whenever biochar is added in the soil, biochar resides in the pores that were previously present in the soil (Ibrahim *et al*., 2013). This blocks the path for water to infilter; leading to decreased infiltration rate.

Mineral fertilizers, i.e., urea increased soil infiltration rate by increasing macroaggregates of the soil (Yu *et al*., 2012).

FYM decreased the infiltration rate of the soil by increasing the pore size distribution of the soil (Ibrahim *et al*., 2020).

5.2.7 Hydraulic conductivity

Biochar decreased the hydraulic conductivity in sandy soil. This is because, the large surface area and high number of pores need to fill up before water drains under the force of gravity (Devereux *et al*., 2012). This implies, that biochar led to the retention of more water in the pores.

Mineral fertilizers, specifically urea increased the volume of macropores in soil, but reduces the amount of micropores and mesopores. This led to increase in saturated hydraulic conductivity in the soil (Yu *et al*., 2012).

Hydraulic conductivity is affected by total porosity, pore size distribution and continuity of soil pores. These are influenced by texture, structure and organic matter content of the soil. Organics have the potential to modify saturated hydraulic conductivity favourable for water movement in the soil (Singh *et al*., 2016).

5.2.8 Plant height

Biochar increased plant height in maize. This is because, biochar improves the physical properties. It increases the retention sites in the soil, thereby increasing the nutrient uptake capacity of the crop. Moreover, rice husk biochar provided the highest K element of about 1.33%. Biochar increased organic carbon in soil. This is due to the decomposition process carried out by decomposing microbes, which ultimately boosts plant growth (Rahayu *et al*., 2021). Biochar incorporation in soil provides for nutrients in soil and high shoot concentration of N, P, K, Mg, Ca and S. This improves soil fertility and ensures better plant growth. Positive plant growth responses with biochar application have also been observed in other studies (Schulz and Glaser, 2012; Obia *et al*., 2016).

Biochar and mineral fertilizers increased plant height in maize. Biochar further enhances the activity of mineral fertilizers in soil. Biochar provides for increased nutrient supply, which enhanced vegetative growth and this led to increased plant height (Yagoub *et al*., 2015). Moreover, NPK application is a direct supplier of nutrients in the soils for the growth of maize.

FYM application increased the plant growth attributes by supplying the crop with organic matter (which increases soil fertility), nutrients and microbial activity (Kumar *et al*., 2017)

5.2.9 Root shoot biomass ratio

The effect of biochar, mineral fertilizer and FYM was non-significant for root-shoot biomass ratio.

5.2.10 Grain yield

All the enhanced physical and chemical properties that lead to the increase in growth attributes result in enhanced grain yield of maize (Obia *et al*. 2016). In case of biochar level, the highest grain yield was found in treatment B_3, wherein biochar was incorporated @ 12 t ha^{-1} and for fertilizer level, highest grain yield was found in F_2, wherein the incorporation rate was 75% N + 100% PK + FYM @ 15 t ha^{-1}. The best treatment for grain yield was B_3F_2.

5.2.11 Nitrogen uptake

Biochar and FYM (organic amendments) increased N uptake in soil. This is because, the organics contain microbes, which makes the nutrients in their available forms by the process of mineralisation (Glaser *et al*., 2001).

Mineral fertilizers; i.e., urea is the direct source of nitrogen and provides the crop with nitrogen which can be taken up (Selvarajh *et al*., 2021).

5.2.12 Phosphorus uptake

The effect of biochar, mineral fertilizers and FYM was non-significant for phosphorus uptake.

5.2.13 Potassium uptake

The higher availability of potassium from biochar, mineral fertilizer and FYM marks up for the higher potassium uptake (Chan *et al*., 2008).

5.4 Effect of biochar, mineral fertilizer and compost on root parameters in Double DeKalb maize

5.4.1 Root volume

Biochar enhanced root volume in sandy loam soil. This is because, biochar used in our study had a wide C:N ratio, which facilitated better root proliferation laterally. Therefore, increasing root volume (Sales *et al*., 2020). Another reason for increased root volume is that biochar incorporation in the soil increased root colonisation (Rafique *et al*., 2020).

Moreover, biochar in conjunction with mineral fertilizers showed maximum root growth and development (Schulz and Glaser, 2012).

5.4.2 Root weight

The increase in root weight on the addition of biochar is attributed to the increased root biomass. Crops provided with biochar tend to invest their root biomass more efficiently to absorb soil water and nutrients rather than accumulate root biomass. This is because biochar application stimulated plant growth and increased the demand for nutrients and water (Jeffery *et al*., 2011; Liu *et al*., 2014).

Mineral fertilizers increased root weight. Nitrogen fertilization increases production of thinner roots with fine root hairs (Sathiyavani *et al.,* 2017). This leads to enormous root growth, ultimately leading to increased root weight.

Incorporation of FYM in soil increased root weight. This is attributed to the decomposition of FYM, which provides for additional nutrients, particularly nitrogen. Higher is the incorporation rate of FYM more is the root biomass and this might be due to release of additional nutrients, which improved the buffering capacity and enhanced nutrient cycling upon decomposition of farm manure (Sabir *et al*., 2015).

5.4.3 Root weight density

The effect of biochar, mineral fertilizer and FYM was non-significant for root weight density.

5.4.4 Root length density

The effect of biochar, mineral fertilizer and FYM was non-significant for root length density.

