

CHARACTERIZATION OF BIOCHARS AND USE OF A BIOCHAR AS SOURCE OF MACRONUTRIENTS

Thesis

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By

**Abhishek Saxena
B.Sc. (Agriculture)**

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*Pantnagar
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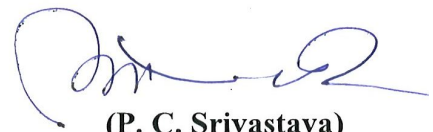
Abhishek
(Abhishek Saxena)
Author

CERTIFICATE

This is to certify that the thesis entitled “**CHARACTERIZATION OF BIOCHARS AND USE OF A BIOCHAR AS SOURCE OF MACRONUTRIENTS**” submitted in partial fulfilment of the requirements for the degree of **Master of Science in Agriculture**, with major in **Soil Science** of the College of Post-Graduate Studies, G. B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Abhishek Saxena, Id. No. 45977** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

Pantnagar
September, 2020



(P. C. Srivastava)
Chairman
Advisory committee

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr. Abhishek Saxena, Id. No. 45977**, a candidate for the degree of **Master of Science in Agriculture**, with major in **Soil Science** agree that the thesis entitled **“CHARACTERIZATION OF BIOCHARS AND USE OF A BIOCHAR AS SOURCE OF MACRONUTRIENTS”** may be submitted in partial fulfilment of the requirements for the degree.



(P. C. Srivastava)
Chairman
Advisory Committee



(S. P. Pachauri)
Member



(Veer Singh)
Member

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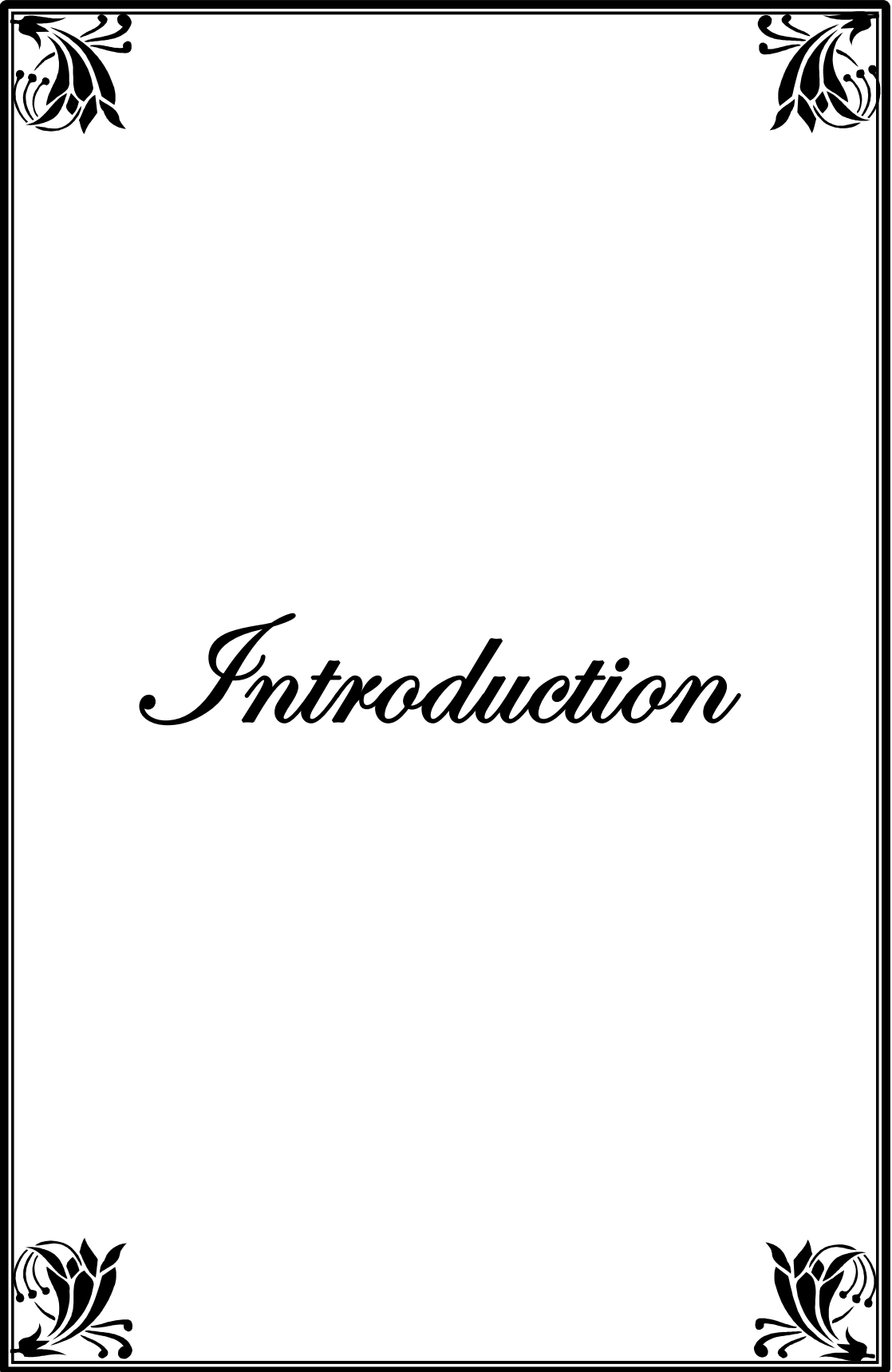
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LIST OF ABBREVIATIONS

%	percent
C. D.	Critical Difference
S.E _m ±	Standard error of mean
pH	Power of Hydrogen ion activity
EC	Electrical Conductivity
<i>et al.</i>	et alia (and others)
<i>t</i>	ton
Fig.	Figure
RDF	Recommended dose of fertilizer
mg	milligram
kg	kilogram
q	quintal
ha	hectare
°C	degree centigrade
NS	Non-significant
ppm	parts per million
g	gram
cm	centimeter
m	meter
μS	microsiemen
cmol	centimole
h	hour
OC	Organic carbon
min	minute
dS	decisiemen
nm	nanometer
C	Carbon
ml	millileter



Introduction

Biochar is a carbon (C) dense solid substance formed by the pyrolysis of organic material and can be used to amend the soil (**Lehmann and Joseph, 2015**). Carbonaceous materials used for production of biochar are converted to aromatic compounds on thermal decomposition and become highly resistant to degradation. So, biochar basically consists of several polycondensed aromatic compounds along with few ion exchange functional groups as a result of dehydration and decarboxylation reactions occurring during production of biochar. Biochar can be prepared from various wastes obtained from plant and animal sources by pyrolysis which otherwise remain unused at the farm after the crop production process. In Amazonian soils of Brazil, the so-called *terra preta* soils identified by Late Wim Sombroek were found more fertile in comparison surrounding soils due to automatic addition of biochar under “slash and char” type of agricultural practices in that soil (**Spokas et al., 2012**). The process of pyrolysis from which biochar is made leads to release of volatile C compounds, Hydrogen (H), methane (CH₄) and carbon monoxide (CO), which all leads to production of bio-oil and ash.

Various properties such as highly porous structure, greater surface area and mostly alkaline pH (**Abewa et al., 2013**) make biochar a suitable soil amendment for managing nutrient content, pH, EC, aeration, porosity, water retention capacity of the soil (**Steiner et al., 2007; Chan et al., 2008; Asai et al., 2009, Smider and Singh, 2014; Purakayastha et al., 2015**). Biochar properties are seen to vary mainly with the feedstock used and the conditions prevailing during the pyrolysis of the biomass such as pyrolysis temperature, residence time, heating rate, supply of oxygen, etc (**Sohi et al., 2010**). With a beneficial character of high adsorption tendency, biochar can be suggested to be used as a tool for retaining nutrient ions on it, thereby increasing the nutrient use efficiency of the plant and ultimately resulting in increment of crop yield (**Ding et al., 2010; Yao et al., 2012**). Thus, biochar serves the purpose of both soil and crop improvement. Biochar when applied to soil @ <30 t ha⁻¹ increased the crop productivity by about 11% (**Liu et al., 2013**). The changes observed in crop productivity or yields of the crop were very diverse and varied with the soil, crop and biochar conditions. Biochar could also be considered as a tool for restoring the microbial population and ultimately making the soil biologically fertile. This increase in microbial biomass and their

habitation in soil might be the result of additional surface area that serve as a habitat of microbes present in soil which ultimately improve the nutrient status of soils.

Indian agriculture has experienced the huge increase in crop productivity during and after green revolution by tapping the yield potential of high yielding varieties and by the addition of fertilizers in very high doses. Fertilizer application in such large amount was quite responsive in the earlier days and are not showing a further increase in yield with the addition of fertilizers. This greed behind increasing the production has made fertilizer application in Indian agriculture, a unguided practice. The recommended doses of fertilizers are often so high that they lead to high cost of production and residual accumulation of applied fertilizers in the soil. As only a minor fraction of applied fertilizer is available to the plant for its use, the remaining fraction remains unavailable. The fertilizer use efficiency of nutrients is low in many soils owing to N losses and fixation of other nutrients. On the other hand, biochar with higher surface area and high adsorptive capacity may help to ensure a better availability of nutrients to the plants by reducing their losses in an eco-friendly way by increasing the cation exchange capacity of the soil (**Liang *et al.*, 2006**). Various organic amendments supplemented to the soil do not have much effect on soil organic carbon content as they are short lived and decompose easily and quickly as compared to the highly stable biochar. An increase in content of soil organic carbon with the application of biochar as compared to various other organic manures might help in improving the soil fertility and consequently increase crop yields.

In India, crop production produces a huge amount of plant residues and wastes. A report by Ministry of New and Renewable Energy (**MNRE**) shows that the amount of total crop residue generated in a year is about 500 million tons, out of which about 92 million tons of surplus is burned every year in our country. The reason behind burning of such a huge amount of crop residues is the unavailability of the proper management mechanism so that it can be safely disposed off. Some residues can also be used as fodder for the animals, while many other residues including weeds, etc are not suitable for feeding to animals and therefore often go as waste. One option left is to incorporate them into soil but in the absence of suitable and popular machinery, farmers often opt to burn these plant residues in open. Apart from these crop residues, forests also generate a huge amount of plant wastes in the form of leaf fall and various dried and dead plant parts,

that neither have any commercial usage nor can be collected and used by anyone as fodder or compost. Biochar production from these agricultural and forest residues could be a good choice for the disposal of these residues which are unsuitable for animal feeding or composting purpose.

Biochar production can help in lowering down the atmospheric emission of CO₂, methane and nitrous oxide by almost 12% of the anthropogenic CO₂-C emission per year (Woolf *et al.*, 2010). Biochar is a long lasting compound, so C sequestration for a very long period of time can be done by the biochar which may accumulate in soil as beneficial terrestrial C. Greenhouse gas (GHG) emission has also been reported to be less from the soil amended with the biochar both in cropped or non-cropped conditions (Karhu *et al.*, 2011; Zhang *et al.*, 2012). The concentration of various environmental pollutants such as inorganic chemicals, pesticides, heavy- and radioactive-metals, etc could also been reduced by the production of biochar (Ahmad *et al.*, 2014). Thus, biochar could be used to improve the availability of nutrients besides improving soil physical conditions.

Despite biochar being such a useful amendment for agriculture with multi-dimensional benefits, the use of biochar in Indian agriculture is not so common till now. Also, there have not been much research work being done in relation to use of biochar and the various aspects related to it such as its production, characterization and its effect on soil environment and crop yields. The proposed investigation mainly aims at characterization of biochar and evaluation of the nutrient-enriched biochar as a source of macronutrients to the soil with the following objectives:

1. To characterize the biochars from various plant residues for various physicochemical properties and nutrient composition.
2. To study the effect of graded levels of fertilizers and biochar on growth and yield of fodder oat.
3. To assess the effect of graded levels of fertilizers and biochar on some soil properties.



Review
of
Literature



Biochar is a condensed carbonaceous material produced by heating of the organic materials under limited oxygen supply. Application of biochar improves soil quality and help mitigation of climate change by carbon sequestration. Biochar being a good adsorbent helps the soil in retaining nutrients, water and other agrochemicals for a longer time preventing groundwater pollution. Plant nutrients present in biochar would make it suitable for agricultural use both as a source of plant nutrients and also as a soil amendment.

