RESIDUAL EFFECT OF BIOCHAR WITH REDUCED DOSES OF CHEMICAL FERTILIZERS ON THE SOIL PROPERTIES, GROWTH AND YIELD RESPONSE OF OKRA

A THESIS

BY

MOST. TANBIN JANNAT

Student No. 1601400

Session: 2022-2023

Semester: January-June 2023

MASTER OF SCIENCE

IN

SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

DECEMBER, 2023

RESIDUAL EFFECT OF BIOCHAR WITH REDUCED DOSES OF CHEMICAL FERTILIZERS ON THE SOIL PROPERTIES, GROWTH AND YIELD RESPONSE OF OKRA

A THESIS

BY

MOST. TANBIN JANNAT

Student No. 1601400

Session: 2022-2023

Semester: January-June 2023

Submitted to

The Department of Soil Science

Hajee Mohammad Danesh Science and Technology University, Dinajpur

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

IN

SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

DECEMBER, 2023

RESIDUAL EFFECT OF BIOCHAR WITH REDUCED DOSES OF CHEMICAL FERTILIZERS ON THE SOIL PROPERTIES, GROWTH AND YIELD RESPONSE OF OKRA

A THESIS
BY

MOST. TANBIN JANNAT
Student No. 1601400
Session: 2022-2023
Semester: January-June 2023

Approved as to the style and content by:

....
Prof. Dr. Md. Abdullah Al Mamun
Supervisor

....
(Prof. Dr. Md. Shahadat Hossain Khan)
Co-supervisor

....
Prof. Dr. Md. Shahadat Hossain Khan
Chairman of
Examination Committee
&
Chairman
Department of Soil Science

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

DECEMBER, 2023

Dedicated

To

My Beloved Family

ACKNOWLEDGEMENTS

All admirations and praises are solely due to Almighty Allah whose endless kindness mercy absolutely enabled the author to accomplish her research work successfully.

It is impossible to describe adequately all of the immense contributions made to this study in terms of suggestions, guidance, time and patience of my honorable and reverent ***supervisor Professor Dr. Md. Abdullah Al Mamun****, Department of Soil Science, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. Not only that, his enduring guidance, constructive criticisms, abundant help during every phase of this research work and preparation were a source of inspiration and good judgment.*

The author also sincerely wishes to expresses gratefulness to her honorable ***co-supervisor Professor Dr. Md. Shahadat Hossain Khan*** *Department of Soil Science of the same university, for his active help, realistic suggestions, co-existed and sympathetic contribution in many ways during the overall research work.*

The author humbly desires to acknowledge to all teachers of the Department of Soil Science, Hajee Mohammad Danesh Science and Technology University, Dinajpur for their important suggestions and all round help and co-operation during the period of this study.

The author is grateful to the laboratory staff and field staff of the Department of Soil Science, HSTU, Dinajpur for their untiringly field and laboratory works and all kinds of help and support

The author extends her special appreciation to express her enormous feelings of gratitude to her dear friends Nafisa Zainab, Habibur Rahman and others for their support and assistance during the study period and the research work.

Finally, the core of her heart, the author humbly desires to express her deepest and profound gratitude and immense indebted to her beloved parents and cousins for their blessing, countless sacrifice and endless inspiration throughout the study period.

The Authoress

ABSTRACT

The research work was conducted in the research field of the Department of Soil Science, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during November 2022 to January 2023 to study the residual effect of biochar with reduced doses of chemical fertilizers on the soil properties, growth and yield response of okra (Local variety: Heera). The experimental soil belongs to the Old Himalayan Piedmont Plain (AEZ-1). The experiment was laid out in the randomized complete block design (RCBD) having eleven (11) treatments with three replications. The treatments were T_1 = No residual biochar + No chemical fertilizer (Control), T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched organic fertilizer (OF), T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched organic fertilizer (OF), T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched organic fertilizer (OF). The results showed that the growth and yield attributing components such as plant height, number of fruit $plant^{-1}$, marketable fruit weight $plant^{-1}$, fruit weight $plot^{-1}$, fruit length, fresh shoot biomass $plant^{-1}$, dry shoot biomass $plant^{-1}$, root length, fresh root weight, dry root weight responded significantly except fruit breadth due to the application of different level of chemical fertilizers along with different level of residual biochar combination. The highest values of different parameters such as plant height (74.2 cm), number of fruit $plant^{-1}$ (16.6), marketable fruit weight $plant^{-1}$ (197.8 g), fruit weight $plot^{-1}$ (1.18 kg), fruit length (11.3 cm), fruit breadth (5.0 cm), fresh shoot biomass $plant^{-1}$ (181.5 g), dry shoot biomass $plant^{-1}$ (30.8 g) were obtained in T_{11} treatment where 100% RDF + Residual 10 t ha^{-1} Biochar enriched organic fertilizer (OF) were applied. The lowest results were found in the control treatment (T_1). In post- harvest soil, the treatments (T_4 and T_5) receiving high amount (20 t ha^{-1}) of biochar gave the highest amount of total N, available P, exchangeable K, available S, organic carbon (OC) and organic matter (OM). In case of pH the highest (7.31) was found in T_5 treatment. The residual effect of biochar with reduced doses of chemical fertilizers might be better for sustainable soil health for growing crops. Overall, the results suggested that reduced doses of chemical fertilizers in previous biochar incorporated field can be better for cultivation of okra in respect to higher yield response and might be advantageous cultivation of crops in the next year.