5.4.5 Root length

Biochar had a positive effect on root morphology. Since biochar reduced the bulk density of the soil, this caused reduction in the mechanical resistance to root growth into the soil environment. Biochar pores marked up as seats for the growth of roots, which led to absorption of moisture and nutrients, thereby stimulating root growth (Chang *et al*., 2021). Moreover, biochar is a good habitat for roots (Prendergast *et al*., 2011). Thereby, causing increase in root length.

Mineral fertilizers increased root length. Interactions between different nutrient elements have a significant effect on the availability of other nutrients. K application can improve N uptake by plants because K^+ acts as an electrochemical balance for NO_3^-. K^+ gets exchanged for NH_4^+ facilitating N availability. P also affects root growth by regulating N acquisition. Consequently, the rise in N uptake upon co-application of N, P, K fertilizers is attributed to increased N availability in the rhizosphere, which is due to enhanced root morphological traits. These interactions (N and P, N and K, or N, P, and K) were associated with increase in root length. Nitrogen fertilization might have also contributed to root growth by increasing soil N availability (Zou *et al*., 2023).

The combined application of biochar, FYM and mineral fertilizers increased root length. This is attributed to enhanced nutrient availability to the growing roots (Luo *et al*., 2011).

CHAPTER-6

SUMMARY AND CONCLUSIONS

The present investigation entitled **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"** was carried out during 2023-24 at Division of Soil Science and Agricultural Chemistry, FoA, SKUAST-J, Chatha J&K. The salient findings of the experiment are summarized and concluded in this chapter.

The pot experiment comprised of twelve treatments and were replicated thrice in factorial completely randomized design (fCRD). There were two factors. Factor-1 was biochar and Factor-2 was fertilizer amendments (organic and inorganic). Factor-1 had three levels: B_1(Biochar @ 4 t ha^{-1}), B_2(Biochar @ 8 t ha^{-1}), B_3(Biochar @ 12 t ha^{-1}), while Factor-2 had four levels: F_1 (100% NPK), F_2 (75% N + 100% PK + FYM @ 15 t ha^{-1}), F_3 (50% N + 100% PK + FYM @ 15 t ha^{-1}), F_4 (FYM @ 15 t ha^{-1}). The initial texture of the soil was sandy loam with a pH of 6.70, EC of 0.26 ds m^{-1} and OC of 0.26 %. The soil was collected from Advanced Centre for Rainfed Agriculture, Dhiansar.

Results revealed that incorporation of biochar and fertilizer amendments significantly affected the soil chemical, physical properties, plant parameters and root parameters.

6.1 Effect on soil chemical properties

The sole and combine application of biochar and fertilizer amendments (mineral fertilizer and compost) showed significant effect on soil chemical properties. The higher soil organic carbon, available nitrogen and available potassium were recorded with addition of higher rate of biochar (12 t ha^{-1}) over low rate (4 t ha^{-1}). Among the fertilizer treatments the increased soil organic carbon, available potassium were noticed with combine application of compost and mineral fertilizer (75% N + 100% PK+ FYM @ 15 t ha^{-1}) over sole application of compost and mineral fertilizer. The interaction effect of biochar and fertilizer amendments indicated that incorporation of biochar (12 t ha^{-1} and fertilizer amendments (75% N+ 100% PK+ FYM @ 15 t ha^{-1}) in mixture improved the soil chemical properties over the rest treatments.

6.2 Effect on soil physical properties

As far as the physical properties are concerned, application of biochar (12 t ha^{-1}) and fertilizer amendments (75% N + 100% PK + FYM @ 15 t ha^{-1}) recorded highest soil moisture, porosity and maximum water holding capacity. However, results showed reduction in bulk density, infiltration rate and hydraulic conductivity when soil was amended with biochar. Further improved soil physical properties were noticed with the co-application of biochar (12 t ha^{-1}) and fertilizer amendments (75 % N + 100% PK + FYM @ 15 t ha^{-1})

6.3 Effect on plant parameters, nutrient uptake, root morphology and maize yield

The plant growth, nutrient uptake, root morphology and yield of maize was significantly influenced by the application of biochar and fertilizer amendments. Among the biochar and fertilizer treatments, the improved plant growth, nutrient uptake, root morphology and grain yield were observed where biochar was applied @ 12 t ha^{-1} and fertilizer were applied @ 75%N + 100% PK + FYM @ 15 t ha^{-1}. Moreover, the combine application of biochar (12 t ha^{-1}) and fertilizer amendments (75% N + 100% PK + FYM @ 15 t ha^{-1}) showed enhanced plant growth, nutrient uptake, root morphology and yield of maize.

6.4 Conclusions

· Results indicated that the co-application of biochar (12 t ha^{-1}) and fertilizer amendments (75% N + 100% PK + FYM @ 15 t ha^{-1}) showed improved soil physical and chemical properties, better root growth, nutrient uptake and yield of rainfed maize than rest of the treatments in sandy loam soil.

Therefore, based on study, it can be concluded that treatment B_3F_2 (biochar @ 12 t ha^{-1} + 75% N, 100% P, K + FYM @ 15 t ha^{-1}) was found better over the RDF in relation to improving grain yield, soil fertility and root morphology.

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CERTIFICATE- IV

Certified that all necessary corrections as suggested by the external examiner and advisory committee have been duly incorporated in the thesis entitled **"Impact of mineral fertilizer, compost and biochar on soil properties, root morphology and crop growth of maize in sandy loam soil"**, submitted by **Ms. Vani Mahindru,** Registration No. **J-22-M-933.**

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