A brief review of the available pertinent literature has been presented as under following headings:

1. Characteristic properties of biochar
 - a. Physio-chemical properties
 - b. Nutrient value of biochar
 - c. Functional group analysis
2. Soil properties affected by biochar
 - a. Physical properties : water holding capacity, bulk density, porosity
 - b. Chemical properties : pH, EC, CEC, OC
 - c. Available nutrients : N, P, K
3. Effect of biochar on plant nutrient concentration and uptake
4. Effect on growth and yields

1. CHARACTERISTIC PROPERTIES OF BIOCHAR

a) Physio-chemical properties

Novak *et al.* (2009) characterized different designer biochar made from peanut hull, pecan shell, poultry litter and switchgrass (*Panicum virgatum* L.) pyrolyzed at different temperatures ranging from 250 to 700 °C. Their study reported a rise in biochar pH and surface area with the increase in pyrolyzing temperature. The pH observed was in the range of 5.9 to 10.3 and surface area ranged between 0.40 to 222 m² g⁻¹.

Ding *et al.* (2010) investigated the effect of bamboo biochar pyrolyzed at 600 °C on nitrogen retention and leaching in multi-layered soil columns by adding 0.5%

BC to the surface soil layer. Their results revealed that the pH of biochar was 8.15 and the C% of biochar was 68.1%. The density and specific surface area of the bamboo biochar was observed to be 0.75 g cm^{-3} and $330 \text{ m}^2 \text{ g}^{-1}$, respectively.

Yao *et al.* (2011) studied the characteristics and phosphate removal potential of biochar derived from anaerobically digested sugar beet tailings at 600°C . The observed pH of biochar obtained from raw sugar beet tailings (STC) and anaerobically digested sugar beet tailings (DSTC) were 9.45 and 9.95 respectively. The CO_2 surface area measurements showed that the surface area of DSTC ($449 \text{ m}^2 \text{ g}^{-1}$) was much higher than that of STC ($351 \text{ m}^2 \text{ g}^{-1}$). The SEM imaging of the STC (500X) showed that the undigested sugar beet tailing biochar had smooth surfaces, however SEM imaging of the DSTC (500X) showed knaggy surfaces due to presence of nano-sized or colloidal magnesium crystal. The reported C content were 50.78 and 30.81% for biochar obtained from raw sugar beet tailings and anaerobically digested sugar beet tailings, respectively.

Cantrell *et al.* (2012) studied the impact of pyrolysis temperature and manure source on physicochemical characteristics of biochars obtained from paved-feedlot manure (FL); dairy manure (MD); poultry litter (PL); and turkey litter (TL); separated swine solids (SW) at 350 and 700°C . The observed values of pH and EC ($\mu\text{S cm}^{-1}$) for all the biochars prepared at 700°C were higher as compared to 350°C . The values of pH ranged from 8 to 9.2 at 350°C and 9.5 to 10.3 at 700°C , of EC ranged between 216 to $1405 \mu\text{S cm}^{-1}$ at 350°C and 702 to $2217 \mu\text{S cm}^{-1}$ except SW which had EC $194 \mu\text{S cm}^{-1}$ at 700°C . On increasing the pyrolysis temperature, the BET surface area ($\text{m}^2 \text{ g}^{-1}$) of the biochars was also found to be increasing to a large extent and ranged from 0.92 to $3.93 \text{ m}^2 \text{ g}^{-1}$ at 350°C , while ranged from 4.1 to $186.5 \text{ m}^2 \text{ g}^{-1}$ at 700°C temperature.

Shenbagavalli and Mahimairaja (2012) produced and characterized biochars from various biological residues such as paddy straw (A), maize stover (B), coconut shell (C), groundnut shell (D), coir waste (E) and prosopis wood (F). The recorded pH values (1:5 biochar water suspension) were 9.68, 9.42, 9.18 9.30, 9.40 and 7.57 for the biochar prepared from the A, B, C, D and E biomass, respectively. The EC (dS/m) values in 1:5 biochar water suspension for the biochar prepared from A, B, C, D, E and F were 2.41, 4.18, 0.73, 0.39, 3.25 and 1.3, respectively. The reported values of CEC (cmol(+)/kg) were 8.2, 6.5, 12.5, 5.4, 3.2 and 16 and Total OC contents were 540, 830, 910, 770, 760 and 940 g/kg in the biochars made from A, B, C, D and E biomass, respectively.

Taghizadeh et al. (2012) studied effect of adsorbed ammonia on biochar by adsorbing ammonia @ 6.7 mg/g and reported an increase in pH of biochar manufactured from Monterey Pine (*Pinus radiata* L.) wood chips at pyrolysis temperatures of 300, 350 and 500°C, the pH was observed to be increasing from 5.15 at 300°C to 7.77 at 350°C and further lowered at 500°C to 6.64. Similar change in values of EC was observed with temperature having values 0.01, 0.53 and 0.02 dS m⁻¹ at 300, 350 and 500°C, respectively. The bulk density and specific surface area (by iodine adsorption (mg g⁻¹)) were found to be the highest in biochar pyrolyzed at 350°C, followed by 500°C and 300°C. The C content (mg g⁻¹) was also found to be increasing with temperature as 622, 772 and 826 mg g⁻¹ at 300, 350 and 500°C, respectively.

Wu et al. (2012) characterized the rice straw-derived biochars produced at different temperatures (300, 400, 500, 600 & 700 °C) and residence time (1, 2, 3 & 5 h) and reported that pH increased from 9.19 to 10.77 with increase in charring temperature from 300°C to 700°C. The CEC of the biochars was observed to be decreasing with the increase in the temperature having values ranging between 56.9 cmol/kg at 300°C to 23.1 cmol/kg at 700°C. The C content (wt. % basis) was also found to be increasing with the increasing pyrolysis temperature. The values of all the parameters such as pH, CEC, C content were also seen to be changing with the different resident time of the biochars.

Yao et al. (2012) prepared biochar from sugarcane bagasse (BG), peanut hull (PH), Brazilian pepperwood (BP), and bamboo (BB) at 300, 450 and 600 °C and analysed their properties. Their experiment revealed that the pH of the biochars ranged from 5.2 to 9.1. The biochars were seen to have highly fluctuating BET surface area which was increasing with the temperature in few biochars and ranged from 0.7 to 470.4 m² g⁻¹. The elemental C content (% mass basis) was found be all over the same varying from 56.4 to 86.4% in the biochars.

Carter et al. (2013) analyzed the effect on biochar on soil properties and lettuce and cabbage crop and also characterized the biochar prepared from rice husk by using gasification unit operating at temperatures between 900 and 1100°C. The biochar was seen to have pH of 7.79, total OC of 28.7% (% dry weight), CEC of 44.5 cmol+/kg.

Yargicoglu et al. (2015) investigated the physical and chemical characteristics of biochars prepared at 350-600 °C from coconut charcoal (GAC), pine wood (BS), 90% pine; 10% fir wood (CK), aged oak and hickory wood (AW), pinewood pellets (CE-WP)

and noted the trends of pH of various biochars as 8.86(GAC) > 8.77 (CK) > 8.47 (BS) > 7.88 (AW) > 6.24 (CE-WP) and of EC (mS cm⁻¹) as 4.15 (CE-WP) > 0.14 (AW) > 0.04 (BS) > 0.01 (GAC) > 0.007 (CK). For different biochars, average dry density ranged from 0.48 to 0.73 g cm⁻³, average specific gravity was 0.77 to 1.65 g cm⁻³, organic matter content having values from 32.3 to 97.5 % and the surface area widely varied from 0.11 to 611.87 m²g⁻¹.

Cybulak *et al.* (2019) examined physicochemical characteristics of wood derived biochar pyrolyzed at 650°C and obtained very low density value of 1.46 g cm⁻³ which was similar to the value observed by **Brewer *et al.* (2014)**. The OC content of the biochar was 15.4% and the nature was alkaline having a pH value of 8.25. The specific surface area of the biochar was observed to be 69.9 m²g⁻¹.

Faloye *et al.* (2019) analysed effects to biochar on various growth parameters of maize crop. The biochar was prepared from maize-cob residues, which was pyrolysed at 500°C with the heating rate of 2.08 °C/min. The biochar was observed to have a pH of 9.42, CEC of 16.26 cmol/kg, total organic carbon of 690 g/kg and bulk density of 0.4 g/cm³.

During their investigation of short term effects of organic amendments on soil fertility and root growth of rubber trees, **Huang *et al.* (2019)** noted that the pH of the biochar made from peanut shells heated at 350-500 °C for 30 minutes was 10.35.

Yadav *et al.* (2019) compared the benefits of biochar over other organic amendments in the crop productivity and nutrient losses. The biochar used in their study was produced by pyrolysis of *Cymbopogon winterianus* J. chaff at 450°C for 60 minutes. They reported that the biochar had a pH of 8, water holding capacity of 45%, CEC of 125.2 cmol/kg, bulk density of 0.58 g cm⁻³ and 58.39% total C contained in it.

b) Nutrient value of biochar

Yao *et al.* (2011) studied the characteristics of biochar derived from anaerobically digested sugar beet tailings at 600° C. Their results indicated that biochar obtained from raw sugar beet tailing had 1.83% N, 0.35% P and 1.04% K and the digested sugar beet tailing biochar contained 2.74% N, 2.18% P and 1.97% K.

Cantrell *et al.* (2012) studied the impact of pyrolysis temperature and source on physicochemical characteristics of biochars obtained from paved-feedlot manure (FL); dairy manure (MD); poultry litter (PL); and turkey litter (TL); separated swine solids (SW) at 350 and 700 °C and noted the elemental N content (wt% oven dry basis) to be

lower at 700 °C (1.51 to 2.61 % N) than at 350°C (2.60 to 4.45% N) while contrary to this trend, the contents of P were 10.0 to 38.9 g kg⁻¹ at 350°C and 16.9 to 59.0 g kg⁻¹ at 700 °C and that of K were 14.3 to 48.5 g kg⁻¹ at 350°C and 23.1 to 74.0 at 700 °C g kg⁻¹ on oven dry basis.

Peterson *et al.* (2012) compared corn stover biochar (CSB) and switchgrass biochar (SB) properties and reported that the N% in SB was 0.78% while it was only 0.44% in CSB.

Shenbagavalli and Mahimairaja (2012) produced and characterized biochar from various biological residues such as paddy straw (A), maize stover (B), coconut shell (C), groundnut shell (D), coir waste (E) and prosopis wood (F). The content of total N (g/kg) was 10.5, 9.2, 9.4, 11, 8.5 and 1.12, total P (g/kg) was 1.2, 2.9, 3.2, 0.6, 1.5 and 1.06 and total K (g/kg) was 2.4, 6.7, 10.4, 6.2, 5.3 and 29 in the biochars made from A, B, C, D and E biomass, respectively.

Wu *et al.* (2012) characterized the rice straw-derived biochars produced at different temperatures (300, 400, 500, 600 & 700 °C) and residence time (1, 2, 3 & 5 h) and reported that 0.5 M NaHCO₃ extractable P declined from 376.6 mg/kg to 138.2 mg/kg with increase in charring temperature from 300 °C to 700 °C. The trends observed for elemental N (dry ash free basis) and extractable K (cmol/kg) were found to be changing with the temperature and residence time but a set pattern of change was not observed in these parameters.

Yao *et al.* (2012) prepared biochar from sugarcane bagasse (BG), peanut hull (PH), brazilian pepperwood (BP), and bamboo (BB) at 300, 450 and 600 °C and analysed their effect on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil through a column leaching experiment. The biochars initially had 0.1 to 1% N, 0.03 to 0.5% P and 0 to 0.94% K on the mass basis. Nutrient content was not found to be much affected by the pyrolysis temperature of the biochar.

Huang *et al.* (2019) investigated short-term effects of organic amendments on soil fertility and root growth of rubber trees on Hainan Island, China and characterized these amendments. These workers observed the content of various macronutrients as 10.38 g total N/kg, 1.97 g total P/kg and 28.75 g total K/kg in the peanut shell biochar.

c) **Functional group analysis**

Yao *et al.* (2011) studied the characteristics and phosphate removal potential of biochar derived from anaerobically digested sugar beet tailings at 600°C. The infrared spectra of the biochar showed three significant bands at wave numbers near 1427, 1049, 874 cm⁻¹ which could be attributed to O—H bending or C—O stretching vibration of phenol, C—O stretching vibrations of polysaccharides, and C—H bending vibration in a β-glucosidic linkage, respectively.

Cantrell *et al.* (2012) studied the impact of pyrolysis temperature and manure source on physicochemical characteristics of biochars obtained from paved-feedlot manure (FL); dairy manure (MD); poultry litter (PL); and turkey litter (TL); separated swine solids (SW) at 350 and 700 °C. The biochars showed peaks at several wave numbers which showed the presence of characteristic vibrations as wave number 3500-3200 for O—H, 2935 for C—H, 1740-1700 for C=O, 1653-1645 for N—C=O, 1600-1595 for CC=C, C=O, C=N, 1514 for C=C, N—H and these functional groups were all seen to be decreasing with the increasing pyrolysis temperature from 350°C to 700°C.

Wu *et al.* (2012) characterized the rice straw-derived biochars produced at different temperatures (300, 400, 500, 600 & 700 °C) and residence time (1, 2, 3 & 5 h). The FTIR analysis and NMR spectroscopy showed that aromatisation of the biochar increased with the increasing pyrolysis temperature, with little effect of the residence time on the FTIR spectral properties. The XRD patterns of the biochar revealed biochar to be an amorphous material having a poorly crystalline, carbon-rich phase.

2. INFLUENCE OF BIOCHAR ON SOIL PROPERTIES

a) Physical properties

Cybulak *et al.* (2019) examined the changes in various properties of the soil due to amendment of the wood derived biochar under both the fallow and grassland condition. The doses of the biochar were 1, 2 and 3 kg m⁻² as soil amendment. Although the soil bulk density had been reported to reduce slightly as reported by Pranagal *et al.* (2017), but their study didn't show any significant changes in the bulk density of the soil due to the addition of the biochar which was attributed to very low dose of the biochar as compared to the soil mass.

Khan *et al.* (2019) compared the effect of mesquite biochar, FYM and chemical fertilizers on soil fertility as well as growth of the onion crop. Mesquite biochar was prepared from the mesquite under slow heating at 575 °C for 3 h. A dose of biochar @

10 t/ha lowered the BD from 1.23 to 1.10 g cm⁻³ and increased the WHC from 0.46 to 0.55 ml water per g dry soil.

b) Chemical properties

Abewa *et al.* (2013) studied the role of *Eucalyptus* biochar in reclamation of acidic soil. The higher pH values 5.67, 5.69 and 5.9 were obtained with application of 4, 8 and 12 t ha⁻¹ biochar, respectively as compared to control with lowest pH (5.38). Higher organic carbon (1.84%) was observed under 12 t ha⁻¹ biochar application as compared to lowest content (1.66%) observed in control plot. An increment of 6.13%, 11.25% and 29.68% in soil CEC was also observed over the control with the application of 4, 8 and 12 t ha⁻¹ of biochar, respectively.

Agegehu *et al.* (2019) studied the changes in plant growth and oil yield of Lemon Grass (*Cymbopogon citratus* L.) as influenced by coffee husk and bagasse derived biochars application @ 5, 10, 15 and 20 t ha⁻¹ and they observed improvement in soil pH from 6.4 to 6.8 and soil organic carbon (OC) from 1.8 to 2.0%.

Huang *et al.* (2019) investigated the short term effects of various organic amendments such as bagasse, coconut husk and biochar on soil fertility and root growth of rubber trees. Their study showed that soil organic matter (SOM) increased from 10.04 g/kg to 46.35 g/kg and soil pH also increased from 4.73 to 6.20 by biochar amendment applied to soil @ 9:1 soil-amendment ratio on mass basis.

Khan *et al.* (2019) compared the effect of mesquite biochar, FYM and chemical fertilizers on soil fertility as well as on growth of the onion crop. Mesquite biochar was prepared from the mesquite under slow heating conditions at 575 °C for 3 h. A dose of biochar @ 10 t/ha increased soil pH from 7.69 to 8.68, EC from 1.33 to 1.47 dS/m and SOM from 0.25 to 0.58 %.

c) Soil extractable nutrients

Abewa *et al.* (2013) studied the role of biochar on reclamation of acidic soil and reported that soil extractable P (by Bray's P) increased from 12.75 ppm (control) to 18.92 ppm with the application of 12 t biochar ha⁻¹.

Agegehu *et al.* (2019) studied plant growth and oil yield of Lemon Grass (*Cymbopogon citratus* L.) as influenced by application of coffee husk and bagasse derived biochars @ 5, 10, 15 and 20 t ha⁻¹. They observed an improvement in total nitrogen (N) (0.20 to 0.27%), soil extractable phosphorus (P) (9.0 to 24.7 mg/kg soil) and K (cmol/kg) (upto 1.32).

Kamau *et al.* (2019) investigated the effect on soil nutrients, fauna and maize growth as influenced by application of biochar alone at a rate of 5 and 10 Mg ha⁻¹ along with three fertilizer types applied separately (di-ammonium phosphate (18:46:0), urea (46:0:0) and composite NPK (23:23:0)); and six fertilizer + biochar blends of the three fertilizer types and two biochar rates (0.05 and 0.1 Mg ha⁻¹). Their results showed that the contents of total C and N were higher in soils where biochar or fertilizer + biochar was applied, and they recorded more than 15.0 g C and 1.9 g N kg⁻¹ as compared to 10.4 g C and 1.0 g N kg⁻¹ in control plots.

Khan *et al.* (2019) compared the effect of mesquite biochar, FYM and chemical fertilizers on soil fertility as well as growth of the onion crop. Mesquite biochar was prepared from the mesquite under slow heating conditions at 575 °C for 3 h. A dose of biochar @ 10 t/ha increased the contents of Nitrate-N from 0.73 to 2.02 mg/kg, Olsen-P from 5.25 to 5.35 mg/kg and extractable K from 13.8 to 17.1 mg/kg.

3. EFFECT OF BIOCHAR ON PLANT NUTRIENT CONCENTRATION AND UPTAKE

Ding *et al.* (2010) investigated the effect of biochar on nitrogen retention and leaching in multi-layered soil columns by adding 0.5% BC to the surface soil layer. Their results revealed a reduction in overall cumulative losses of NH₄⁺-N via leaching at 20 cm by a magnitude of 15.2%.

Yao *et al.* (2012) analysed the effect of biochar amendment made from Brazilian pepperwood and peanut hull at 600°C (PH600 and BP600, respectively) on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil through a column leaching experiment. Their experiment concluded that the BP600 biochar effectively reduced the total amount of nitrate, ammonium, and phosphate in the leachates by 34.0%, 34.7%, and 20.6%, respectively relative to the soil alone. The PH600 biochar also reduced the leaching of nitrate and ammonium by 34% and 14%, respectively but caused an additional phosphate release from the soil columns which indicated that the effect of biochar on the leaching of agricultural nutrients in soils was not uniform and varies with the biochar and nutrient type.

Badu *et al.* (2019) experimentally determined the synergistic effect of biochar and inorganic fertilizer on the nitrogen uptake, nitrogen use efficiency, and yield of maize in a field experiment by applying biochar @ 0, 5, 10, 15, and 20 t ha⁻¹ and fertilizer N

applied at 0, 45, and 90 kg ha⁻¹. Their results revealed that biochar applied at 10 t ha⁻¹ supplemented with 45 kg N ha⁻¹ increased N uptake by 200% relative to the control.

Dong *et al.* (2019) carried out an experiment to get a view about the dynamic responses of ammonia volatilization under different rates of fresh and 3 years field-aged biochar treatments in a rice-wheat rotation system. Ammonia volatilization decreased by 13.3% to 36.8% in the wheat season and by 17.6% to 20.8% in the rice season only by application of aged biochar at low N rate (250 kg N ha⁻¹ per crop, 20 t ha⁻¹ biochar).

Mandal *et al.* (2019) investigated the effect of biochar amendment on NH₃ volatilization and plant N uptake from a calcareous soil using two well-characterized biochars prepared from poultry manure (PM-BC) and green waste compost (GW-BC) applied @ 0, 7.5, 15, 22 and 30 t ha⁻¹ and the wheat (*Triticum aestivum* L., variety: *Calingiri*) crop was grown for 30 days. Their findings indicated that both PM-BC and GW-BC decreased NH₃ volatilization to a similar degree (by 47 and 38%, respectively), in the soil-plant system compared to the unamended control. With the biochar addition, plant biomass production increased up to 70% and plant N uptake was improved by as much as 58%.

4. EFFECT ON GROWTH AND YIELDS

Major *et al.* (2010) examined maize yield under application of wood biochar @ 0, 8 and 20 t ha⁻¹ to a Colombian savanna Oxisol for 4 years (2003–2006), in a maize-soybean rotation and noted that maize grain yield did not increase significantly in the first year, but increased in treatments receiving 20 t ha⁻¹; the magnitude of increase was 28, 30 and 140% for 2004, 2005 and 2006, respectively, over the control.

Husk and Major (2010) determined the effect of application of biochar obtained by the fast pyrolysis of the wood waste in their commercial scale biochar on crop productivity of various crops in field trial experiment. The study indicated doubling of the fresh weight of the oat crop and the yield increase by 20% in soyabean crop with the application of the biochar @ 5.6 t/ha as compared to control.

Abewa *et al.* (2013) studied the role of biochar on reclamation of acidic soil and yield of Teff (*Eragrostis tef* [Zucc] Trotter) in North-western Ethiopia and reported that incorporation of 12 t ha⁻¹, 8 t ha⁻¹ and 4 t ha⁻¹ biochars increased the yields by 85.66%, 70.63%, 37.79% and 19.97%, respectively over the untreated plots.

Schulz *et al.* (2013) reported the positive impacts of application of mixture of biochar prepared from beech wood at 350–450 °C and compost prepared by 50 % sewage

sludge, 25 % freshly chaffed lop and 25 % sieve leftovers of earlier composting on plant growth of Oat crop. The application of composted biochar significantly increased the plant height, above ground biomass ($p < 0.01$) and grain yield ($p < 0.001$) as compared to control. This increase was only due to the addition of biochar while compost did not significantly contribute to this effect.

Concilco *et al.* (2018) studied the influence of application of biochar along with the conventional fertilization on yield and quality attributes of fodder oat. The results indicated a statistically significant increase by 33 and 102% in the plant height and green matter of the forage oat crop, respectively by the application of 2.25 Mg biochar ha⁻¹ along with the conventional fertilization as compared to control with no application of biochar and fertilizers.

Agegnehu *et al.* (2019) studied plant growth and oil yield of Lemon Grass (*Cymbopogon citratus* L.) as influenced by coffee husk and bagasse derived biochars application @ 5, 10, 15 and 20 t ha⁻¹. They observed the highest mean fresh biomass (7996 and 7898 kg/ha), total dry matter (2033 and 2050 kg/ha) and moisture content (75.3 and 75.2%) with the application of 15 t ha⁻¹ coffee husk biochar and same rate of bagasse biochar.

Badu *et al.* (2019) experimentally determined the synergistic effect of biochar and inorganic fertilizer on the nitrogen uptake, nitrogen use efficiency, and yield of maize in a field experiment receiving biochar @ 0, 5, 10, 15, and 20 t ha⁻¹ and fertilizer N @ 0, 45, and 90 kg ha⁻¹. The results revealed that biochar applied at 10 t ha⁻¹ supplemented with 45 kg N ha⁻¹ increased grain yield by 213% and 160% relative to the control in the minor and major rainy seasons, respectively.

Kamau *et al.* (2019) investigated the effect of biochar application alone at a rate of 5 and 10 Mg ha⁻¹ along with three fertilizer types applied separately (di-ammonium phosphate (18:46:0), urea (46:0:0) and composite NPK (23:23:0)); and six fertilizer + biochar blends of the three fertilizer types and two biochar rates (0.05 and 0.1 Mg ha⁻¹) on soil nutrients, soil fauna and maize growth. Their results showed that six times higher maize grain yield (5.6 Mg ha⁻¹) was obtained from plots amended with biochar (without fertilizer) than yield harvested from unfertilised control at 0.9 Mg ha⁻¹.

Khan *et al.* (2019) compared the effect of mesquite biochar (MB, 10 tons ha⁻¹), farmyard manure (FYM, 10 tons ha⁻¹), and NPK fertilizers (120:80:80 kg ha⁻¹) on soil fertility and growth of onion. The maximum bulb weight (6.13 kg per plot), leaf length

(32.38 cm), total onion yield (268.55 kg ha⁻¹) were observed in the plots treated with MB as compared with FYM and NPK fertilizers.

Yan *et al.* (2019) experimentally determined the effects of maize straw-derived biochar application @ 0, 20, 40 and 60 t ha⁻¹ on soil temperature, water conditions and growth of winter wheat. Their results indicated a difference in temperature range from -0.5°C to 1.75°C at the 20-cm depth and from -1.19°C to 2.66°C at the 40-cm depth. The aboveground biomass at tillering stage increased by 19.5, 25.5 and 27.0% in the treatments receiving 20, 40 and 60 t biochar ha⁻¹, respectively as compared with the unamended controls.

Kaur and Sharma (2020) evaluated the significance of mixed wood biochar application on the growth parameters of the berseem crop. Their study indicated that application of 5% biochar increased plant height by 28-50% and plant biomass by 30-60% in a period of 180 days over no application of biochar.



*Materials and
Methods*



The study “Characterization of biochars and use of a biochar as source of macronutrients” was conducted in 2019-2020 in the laboratory and net house of Department of Soil Science, G.B.P.U.A &T., Pantnagar. The details of the materials used and methodology followed during the study are embodied in this chapter.

3.1 Collection and preparation of biochar samples

Various residues such as wheat straw, *Lantana camara* (a bushy weed) and dried pine needles were collected from N.B. Crop Research Centre and guest house. These residues were dried in an electric oven to remove the moisture content of the biomass. The dried materials were chopped into small pieces to make them ready for the biochar preparation. Thereafter, these materials were incinerated in the muffle furnace at controlled temperature of 300, 450 and 550°C under limited oxygen supply in the Micronutrient testing laboratory in Soil Science department, College of Agriculture, G.B.P.U.A&T, Pantnagar. The charred materials obtained after the limited oxygen incineration were crushed in a pestal and mortar to make them fine and homogenous powder-like material. Crushed samples were passed through 0.5 mm sieve and stored in plastic containers for subsequent analysis and use.

3.2 Characterization of biochar

3.2.1 pH

The pH of the biochar samples was determined by making a suspension of biochar in water (ratio 1:10) through a continuous stirring for 5 minutes and subsequent intermittent mixing for 15-20 minutes. This suspension was used for measuring pH by using the pH meter having a combined glass electrode with digital display (**Jackson, 1973**).

3.2.2 Electrical Conductivity (EC)

The biochar water suspension (ratio 1:10) used for measuring the pH was kept undisturbed for 30 minutes and then the electrical conductivity of the biochar was recorded on a conductivity meter (**Bower and Wilcox, 1965**) and the values were expressed in dSm^{-1} at 25 °C.

Specific conductance = Conductance x cell constant x temperature correction factor (f_t)

3.2.3 Total Organic Carbon

Organic carbon content of the biochar was determined by the colorimetric analysis of the biochar samples. For the determination, 0.05 g finely powdered biochar samples were taken, thereafter, 20 ml each of the 1 N $K_2Cr_2O_7$ and $H_2SO_4+Ag_2SO_4$ mixture (5 g Ag_2SO_4 /l). This mixture was heated on the hot plate for digestion of the biochar samples. After digestion, the volume was made to 100 ml with distilled water and the suspension was filtered with the help of Whatman No. 42 filter paper. The absorbance of the filtrate was recorded at 660 nm. A standard curve was also prepared in the range of 0 to 200 ppm C using glucose as C source. The final amount of the C in the biochar samples was expressed in g/kg.

3.2.4 Total N in biochar

Twenty milligram of biochar was weighed and loaded in N analyzer (Elementar N). The results were expressed as N concentration (g/kg) in the biochar.

3.2.5 Total P and K in biochar

One gram biochar was transferred to 150 ml conical flask. Then, 10 ml of di-acid mixture (HNO_3 : $HClO_4$ 4:1 v/v) was added to it. The biochar samples were digested on the sand bath until the brown fumes subsidized and digestion was continued till a clear and colorless viscous liquid was obtained. After cooling of the digested sample, 2 ml of 6 N HCl was added to it and the volume was made up to 50 ml in a volumetric flask with the help of distilled water.

Five ml of di-acid digested material was taken in 25 ml volumetric flask and 5 ml of ammonium molybovanadate reagent was added to it. This mixture was diluted to 25 ml with the help of distilled water and mixed well. This mixture was kept undisturbed for 25-30 minutes till the complete development of yellow color in the solution. The absorbance of this yellow color was recorded at 420 nm (blue filter). The standard curve was prepared using the working standard solutions in the range of 0 to 10 ppm and the final concentration of total P in the biochar samples was expressed in the terms of P/kg.

A 2 ml volume of the di-acid digested aliquot was taken in a 25 ml volumetric flask and the volume was made up to mark with distilled water. These flasks were then stoppered and mixed well. Then, the solutions were aspirated in the Flame Photometer and the readings were recorded. The standard curve was also prepared in the range of 0-50 μg K/ml.

3.3 Pot culture experiment

3.3.1 Selection of biochar for experiment

In Uttarakhand, pine forests cover a large area of about 3.43 lakh hectares in the hilly areas. These pine forests produce huge amount of dry biomass (about 20.58 lakh tonnes) every year in the state, which also becomes a huge problem as this biomass is highly inflammable and becomes a big reason for the common forest fires occurring in these areas during the summer season. This inflammable biomass, easily available in huge quantity can be used to prepare biochar for use as an amendment. Keeping this point in view, pine needles biochar was selected for use in the pot culture study.

3.3.2 Collection and processing of soil samples

A bulk sample of surface (0-15 cm) soil was collected from E₁ plot of the Norman E. Borlaug Research Centre of the University. This soil developed from calcareous alluvium has been classified as Typic Hapludoll.

The detailed taxonomic classification of the soil is given as under:

Order	:	Mollisol
Suborder	:	Udoll
Great Group	:	Hapludoll
Subgroup	:	Typic Hapludoll
Family	:	Fine, loamy, mixed hyperthermic
Series	:	Patharchatta sandy loam soil

The collected soil was air dried under shade and crushed with a wooden roller to pass through a 2 mm sieve and stored in plastic bags for analyzing different soil properties.

3.3.3 Estimation of soil properties

3.3.3.1 Soil pH

Soil pH was determined in 1:2 soil water suspension using a combined glass electrode on a digital pH meter (**Jackson, 1958**).

3.3.3.2 Electrical Conductivity

The electrical conductivity (EC) of the soil sample was determined in soil-water suspension (1:2) using a conductivity meter. Electrical Conductance was expressed in dSm⁻¹ at 25 °C (**Bower and Wilcox, 1965**).

Specific conductance (dSm^{-1}) = Conductance x cell constant x temperature correction factor (f_t)

3.3.3.3 Organic Carbon

The organic carbon content of the soil sample was determined following the modified Walkley and Black method (Jackson, 1967). One gram of the air dried soil sample was taken in a 500 ml conical flask and 10 ml of 1 N $\text{K}_2\text{Cr}_2\text{O}_7$ was added to it. Further, 20 ml conc. H_2SO_4 was added to the flask and contents were swirled gently for about 1 minute. This flask was then left over for 30 minutes to allow oxidation of the organic matter. Then, the contents of the flask were diluted with the addition of 200 ml water. After this, 85% H_3PO_4 , 0.2 g NaF powder and about 30 drops of the diphenylamine indicator were added to it. The contents were titrated with the 0.5 N Ferrous Ammonium Sulphate solution. Near the end point, the colour changed to turbid blue and finally to brilliant green. A blank sample was also run without the soil.

Calculation:

$$\text{Organic C in soil (\%)} = \frac{10(B - S) \times 0.003 \times 100 \times 1.3}{B \times \text{Dry weight of soil (g)}}$$

Where

B = Volume (ml) of Ferrous Ammonium Sulphate consumed for Blank

S = Volume (ml) of Ferrous Ammonium Sulphate consumed for Soil sample

3.3.3.4 Mineralizable Nitrogen

The amount of the mineralizable N in the soil sample was determined by the KEL PLUS Automatic Nitrogen Estimation System. For this, 5 g of the soil sample was transferred to the digestion tube of the unit and 25 ml of the 0.32% KMnO_4 was added to it. The contents were mixed with 25 ml of 2.5% NaOH solution and the mixture was simultaneously distilled. The released ammonia was trapped in 20 ml of 2% boric acid solution containing the mixed indicator. The color of the trapping solution was initially wine red, which changed to green after NH_3 entrapment. The distillate was titrated with 0.02 N H_2SO_4 and at the end point the color again changed to wine red. Simultaneously, a blank sample was also run in the same manner without the soil.

Calculation:

$$\text{Available N in soil (kg/ha)} = \frac{(S - B) \times 0.02 \times 14 \times 2.24 \times 10^6}{1000 \times \text{Dry weight of soil (g)}}$$

Where

B = Titration value of the Blank sample

S = Titration value of the Soil sample

3.3.3.5 Extractable soil Phosphorus

The extractable soil P was estimated following the method of **Olsen *et al.* (1954)**. One gram of air-dried soil sample was taken in a 150 ml conical flask, 0.2 g P free activated charcoal and 20 ml of 0.5 M NaHCO₃ (extracting solution) were added to it. Thereafter, the flask was shaken for 30 minutes on a mechanical shaker. The solution was then filtered after shaking with the help of Whatman No. 42 filter paper and the filtrate obtained was used for determination of P following Ascorbic acid method (**Murphy and Riley, 1962**). For the determination, 5 ml of the extract was taken in a 25 ml volumetric flask and 2-3 drops of p-nitrophenol indicator was added to it. The pH of the extract was then adjusted to 5.3 by adding dilute HCl drop by drop to finally make the solution colorless. Then, after making the solution colorless, 4 ml of Reagent B (1.056 g ascorbic acid in 200 ml of reagent A which was prepared by mixing solutions having 12.0 g ammonium paramolybdate/250 ml distilled water and 0.2908 potassium antimony tartarate/100 ml distilled water to 5N H₂SO₄ and making volume to 2 litres) was added to it and mixed well. The volume was then made to 25 ml with the help of distilled water. After half an hour, the color intensity was recorded on a colorimeter at 882 nm wavelength by using red filter. A standard curve was also prepared by recording the absorbance of the standards of known P concentrations in the range of 0-0.4 ppm. Finally, the values of P as extracted by Olsen's method were expressed in terms of mg/kg soil.

3.3.3.6 Ammonium acetate extractable potassium

The soil sample was extracted by 1N ammonium acetate (pH 7.0) as described by **Hanway and Hiedal, 1952**. Five gram of the air-dried soil sample was taken in a 100 ml conical flask and 25 ml of the extractant (1N ammonium acetate (pH 7.0)) was added to it. Thereafter, the flask was shaken on a mechanical shaker at 180 rpm for 5 minutes. After shaking, the contents in the flask were filtered with the help of Whatman No. 42 filter paper and the filtrate was used for K concentration determination with the help of Flame Photometer. The values of soil extractable K were expressed in terms of mg/kg soil.

Table 1: Initial properties of soil taken for pot experiment

S.No.	Parameters	Value obtained	References
1	pH (1:2 soil:water suspension)	7.90	Jackson (1958)
2	EC (dS m ⁻¹) in 1:2 soil : water suspension at 25°C	0.998	Bower and Wilcox (1965)
3	Organic carbon (g/kg soil)	5.85	Modified Walkley and Black method (Jackson, 1967)
4	Alkaline KMnO ₄ hydrolyzable Nitrogen (mg/kg soil)	33.59	Subbiah and Asija (1956)
5	Olsen's phosphorus (mg/kg soil)	11.96	Olsen's extraction method (Olsen <i>et al.</i>, 1954)
6	NH ₄ OAc-extractable potassium (mg/kg soil)	45.85	Neutral 1N NH ₄ OAc extraction method (Hanway and Hiedal, 1952)

3.3.4 Pot culture experiment:

A pot experiment was carried out to assess the effect of graded levels of fertilizer and biochar (Pine needle biochar pyrolyzed at 450 °C) addition on the crop growth and soil properties. For this, 4 kg of air dry and clod free soil was filled in plastic containers (pots) of 5 kg capacity. Treatments applied to soil were as under:

- T₁ : Control
- T₂ : 0.5 t/ha biochar
- T₃ : 1.0 t/ha biochar
- T₄ : 2.5 t/ha biochar
- T₅ : 5.0 t/ha biochar
- T₆ : 75% Recommended fertilizer dose
- T₇ : 75% Recommended fertilizer dose + 0.5 t/ha biochar
- T₈ : 75% Recommended fertilizer dose + 1.0 t/ha biochar
- T₉ : 75% Recommended fertilizer dose + 2.5 t/ha biochar
- T₁₀ : 75% Recommended fertilizer dose + 5.0 t/ha biochar
- T₁₁ : 100% Recommended fertilizer dose
- T₁₂ : 100% Recommended fertilizer dose + 0.5 t/ha biochar
- T₁₃ : 100% Recommended fertilizer dose + 1.0 t/ha biochar

- T₁₄ : 100% Recommended fertilizer dose + 2.5 t/ha biochar
T₁₅ : 100% Recommended fertilizer dose + 5.0 t/ha biochar

Replication: 3

- 100% Recommended fertilizer dose was equivalent to 120 kg N, 60 kg P₂O₅ and 40 kg K₂O ha⁻¹ added in solution form through Urea, KH₂PO₄ and KCl.

After application of treatments, the treated soil was thoroughly mixed, watered and left for equilibration. Four days after application of treatments when the soil moisture content was near field capacity, twenty seeds of Oat (*Avena fatua* L., Cv. UPO-212) were sown in all the pots. After emergence and establishment of seedlings, fifteen plants were maintained in each pot. All the pots were regularly watered to maintain soil moisture near field capacity. Plants were harvested at 60 DAS, washed and the dry matter yield was recorded after drying plant samples at 60°C for 48 hours. Soil samples were also collected after harvest and processed for determining important soil properties.

3.3.5 Chemical analysis of plant samples

Finely ground plant sample (20 mg) was weighed and used to determine total N content in plant samples using N analyzer (Duma's method). Nitrogen concentration in plant samples was expressed as g N/kg.

3.3.6 Digestion of plant samples

The oven dried plant samples were chopped into small pieces and 1g of the sample was weighed and taken in 150 ml conical flask. Then, 10 ml of conc. HNO₃ was added to the flask and kept overnight. Next morning, the flask were placed on a sand bath. After the samples turn to brown color on the hot plate, di-acid mixture (HNO₃ : HClO₄ 4:1 v/v) was added to the flask after cooling. The flask was then kept on the sand bath until the brown fumes changed to white, leaving a clear and colorless viscous residue, which marks the completion of the digestion. After cooling the digested sample, 5 ml of 6 N HCl was added and the contents were boiled, cooled and made up to 50 ml with the help of distilled water. The suspension was then filtered through Whatman No. 42 filter paper. The aliquot obtained was used for determining the available P and K for the plant samples.

3.3.7 Analysis of P and K in plant digest

Phosphorus in the acid digest of plant samples was determined colorimetrically following vanadomolybdate yellow colour method in HNO₃ medium (**Jackson, 1973**). Potassium concentrations in the digested plant extracts were determined by a flame photometer (**Jackson, 1973**).

Total uptake of N, P and K by the plants under different treatments were computed by multiplying the nutrient concentration with total dry matter yield and expressed as mg nutrient/pot.

3.3.8 Statistical analysis

The data on greenhouse experiment were subjected to statistical analyses using two factorial completely randomized design as outlined by **Snedecor and Cochran (1967)**. The significance of the data was tested by F-test at $p \leq 0.05$.



Results
and
Discussion

This chapter deals with the results obtained in the present research study, which are described and discussed in detail under the following subheads.

- 4.1 Effect of incineration temperature and biochar sources on nutrient composition, nutrient ratios and some physico-chemical properties of biochars.
- 4.2 Effect of different levels of biochar application and recommended dose of fertilizers on dry matter yield and nutrient composition of Oat plants.
- 4.3 Effect of different levels of biochar application and recommended dose of fertilizers on nutrient uptake by Oat plants.
- 4.4 Effect of different levels of biochar application and recommended dose of fertilizers on various soil properties and amount of soil extractable nutrients after plant harvest.

4.1 Effect of incineration temperature and biochar sources on nutrient composition, nutrient ratios and some physico-chemical properties of biochars

The data on effect of incineration temperature and biochar sources on nutrient, composition, nutrient ratios and some physico-chemical properties of biochars are presented in Table 2.

It is evident from the data contained in Table 2 that an increase in the incineration temperature significantly influenced the average concentration of C, P, K, C:N, C:P ratios, pH and electrical conductivity in biochar materials. The average concentrations of C, K and the value of equilibrium pH, significantly and regularly increased with an increase in incineration temperature. **Taghizadehet *et al.* (2012)** also noted an increase in C content of biochar with increase in pyrolysis temperature. An increase in incineration temperature from 300 to 450°C significantly increased the average concentration of P and electrical conductivity but decreased the average C:P ratio, however no significant change occurred in C:N ratio. Further, an increase in incineration temperature from 450 to 550°C significantly decreased the average concentration of P and electrical conductivity of biochar but increased the average C:N and C:P ratio. **Cantrell *et al.* (2012)** also observed that an increase in pyrolysis

temperature from 350 to 700°C decreased N content but increased P and K content of biochars prepared from different animal wastes. As regards the effect of biochar sources, wheat straw biochar had the lowest average concentrations of C, N, C:P ratio, pH but had the highest average concentration of K, C:N ratio. The biochar produced from pine needles had the highest average concentration of an N, P but the lowest concentration of K, C:N ratio, pH and electrical conductivity. The biochar produced from lantana had the highest average concentration of C, C:P ratio and electrical conductivity but the lowest average concentration of P.

The interaction effect of incineration temperature and biochar had a significant influence on almost all monitored properties of biochar except the concentration of N and C:N ratio. In the case of C concentration in biochars, an increase in incineration temperature regularly increased the concentration of C in all biochars except in wheat straw where an increase in incineration temperature from 450°C to 550°C resulted in a significant decrease in the concentration of C possibly due to conversion of some biomass into ash. **Wu *et al.* (2012)** reported that an increase in pyrolysis temperature increased the aromatization of the biochars prepared from rice straw.

The concentration of P in wheat and pine needle biochar increased significantly with the increase in incineration temperature from 300 to 450°C but no significant increase was noted in the case of lantana biochar. Further, an increase in incineration temperature from 450 to 550°C decreased the concentration of P in wheat straw and pine needle biochar but no such effect was noted for lantana biochar which could be possibly related to woody nature of lantana biomass.

The concentration of K in all biochar increased significantly with the increase in incineration temperature from 300 to 450°C and further increase in incineration temperature from 450 to 550 °C increased the concentration of K significantly in lantana biochar alone while the increase recorded in concentration of K for wheat straw and pine needles biochars was found to be statistically not significant.

The C:P ratio of wheat straw and pine needle biochars decreased significantly with the increase in incineration temperature from 300 to 450 °C but no such effect was recorded for lantana biochar. Further increase in incineration temperature from 450 to 550 °C increased the C:P ratio significantly for wheat straw and pine needle biochars but no such effect was recorded for lantana biochar.

Table 2: Effect of incineration temperature and biochar sources on nutrient composition, nutrient ratios and some physico-chemical properties of biochars

Incineration temperature (°C)	Biochar source	C (g/kg)	N (g/kg)	P (g/kg)	K (g/kg)	C:N	C:P	pH	EC (µS/cm)
300	WHEAT STRAW	567.7	6.7	0.64	10.3	85.2	900	6.9	67.25
	PINE NEEDLE	597.2	14.2	0.88	4.7	44.4	676.8	5.81	37.21
	LANTANA	597.2	9.3	0.41	8.8	64	1454	5.82	58.64
Average		587.4	10.1	0.64	7.9	64.5	1010.3	6.18	54.37
450	WHEAT STRAW	606.9	6.5	0.96	18.8	93.9	632.8	7.4	190.35
	PINE NEEDLE	604.6	15.4	1.29	9.1	40.3	467.2	7.36	128.48
	LANTANA	656.2	8.6	0.47	14.4	77.4	1391.1	9.04	334.61
Average		622.6	10.2	0.91	14.1	70.5	830.4	7.93	217.81
550	WHEAT STRAW	575.1	5.8	0.78	17.8	99.9	745.4	8.87	120.48
	PINE NEEDLE	663.6	12.4	0.35	10.9	53.3	1897.1	7.82	176.49
	LANTANA	781.6	8.4	0.53	18.1	93.1	1467.3	7.85	191.03
Average		673.4	8.9	0.55	15.6	82.1	1369.9	8.18	162.67
Averaged over	WHEAT STRAW	583.2	6.3	0.79	15.6	93	759.4	7.72	126.03
	PINE NEEDLE	621.8	14	0.84	8.2	46	1013.7	7	114.06
	LANTANA	678.3	8.8	0.47	13.8	78.2	1437.5	7.57	194.76
C.D. (p ≤ 0.05)	Incineration temperature (T)	0.6	NS	0.04	1.3	6.2	62.3	0.17	0.19
	Biochar Source (B)	0.6	1.7	0.04	6.2	6.2	62.3	0.17	0.19
	T x B	1.1	NS	0.07	2.2	NS	107.9	0.3	0.33

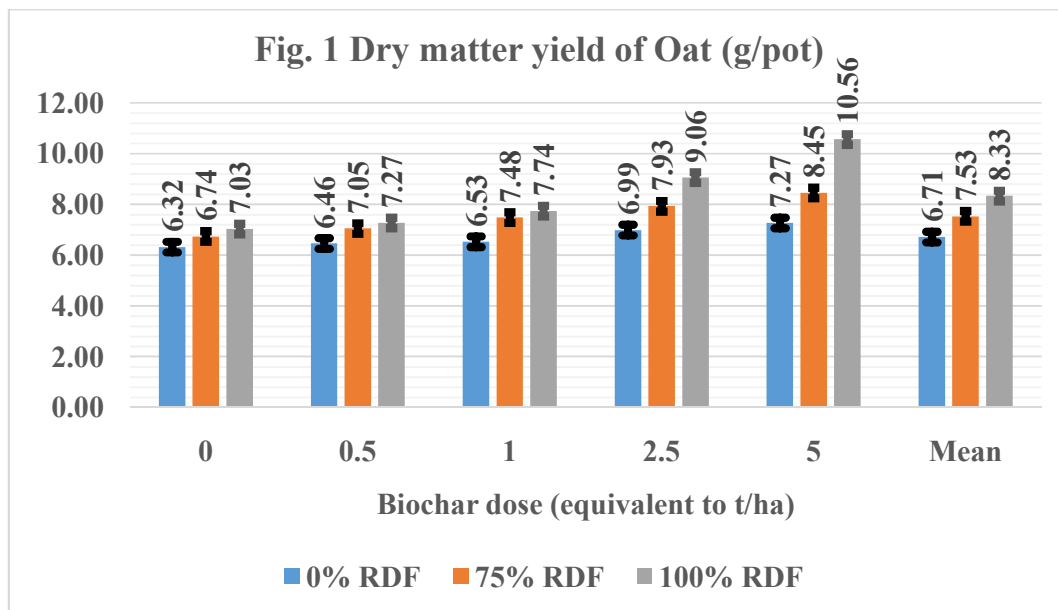
The equilibrium pH of all three biochars increased significantly with the increase in incineration temperature from 300 to 450 °C. **Novak *et al.* (2009)** also observed that biochar pH increased with increase in pyrolysis temperature. Further increase in incineration temperature from 450 to 550 °C significantly increased the equilibrium pH of wheat straw and pine needle biochars but in case of lantana biochar such increase in incineration temperature caused a decrease in equilibrium pH possibly due to partial loss of alkaline and alkaline earth metals as oxides in ash.

The equilibrium EC of all three biochars increased significantly with the increase in incineration temperature from 300 to 450 °C and the highest increase was registered in lantana biochar. Further increase in incineration temperature from 450 to 550 °C also significantly increased EC of pine needle biochar while for wheat straw and lantana biochars, the equilibrium EC decreased significantly with such increase in incineration temperature. Similar trend was recorded by **Taghizadehet *al.* (2012)** for biochar manufactured from Monterey Pine wood chips

4.2 Effect of different levels of biochar application and recommended dose of fertilizers on dry matter yield and nutrient composition of Oat plants.

4.2.1 Dry matter yield

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on dry matter yield of Oat are presented in Figure 1.





T₁	T₂	T₃	T₄	T₅
0% RDF 0 t B/ha	0% RDF 0.5 t B/ha	0% RDF 1.0 t B/ha	0% RDF 2.5 t B/ha	0% RDF 5.0 t B/ha



T₆	T₇	T₈	T₉	T₁₀
75% RDF 0 t B/ha	75% RDF 0.5 t B/ha	75% RDF 1.0 t B/ha	75% RDF 2.5 t B/ha	75% RDF 5.0 t B/ha



T₁₁	T₁₂	T₁₃	T₁₄	T₁₅
100% RDF 0 t B/ha	100% RDF 0.5 t B/ha	100% RDF 1.0 t B/ha	100% RDF 2.5 t B/ha	100% RDF 5.0 t B/ha

Plate 1. Effect of different levels of recommended dose of fertilizers and biochar on performance of fodder Oat (*Avena sativa* L.) at 60 days after sowing. RDF- Recommended dose of fertilizer (120 N: 60 P₂O₅: 40 K₂O), Biochar- B.

It is evident from the data that application of 75% and 100% RDF significantly increased the dry matter yield of Oat by 12.3 and 24.2 percent over no application of fertilizer, respectively. Application of biochar at rates equivalent to 1.0, 2.5 and 5 t/ha also significantly increased the dry matter yield of Oat by 8.2, 19.3 and 30.7 percent over no biochar application, respectively. **Agegnehu et al. (2019)** also reported an increase in total dry matter yield of lemon grass with application of coffee husk biochar.

The interaction effect of RDF and biochar levels also significantly influenced the dry matter yield of Oat. In the absence of fertilizer application (0% RDF), application of biochar dose equivalent to 2.5 and 5.0 t/ha significantly increased the dry matter yield of Oat by 10.6 and 15.0 percent over no application of biochar. Under 75% RDF, application of biochar doses equivalent to 1.0, 2.5 and 5.0 t biochar/ha significantly increased the dry matter yield of Oat by 11.0, 17.7 and 25.4 percent over no application of biochar, respectively. Under 100% RDF, application of biochar doses equivalent to 1.0, 2.5 and 5 t biochar /ha increased the dry matter yield of Oat by 10.1, 28.9 and 50.2 percent over no application of biochar, respectively. Since the C:N ratio of pine needle biochar was 40.3, there was a likelihood that application of this biochar in the absence of fertilizer N might cause N immobilization to limit the increase in dry matter yield due to biochar application. However, with application of 75 and 100% RDF, application of biochar resulted in a significant and substantial increase in dry matter yield of Oat.

4.2.2 N concentration

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on N concentration (g/kg) in Oat plants are presented in Table 3.

It is evident from the data that application of 75% and 100% RDF significantly increased the N concentration (g/kg) in Oat plants by 62.6 and 61.9 percent over no application of fertilizer, respectively. While the application of biochar doses equivalent to 1.0 and 5.0 t biochar/ ha were found to significantly decrease the N concentration (g/kg) in Oat plants by 8.2 and 3.3 percent as compared to no biochar application, respectively.

The interaction effect of RDF and biochar levels had a significant influence on the N concentration (g/kg) in Oat plants. In the absence of fertilizer application (0% RDF), application of biochar dose equivalent to 1.0 and 5.0 t/ha were found to be significantly decrease the N concentration (g/kg) in Oat plant by 3.9 and 16.3 percent in comparison to no application of biochar, respectively. The observed effect could be related to immobilization of plant available N in soil by microbes which were responsible for partial decomposition of biochar C. Under 75% RDF, application of biochar doses equivalent to 0.5 t biochar/ha significantly increased the N concentration (g/kg) in Oat plants by 9.1 percent, while application of 1.0 and 2.5 t biochar/ ha significantly decreased the N concentration (g/kg) in Oat plants by 16.7 and 12.5 percent, respectively over no application of biochar. A lowering in the concentration of N in Oat plants at 1.0 and 2.5 t biochar/ha could possibly be attributed to N immobilization by biochar material. Under 100% RDF, application of biochar doses equivalent to 2.5 t biochar /ha increased the N concentration (g/kg) in Oat plants by 13.5 percent, while the application of biochar dose equivalent to 0.5 and 1.0 t/ha significantly decreased the N concentration (g/kg) in Oat plants by 8.9 and 1.9 percent, respectively over no application of biochar. In the present investigation, no regular trend for change in plant N concentration was observed partly due to N immobilization by soil microbes and also dilution effect on N concentration owing to higher dry matter production.

Table 3: Effect of different levels of biochar application and recommended dose of fertilizers on N concentration (g/kg) in Oat plants.

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			Mean
	0	75	100	
0	21.56	35.08	33.44	30.03
0.5	22.07	38.28	30.45	30.27
1.0	20.72	29.22	32.79	27.58
2.5	21.43	30.70	37.94	30.02
5.0	18.05	35.55	33.53	29.04
Mean	20.77	33.77	33.63	
Effect	RDF	B	RDF x B	
S.E _m ±	0.08	0.11	0.19	
C.D.≤ 0.05	0.24	0.31	0.54	

4.2.3 P concentration

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on P concentration (g/kg) in Oat plants are presented in Table 4.

Table 4: Effect of different levels of biochar application and recommended dose of fertilizers on P concentration (g/kg) in Oat plants.

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			Mean
	0	75	100	
0	1.78	1.84	2.07	1.90
0.5	1.80	2.06	2.32	2.06
1.0	1.99	2.03	2.33	2.12
2.5	1.81	2.12	2.15	2.03
5.0	1.93	2.07	2.18	2.06
Mean	1.86	2.02	2.21	
Effect	RDF	B	RDF x B	
S.E_m±	0.06	0.06	0.10	
C.D.≤ 0.05	0.13	NS	NS	

It is evident from the data that application of 75% and 100% RDF significantly increased the P concentration (g/kg) in Oat plants by 8.8 and 18.8 percent over no application of fertilizer, respectively. Though the use of biochar helped in increasing P concentration in plants yet the magnitude of increase was statistically not significant and the effect of biochar application P concentration (g/kg) in Oat plants was found to be statistically non-significant.

4.2.4 K concentration

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on K concentration (g/kg) in Oat plants are presented in Table 5.

It is evident from the data that application of 75% and 100% RDF significantly increased the K concentration (g/kg) in Oat plants by 19.7 and 31.2 percent as compared to no application of fertilizer, respectively. Application of biochar dose equivalent to 1.0, 2.5 and 5.0 t biochar/ha showed a significant increase in K concentration (g/kg) in Oat plants by 13.0, 22.1 and 20.7 percent, respectively compared to no biochar application, respectively. Potassium is known to be highly

mobile mineral nutrient and not liable to microbial immobilization in plant residues/ organic amendments, therefore, use of pine biochar helped in increasing average K concentration of Oat plants.

The interaction effect of RDF and biochar levels had no statistically significant influence on the K concentration (g/kg) in Oat plants.

Table 5: Effect of different levels of biochar application and recommended dose of fertilizers on K concentration (g/kg) in Oat plants

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	11.8	16.3	18.4	15.5
0.5	12.4	16.4	18.4	15.7
1.0	14.6	18.6	19.4	17.5
2.5	17.0	17.9	21.9	18.9
5.0	18.1	19.2	18.9	18.7
Mean	14.8	17.7	19.4	
Effect	RDF	B	RDF x B	
S.E _m ±	0.5	0.6	1.1	
C.D.≤ 0.05	1.4	1.9	NS	

4.3 Effect of different levels of biochar application and recommended dose of fertilizers on nutrient uptake by Oat plants

4.3.1 N uptake

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on N uptake (mg/pot) by Oat plants are presented in Table 6.

It is evident from the data that application of 75% and 100% RDF significantly increased the N uptake (mg/pot) by Oat plants by 82.7 and 102.7 percent over no application of fertilizer, respectively. Application of biochar at rates equivalent to 2.5 and 5 t/ha also significantly increased the N uptake (mg/pot) by Oat plants by 19.6 and 29.2 percent over no biochar application, respectively.

The interaction effect of RDF and biochar levels also significantly influenced the N uptake (mg/pot) by Oat plants. In the absence of fertilizer application (0% RDF), application of biochar was found to have no significant influence on the N uptake (mg/pot) by Oat plants compared to no application of biochar and the effect could be ascribed to microbial immobilization of N by pine needle biochar which had a C:N ratio of 40.3. Under 75% RDF, application of 0.5 t biochar/ha significantly increased

the N uptake (mg/pot) by Oat plants by 14.1 percent, while application of 5.0 t biochar/ha significantly increased the N uptake (mg/pot) by Oat plants by 27.0 percent over no application of biochar. Under 100% RDF, application of 2.5 and 5.0 t biochar /ha increased the N uptake (mg/pot) by Oat plants by 46.3 and 50.6 percent over no application of biochar, respectively.

Table 6: Effect of different levels of biochar application and recommended dose of fertilizers on N uptake (mg/pot) by Oat plants

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	136.2	236.5	235.0	202.6
0.5	142.6	269.8	221.4	211.3
1.0	144.9	218.7	253.8	205.8
2.5	139.9	243.4	343.7	242.3
5.0	131.1	300.3	354.0	261.8
Mean	138.9	253.7	281.6	
Effect	RDF	B	RDF x B	
S.E _m ±	3.1	3.9	6.8	
C.D.≤ 0.05	8.8	11.4	19.7	

4.3.2 P uptake

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on P uptake (mg/pot) by Oat plants are presented in Table 7.

Table 7: Effect of different levels of biochar application and recommended dose of fertilizers on P uptake (mg/pot) by Oat plants

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	11.25	12.40	14.63	12.76
0.5	11.63	14.51	16.91	14.35
1.0	13.97	15.21	18.05	15.74
2.5	11.81	16.86	19.44	16.04
5.0	14.00	17.50	23.04	18.18
Mean	12.53	15.30	18.41	
Effect	RDF	B	RDF x B	
S.E _m ±	0.46	0.59	1.03	
C.D.≤ 0.05	1.33	1.71	NS	

It is evident from the data that application of 75% and 100% RDF significantly increased the P uptake (mg/pot) by Oat plants by 22.1 and 47.0 percent over no application of fertilizer, respectively. Application of biochar at rates equivalent to 1.0, 2.5 and 5.0 t/ha also significantly increased the P uptake (mg/pot) by Oat plants by 23.4, 25.7 and 42.5 percent over no biochar application, respectively.

The interaction effect of RDF and biochar levels had no statistically significant influence on the P uptake (mg/pot) by Oat plants.

4.3.3 K uptake

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on K uptake (mg/pot) by Oat plants are presented in Table 8.

It is evident from the data that application of 75% and 100% RDF significantly increased the K uptake (mg/pot) of Oat plants by 34.1 and 62.5 percent over no application of fertilizer, respectively. Application of biochar at rate equivalent to 1, 2.5 and 5.0 t/ha also significantly increased the K uptake (mg/pot) by Oat plants by 24.3, 42.8 and 56.1 percent, respectively, over no biochar application.

The interaction effect of RDF and biochar levels had no significant influence on the K uptake (mg/pot) by Oat plants. The results obtained in the present investigation indicated that in a soil of low extractable K status, application of pine biochar in the absence of fertilizer application might help to improve K supply to plants. However, lower rate (0.5 t/ha) of pine biochar (9.1 g K/kg) were not effective to match the increased demand of K by fertilizer responsive crop plants.

Table 8: Effect of different levels of biochar application and recommended dose of fertilizers on K uptake (mg/pot) by Oat plants

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	74.8	110.1	130.4	105.1
0.5	80.0	115.9	133.8	109.9
1.0	102.1	139.4	150.3	130.6
2.5	110.9	141.7	197.6	150.1
5.0	131.3	162.2	198.8	164.1
Mean	99.8	133.9	162.2	
Effect	RDF	B	RDF x B	
S.E _m ±	4.1	5.3	9.2	
C.D.≤ 0.05	11.9	15.4	NS	

4.4 Effect of different levels of biochar application and recommended dose of fertilizers on various soil properties and amount of soil extractable nutrients after plant harvest

4.4.1 Soil extractable N

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on soil extractable N (mg/kg soil) after plant harvest are presented in Table 9.

It is evident from the data that application of 75% and 100% RDF significantly increased the soil extractable N (mg/kg soil) after plant harvest by 32.8 and 65.7 percent, respectively over no application of fertilizer. Application of biochar at rate equivalent to 2.5 and 5.0 t/ha also significantly increased the soil extractable N (mg/kg soil) after plant harvest by 25.3 and 36.6 percent, respectively over no biochar application. **Khan *et al.* (2019)** also reported an increase in the content of nitrate N in soil from 0.73 to 2.02 mg/kg with application of 10 t biochar/ ha under onion crop.

The interaction effect of RDF and biochar levels had no statistically significant effect on soil extractable N (mg/kg soil) after plant harvest.

Table 9: Effect of different levels of biochar application and recommended dose of fertilizers on soil extractable N (mg/kg soil) after plant harvest

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	25.2	31.7	42.9	33.3
0.5	25.2	31.7	42.9	33.3
1.0	28.0	31.7	44.8	34.8
2.5	29.9	46.7	48.5	41.7
5.0	33.6	46.7	56.0	45.4
Mean	28.4	37.7	47.0	
Effect	RDF	B	RDF x B	
S.E _m ±	1.2	1.5	2.6	
C.D. _{≤ 0.05}	3.3	4.3	NS	

4.4.2 Soil extractable P

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on soil extractable P (mg/kg soil) after plant harvest are presented in Table 10.

It is evident from the data that application of 75% and 100% RDF significantly increased the soil extractable P (mg/kg soil) after plant harvest by 13.9 and 19.7 percent, respectively over no application of fertilizer. Application of biochar had no statistically significant effect on the soil extractable P (mg/kg soil) after plant harvest. In general, the soil used in the present investigation had higher content of soil extractable P and the rates of biochar used in the study were also low, therefore, the relative increase in soil extractable P with the application of low doses of biochar did not produce any statistically significant impact on soil extractable P content.

The interaction effect of RDF and biochar levels also significantly influenced the soil extractable P (mg/kg soil) after plant harvest. In the absence of fertilizer application (0% RDF), application of 5.0 t biochar/ha was found to significantly increase the soil extractable P (mg/kg soil) after plant harvest by 19.0 percent as compared to no application of biochar. Under 75% RDF, application of biochar was not found to significantly influence the soil extractable P (mg/kg soil) after plant harvest over no application of biochar. Under 100% RDF, application of only 1.0 t biochar /ha significantly increased the soil extractable P (mg/kg soil) after plant harvest by 19.6 percent over no application of biochar. In the present investigation, no regular trend in the buildup of soil extractable P after crop harvest was recorded in soil.

Table 10: Effect of different levels of biochar application and recommended dose of fertilizers on soil extractable P (mg/kg soil) after plant harvest

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	18.14	22.68	22.41	21.08
0.5	19.24	20.62	24.88	21.58
1.0	20.34	20.41	26.81	22.52
2.5	19.38	23.09	23.71	22.06
5.0	21.58	25.57	20.34	22.50
Mean	19.74	22.47	23.63	
Effect	RDF	B	RDF x B	
S.E _m ±	0.46	0.59	1.02	
C.D.≤ 0.05	1.32	NS	2.95	

4.4.3 Soil extractable K

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on soil extractable K (mg/kg soil) after plant harvest are presented in Table 11.

Table 11: Effect of different levels of biochar application and recommended dose of fertilizers on soil extractable K (mg/kg soil) after plant harvest

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	28.47	28.15	27.95	28.19
0.5	28.70	26.15	29.10	27.98
1.0	28.22	25.43	26.67	26.77
2.5	28.55	30.48	27.42	28.82
5.0	31.93	31.45	29.03	30.81
Mean	29.17	28.33	28.03	
Effect	RDF	B	RDF x B	
S.E _m ±	0.42	0.54	0.93	
C.D. ≤ 0.05	NS	1.55	NS	

It is evident from the data that application of 75% and 100% RDF failed to significantly influence the soil extractable K (mg/kg soil) after plant harvest. Application of 5.0 t biochar/ ha significantly increased the soil extractable K (mg/kg soil) after plant harvest by 9.3 percent over no application of biochar.

The interaction effect of RDF and biochar levels had no statistically significant influence on the soil extractable K (mg/kg soil) after plant harvest. In general, the soil used in the present investigation was low in K and the application of 75% and 100% RDF could not permit a buildup of soil extractable K in the soil after crop harvest. As such pine needle biochar had the lowest content of K. However, the highest dose of pine needle biochar used (5 t/ha) especially under no fertilizer application (0% RDF) brought a significant increase in soil extractable K content in the soil after crop harvest.

4.4.4 Soil pH

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on soil pH (1:2, soil water suspension) after plant harvest are presented in Table 12.

It is evident from the data that application of 75% and 100% RDF significantly decreased the soil pH (1:2, soil water suspension) after plant harvest and the magnitude of decrease was found to be 2.7 and 5.3 percent compared to no application of fertilizer, respectively. Application of biochar at rate equivalent to 1.0 t/ha significantly decreased the soil pH (1:2, soil water suspension) after plant harvest over no biochar application.

The interaction effect of RDF and biochar levels had statistically significant effect on the soil pH (1:2, soil water suspension) after plant harvest. At 0% RDF or no application of fertilizer, no level of biochar was effective to significantly alter the soil pH after plant harvest. Under 100% RDF, application of 1.0 and 2.5 t biochar /ha decreased the soil pH (1:2, soil water suspension) after plant harvest significantly by 3.89 and 2.13 percent, respectively compared to no application of biochar. Several workers (*Abewaet et al., 2013, Agegnehu et al., 2019*) also reported an increase in soil pH upon addition of biochar at higher rates (5 to 20 t/ha) in acidic soils. Even for a neutral soil (pH 7.69), *Khan et al. (2019)* observed that application of 10 t biochar/ha increased the soil pH to 8.68. In contrast to these studies, we noted an increase in soil pH compared to the initial soil pH in the present investigation, no regular trend in soil pH after crop harvest could be related partly to low rates of pine biochar use and enough buffering power of the soil to resist any significant change in pH.

Table 12: Effect of different levels of biochar application and recommended dose of fertilizers on soil pH (1:2, soil water suspension) after plant harvest

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	8.28	8.07	7.97	8.11
0.5	8.23	8.03	7.96	8.07
1.0	8.33	8.10	7.66	8.03
2.5	8.39	8.16	7.80	8.12
5.0	8.36	8.13	7.99	8.16
Mean	8.32	8.10	7.88	
Effect	RDF	B	RDF x B	
S.E _m ±	0.02	0.03	0.05	
C.D.≤ 0.05	0.06	0.08	0.14	

4.4.5 Soil EC

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on soil EC (dS m^{-1} , 1:2, soil water suspension) after plant harvest are presented in Table 13.

It is evident from the data that application of 75% and 100% RDF significantly increased the soil EC (dS m^{-1} , 1:2, soil water suspension) after plant harvest by 20.2 and 73.8 percent, respectively over no application of fertilizer. Application of biochar at the rate equivalent to 1.0, 2.5 and 5.0 t/ha significantly increased the soil EC (dS m^{-1} , 1:2, soil water suspension) after plant harvest by 31.8, 32.7 and 30.6 percent, respectively over no application of biochar. Such increase in soil E. C. had also been reported by **Khan *et al.*, (2019)** and could be ascribed to release of soluble salts from the biochar material.

The interaction effect of RDF and biochar levels had statistically significant effect on the soil EC (dS m^{-1} , 1:2, soil water suspension) after plant harvest. Like soil pH, no significant effect of different levels of biochar application was noted on soil E.C. after plant harvest both under 0% and 75% RDF. Under 100% RDF application, biochar dose equivalent to 1.0, 2.5 and 5.0 t biochar/ha application increased the soil EC (dS m^{-1} , 1:2, soil water suspension) after plant harvest significantly by 83.3, 88.3 and 46.7 percent, respectively over no application of biochar.

Table 13: Effect of different levels of biochar application and recommended dose of fertilizers on soil EC (dS m^{-1} , 1:2, soil water suspension) after plant harvest

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	0.096	0.115	0.123	0.111
0.5	0.106	0.121	0.124	0.117
1.0	0.102	0.113	0.220	0.145
2.5	0.103	0.109	0.226	0.146
5.0	0.112	0.143	0.176	0.144
Mean	0.104	0.120	0.174	
Effect	RDF	B	RDF x B	
S.E _m ±	0.007	0.009	0.015	
C.D.≤ 0.05	0.020	0.026	0.045	

4.4.6 Soil organic C

The data on effect of different levels of biochar application and recommended dose of fertilizers (RDF) on soil organic C (g/kg soil) after plant harvest are presented in Table 14.

It is evident from the data that application of 75% and 100% RDF had no statistically significant effect on the soil organic C (g/kg soil) after plant harvest. Application of biochar at doses equivalent to both 0.5 and 1.0 t biochar/ha was found to be significantly increasing the soil organic C (g/kg soil) after plant harvest by 2.2 percent while biochar dose equivalent to 5.0 t biochar/ha significantly increased the soil organic C (g/kg soil) after plant harvest by 4.35 percent over no application of biochar. Other workers (**Abewaet *al*, 2013; Agegehuet *al*, 2019; Huang *et al*, 2019**) had reported relatively much higher increase in soil organic C content due to biochar application as the doses of biochar used by these workers were many fold higher than the dose used in the present investigation

Table 14: Effect of different levels of biochar application and recommended dose of fertilizers on soil organic C (g/kg soil) after plant harvest

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	5.92	5.85	5.92	5.90
0.5	6.05	6.05	5.98	6.03
1.0	5.98	6.05	6.05	6.03
2.5	5.98	5.92	6.11	6.00
5.0	6.18	6.05	6.24	6.16
Mean	6.02	5.98	6.06	
Effect	RDF	B	RDF x B	
S.E _m ±	0.03	0.04	0.07	
C.D.≤ 0.05	NS	0.11	NS	

The interaction effect of RDF and biochar levels had no statistically significant influence on the soil organic C (g/kg soil) after plant harvest.



*Summary
and
Conclusion*



The present research study was conducted during 2019-20 in the Department of Soil Science, G.B.P.U.A.&T., Pantnagar which includes laboratory studies and pot culture experiment. In the laboratory studies three residues (Wheat straw, Pine needles and Lantana camara) were pyrolyzed at three temperatures (300, 450 and 550 °C) producing nine biochars. All these biochars were characterized for various physico-chemical properties and nutrient compositions. In pot culture experiment, Oat crop was grown with pine needle biochar prepared at 450 °C at five biochar rates (equivalent to 0, 0.5, 1.0, 2.5 and 5.0 t biochar/ha) and three fertilizer rates (0, 75 and 100% RDF). Crop yield and nutrient uptake was determined. Soil after harvest of Oat crop was analyzed to assess the impact of different treatments on extractable nutrients and various physico-chemical properties. Salient experimental findings of the present investigation are summarized below:

Biochar characterization

- Among the biochars prepared from different residues, pH ranged from 5.81 to 9.04 and decreased in the following order: L 450 > WS 550 > L 550 > PN 550 > WS 450 > PN 450 > WS 300 > L 300 > PN 300.
- The L 450 biochar had the highest EC (334.61 µS/cm) among all the biochars followed by L 550, WS 450, PN 550, PN 450, WS 550, WS 300, L 300 and PN 300 biochars, respectively in a range of 191.03 to 37.21 µS/cm.
- On overall basis, the pH and EC of the biochars was found to be significantly increasing on increasing the incineration temperature from 300 to 450 °C, but the values decreased on further increasing the incineration temperature from 450 to 550 °C. Also, the change in residues significantly influenced the pH and EC of the biochars.
- The total C content was found in the range of 567.7 g/kg (WS 300 biochar) to 781.6 g/kg (L 550 biochar). The average values of the total C were found to significantly increase with increasing incineration temperature. The C content was also found to significant change with the change of residue used for biochar preparation.

- The total N content ranged from 5.8 g/kg in WS 550 to 15.4 g/kg in PN 450 biochar. The N content varied significantly with change in residue used for biochar preparation.
- Among all the biochars prepared from different residues, the trend for the total P (g/kg) was as follows: PN 450 > WS 450 > PN 300 > WS 550 > WS 300 > L 550 > L 450 > L 350 > PN 550 in a range from 1.29 to 0.35 g/kg. The values of total P (g/kg) varied significantly with change in incineration temperature, residue used and also with the interaction effect of these variables.
- Among all the biochars prepared from different residues, the trend for the total K (g/kg) was as follows: WS 450 > L 550 > WS 550 > L 450 > PN 550 > WS 300 > PN 450 > L 350 > PN 300 in a range from 18.8 to 4.7 g/kg. The values of total K (g/kg) varied significantly with change in incineration temperature, residue used and also with the interaction effect of these variables.
- The C:N ratio of the biochars ranged from 99.9 for WS 550 to 40.3 for PN 450 biochar. The values of the C:N ratio increased significantly with increase of incineration temperature and varied significantly with change in biochar source and interaction effect of incineration temperature and biochar source.
- The C:P ratio of the biochars ranged from 1897.1 for PN 550 to 467.2 for PN 450 biochar. The values of the C:P ratio increased significantly with increase of incineration temperature only from 450 to 550°C and varied significantly with change in biochar source. While the interaction effect of incineration temperature and biochar source had no statistically significant effect on C:P ratio of the biochars.

Oat yield, nutrient composition and nutrient uptake

- The dry matter yield was found to be significantly increasing with the application of the fertilizer doses (75 and 100% RDF) and biochar (0.5, 1.0, 2.5 and 5.0 t/ha). Among all the treatments the maximum dry matter yield was obtained in treatment with application of 100% RDF + 5.0 t biochar/ha.
- The fertilizer application of both 75 and 100% RDF significantly increased the N concentration in plants. No regular trend was observed for change in N concentration with the application of biochar.

- The P concentration in plants increased significantly only with the application 75 and 100 % RDF, but there was no statistically significant effect of biochar application and interaction effect of biochar and fertilizer application on the P concentration in plants.
- Both the fertilizer (75 and 100% RDF) and biochar application rates (1.0, 2.5 and 5.0 t/ha) were found to significantly increase the K concentration in plants as compared to control. There was no statistically significant effect of interaction of biochar and fertilizers on the K concentration in plants.
- Among all the treatments highest N uptake was found in treatment under 100%RDF + 5.0 t biochar/ha. The N uptake was found to be significantly influenced by the fertilizer and biochar application interaction.
- Phosphorus uptake by Oat plant increased with fertilizer application and biochar addition @ 1.0, 2.5 and 5.0 t/ha. However, the interaction of RDF and biochar rates had no significant effect on P uptake by Oat plants
- The K uptake by the Oat plants was seen to be significantly increasing by the increasing doses of the fertilizer and biochar application of 1.0, 2.5 and 5.0 t/ha. The maximum K uptake was found in treatment with application of 100%RDF + 5.0 t biochar/ha. The interaction effect of fertilizer dose and biochar rates had no statistically significant influence of K uptake of Oat plants.

Properties of soil after crop harvest

- The soil pH significantly decreased with the application of fertilizer and 1.0 t biochar/ha. The interaction effect of biochar and fertilizer application significantly decreased the soil pH in case of application of 1.0 and 2.5 t biochar/ha with 100% RDF.
- Both the fertilizer (75 and 100% RDF) and biochar application rates (1.0, 2.5 and 5.0 t/ha) were found to significantly increase the soil EC compared to control. The interaction effect of biochar and fertilizer application significantly increased the soil EC in case of application of 1.0, 2.5 and 5.0 t biochar/ha with 100% RDF.
- Soil organic C was not significantly affected by the fertilizer application. The application of biochar at rates 0.5, 1.0 and 5.0 t/ha were only effective to significantly increase the soil organic C after crop harvest.

- Both the fertilizer (75 and 100% RDF) and biochar application rates (2.5 and 5.0 t/ha) were found to significantly increase the soil extractable N compared to control. There was no significant effect of fertilizer and biochar interaction on soil extractable N in the present study.
- Soil extractable P significantly increased with the application of 75 and 100% RDF compared to control. There was no significant influence of biochar application on the soil extractable P in the current study.
- The biochar dose of 5.0 t/ha was only found to be significantly increasing the extractable K in soil as compared to control. The application of fertilizer at any rate or the interactive effect of biochar and fertilizer had no statistically significant influence on the soil extractable K in soil.

Thus based on the results it is concluded that biochar properties change with the nature of source and also with increase in incineration temperature. Biochars are the materials with wide C:N ratio so these may be used conjointly with 100% RDF to achieve higher forage production. The conjunctive use of biochar and chemical fertilizers helps to maintain soil fertility.

Since these conclusions are based on a short-term pot culture experiment and therefore, field experiments need to be planned for the verification and further recommendation to the farmers.



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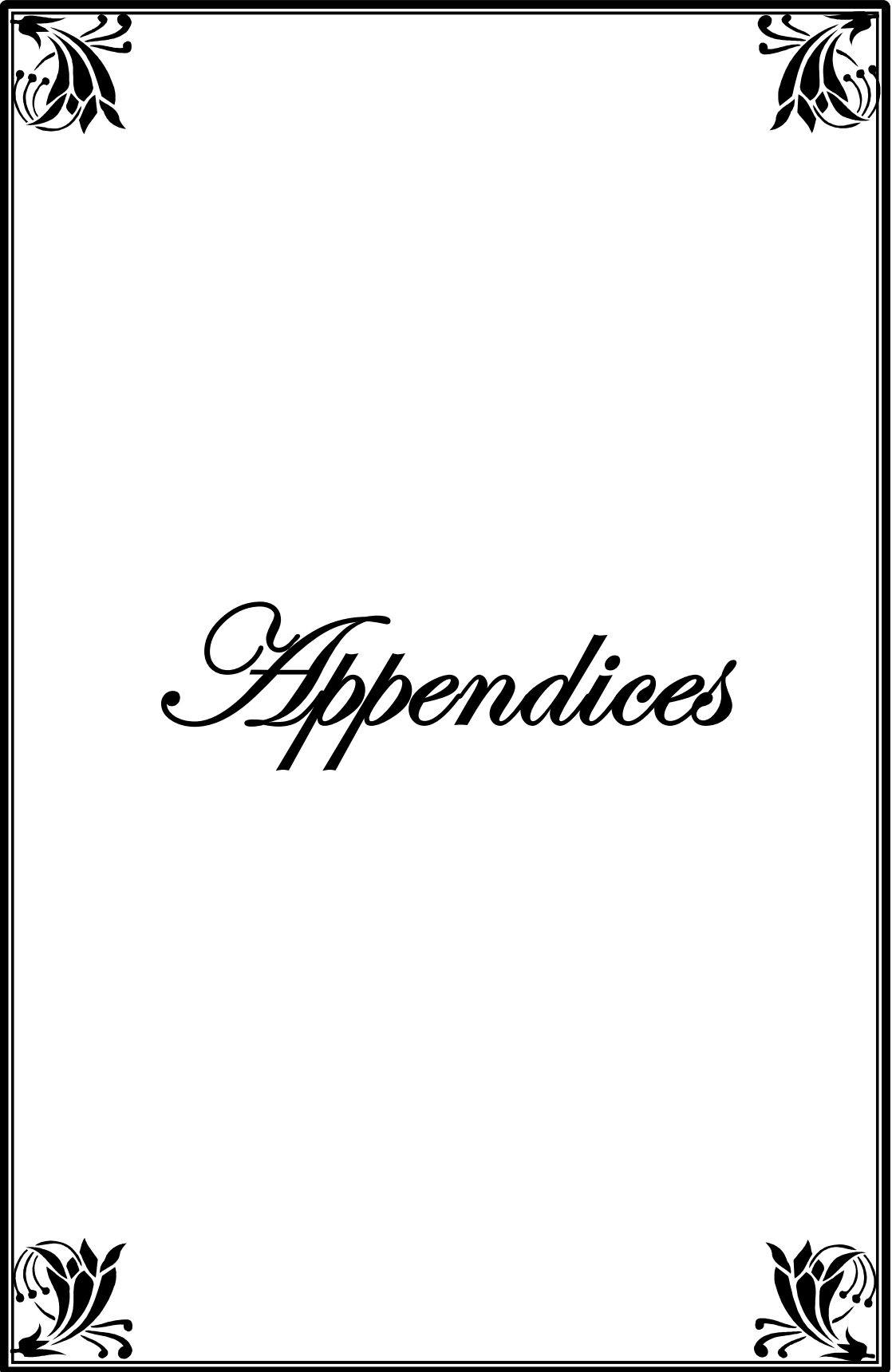
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Appendices

APPENDICES

Appendix I

Effect of different levels of biochar application and recommended dose of fertilizers on dry matter yield of Oat (g/pot)

Biochar dose (in equivalence to t/ha)	Recommended dose of fertilizer (RDF, %)			
	0	75	100	Mean
0	6.32	6.74	7.03	6.70
0.5	6.46	7.05	7.27	6.93
1	6.53	7.48	7.74	7.25
2.5	6.99	7.93	9.06	7.99
5	7.27	8.45	10.56	8.76
Mean	6.71	7.53	8.33	
Effect	RDF	B	RDF x B	
S.E_m±	0.10	0.12	0.21	
C.D.≤ 0.05	0.28	0.36	0.62	

VITA

The author was born on 30th July, 1996 at Haldwani (Uttarakhand). He passed his High School examination in 2011 from St. Peter's Sr. Secondary School, Kichha and Intermediate examination in 2013 from Brij Bhushan Lal Public School, Bareilly. He has completed his B.Sc. (Ag.) degree from G. B. Pant University of Agriculture and Technology, Pantnagar in 2018. Thereafter, he joined the G. B. Pant University of Agriculture and Technology, Pantnagar for the degree of M.Sc. Ag. Soil Science in the year 2018.

Address for correspondence:

Abhishek Saxena

S/O Anuj Saxena

H. No. 67, Village Kishanpur

Kichha

District: Udham Singh Nagar

(Uttarakhand)

Pin code-263148

☎ : 8057140999

E-mail: guggalvcr@gmail.com

ABSTRACT

Name : Abhishek Saxena **Id. No.** : 45977
Semester : 1st Semester, **Degree** : M.Sc.(Ag.)
Year of Admission : (2018-2019) **Department** : Soil Science
Advisor : **Dr. P. C. Srivastava**
Thesis Title : **“CHARACTERIZATION OF BIOCHARS AND USE OF
A BIOCHAR AS SOURCE OF MACRONUTRIENTS”**

A pot experiment was conducted in the nethouse of Department of Soil Science, G.B.P.U.A.&T., Pantnagar to study the effect of graded levels of chemical fertilizers and biochar on dry matter yield, nutrient concentration and uptake by Oat (*Avena sativa* L.) and soil properties. Treatments imposed were combination of three fertilizer doses (0, 75 and 100% RDF) and five rates of biochar application rates (equivalent to 0, 0.5, 1.0, 2.5 and 5.0 t/ha) in a two factorial completely randomized design with three replications. The experiment was carried out by selecting Fodder Oat (variety UPO 212) crop which was harvested sixty days after sowing.

The present study revealed that application of 100% RDF and 5 t/ha biochar gave the higher dry matter yield of the fodder Oat crop. The application of the fertilizer doses although increased the N concentration in plants but it was declined by increasing the biochar dose. Phosphorus concentration in the plant was however unaffected by the application of biochar. Both the biochar and fertilizer application significantly increased the K concentration in plants. Total uptake of N, P and K by plants were the highest under the treatment receiving 100% RDF + 5 t biochar/ha. The soil after the experiment showed lower pH and elevated EC on fertilizer and biochar application. The soil organic C also showed a significant rise only by the application of the biochar doses. Soil extractable N was found to increase significantly with fertilizer application and higher biochar doses only. The biochar application failed to influence soil extractable P content. Soil extractable K increased significantly with the application of high biochar dose. Thus, biochar can be considered as a good soil amendment to be used conjointly with fertilizers which can supplement the crop yield and improve the soil quality.



(P. C. Srivastava)
Advisor



(Abhishek Saxena)
Author

सारांश

नाम	: अभिषेकसक्सेना	परिचयांक	: 45977
सत्र	: प्रथम	उपाधि	: स्नातकोत्तरकृषि
प्रवेशवर्ष	: 2018-19	विभाग	: मृदाविज्ञान
सलाहकार	: डॉ.पी.सी.श्रीवास्तव		

शोधग्रन्थशीर्षक : “विभिन्न बायोचारकालक्षणवर्णन एवं मैक्रोन्यूट्रिएंट्स के स्रोत के रूप में एक बायोचारका उपयोग”

जई (एवेना सटाइवा एल.) की शुष्क पदार्थ की उपज, पोषक तत्वों की सघनता और उठाव एवं मृदा गुणों पर रासायनिक उर्वरकों और बायोचार के वर्गीकृत स्तरों के प्रभाव का अध्ययन करने के लिए गो. ब. पंत कृषि एवं प्रौद्योगिक विश्वविद्यालय, पंतनगर के मृदा विज्ञान विभाग के नेट हाउस में एक पॉट प्रयोग किया गया था। लगाए गए उपचार तीन उर्वरक खुराक (0, 75 और 100 प्रतिशत उर्वरक की अनुशंसित खुराक) और बायोचार आवेदन दरों की पांच दरों (0, 0.5, 1.0, 2.5 और 5.0 टन प्रति हेक्टेयर के बराबर) के संयोजन थे, जो तीन प्रतिकृतिओं के साथ दो गुट सम्पूर्ण यादृच्छिक डिजाइन में थे। यह प्रयोग के लिए चारा जई (किस्म यू. पी. ओ. 212) फसल का चयन किया गया था जिसकी कटाई बुवाई के साठ दिन बाद की गयी थी।

वर्तमान अध्ययन से पता चला है कि 100 प्रतिशत उर्वरक की अनुशंसित खुराक और 5.0 टन प्रति हेक्टेयर के बराबर के आवेदन ने चारा जई की फसल की अधिक शुष्क पदार्थ उपज दी। उर्वरक खुराक के प्रयोग से पौधों में नाइट्रोजन एकाग्रता में वृद्धि हुई है लेकिन बायोचार खुराक में वृद्धि से पौधों में नाइट्रोजन एकाग्रता बढ़ती हुई नहीं पायी गयी। संयंत्र में फास्फोरस एकाग्रता बायोचार के प्रयोग से अप्रभावित थी। बायोचार और उर्वरक अनुप्रयोग दोनों से पौधों में पोटेशियम एकाग्रता में काफी वृद्धि पायी गयी। पौधों द्वारा नाइट्रोजन, फास्फोरस और पोटेशियम का कुल उठाव, उर्वरक की 100 प्रतिशत अनुशंसित खुराक के साथ 5.0 टन बायोचार प्रति हेक्टेयर प्राप्त करने वाले उपचार के तहत सबसे अधिक था। उर्वरक और बायोचार प्रयोग के बाद घटित मृदा अभिक्रिया (पी. एच.) एवं विद्युत चालकता (ई.सी.) बढ़ी हुई पाई गई। मृदा जैविक पदार्थ में बायोचार खुराक के उपयोग से एक महत्वपूर्ण वृद्धि दिखाई दी। उर्वरक और उच्च बायोचार खुराक के उपयोग से मृदा उपलब्ध नाइट्रोजन में काफी वृद्धि पाई गई थी। बायोचार उपयोग मृदा उपलब्ध फॉस्फोरस को प्रभावित करने में नाकाम रहा। उच्च बायोचार खुराक के उपयोग के साथ मृदा उपलब्ध पोटेशियम में काफी वृद्धि हुई। इस प्रकार, बायोचार को उर्वरकों के साथ संयुक्त रूप से उपयोग किए जाने वाले एक अच्छे मृदा संशोधन के रूप में माना जा सकता है जो फसल की उपज को पूरक कर सकता है और मिट्टी की गुणवत्ता में सुधार कर सकता है।



(पी.सी.श्रीवास्तव)

सलाहकार



(अभिषेकसक्सेना)

लेखक