CONTENTS

CONTENTS (Contd.)

CONTENTS (Contd.)

LIST OF TABLES

LIST OF FIGURE

LIST OF APPENDICES

ABBREVIATION

%	:	Percent
@	:	At the rate of
AEZ	:	Agro-ecological Zone
ANOVA	:	Analysis of Variance
BARI	:	Bangladesh Agricultural Research Institute
BAU	:	Bangladesh Agricultural University
BBS	:	Bangladesh Bureau of Statistics
CV%	:	Percentage of Coefficient of Variance
DAS	:	Days after Sowing
et al.	:	And others
FAO	:	Food and Agricultural Organization
Fig.	:	Figure
g	:	Gram
ha	:	Hectare
K	:	Potassium
LS	:	Level of Significance
MOP	:	Muriate of Potash
N	:	Nitrogen
P	:	Phosphorus
PPM	:	Parts Per Million
RCBD	:	Randomized Complete Block Design
S	:	Sulphur
SEM	:	Standard error of mean
TSP	:	Triple Super Phosphate
UNDP	:	United Nations Development Programme
Viz.	:	Namely

CHAPTER I

INTRODUCTION

Okra (*Abelmoschus esculentus*) is a member of the Malvaceae Family and is also known as Lady's finger. It is an annual vegetable crop grown from seed. It is mostly grown in tropical and subtropical part of India as a warm season vegetable crops, require warm nights (> 20ºC) for proper growth and development (Seth *et al.*, 2017). Okra is probably originated in tropical Africa or possibly tropical Asia and is now widely grown throughout the tropics (Tindall, 1988). The crop is well distributed throughout the Indian subcontinent and East Asia (Rashid, 1999). Okra is popular due to its healthy aspects, such as high fiber, antioxidants, vitamin C, minerals, potassium, and calcium. It is also important as a medicinal plant for plasma replacement (Kumar *et al*., 2013; Sorapong, 2012). It also contains carbohydrate, proteins and vitamin-c in large quantities (Adeboye and Oputa, 1996). The essential and non-essential amino acids that okra contains are comparable to that of soybean. Hence it plays a vital role in human diet. Okra mucilage is suitable for medicinal and industrial applications. Okra leaves are medicinal and can be used as a curative medicine against ulcer and haemorrhage (Khetran *et al.*, 2016). It has medically found application as a plasma replacement or blood volume expander. Industrially, okra mucilage is usually used in to glace certain papers and also useful in confectionery among other uses (Markose and Peter, 1990). In Bangladesh vegetable production is not uniform round the year. Vegetables are plenty in winter, but are lower in summer. The total vegetable production, around 30% is produced during kharif season (April to September) and 70% is produced in Rabi season (October to March) (Annon, 1993). Total production of okra was about 54183 metric tons from 28647 acres of land in Bangladesh (BBS, 2019). Though okra is popular in the country, its production is mainly concentrated during summer. So, okra can get an importance in summer as vegetable.

Biochar is fine grained charcoal like materials, rich in carbon, produced by the process pyrolysis of biomass at temperatures between 300 °C and 600 °C in absence of oxygen. It is said that biochar can endure in soil for thousands of years (Julie, 2010). It has been reported that use of charcoal as a fuel replacing wood leads to lower levels of household indoor pollution (Bailis *et al.,* 2005). The application of different biochar (charcoal or biomass derived black carbon) and biochar based organic fertilizers to agricultural soil is proposed as a novel approach to improve soil fertility, improve soil water holding capacity and consequently moisture retention, and to increase crop production of newly reclaimed sandy soil (Bakry *et al.*, 2015). Biochar is a stable form of carbon has complex of physical and chemical properties which make it a potentially powerful soil amendment material (Mutezo, 2013). It can act as a soil conditioner enhances the growth of the plants by supplying and more specifically retaining nutrients and improving soil physical and biological properties and consequently improving soil water holding capacity (Lehmann and Rondon, 2005). Biochar is produced from a variety of biomass residues (feedstocks) and under different pyrolytic conditions, and thus has varying nutrient contents. For example, in case of biochar produced from feedstocks of animal higher amount of nitrogen and phosphorus in compare to plant origin (Chan and Xu, 2009).

Growth, yield and quality of okra depend on nutrient availability in soil, which is related to the judicious application of manures and fertilizers. Nutrient may he applied through two sources viz, organic and inorganic. Increased use of inorganic fertilizer in crop production creates problem to the environment including the pollution of air, water and soil. Continuous use of chemical fertilizers badly affects the soil, structure, color, aeration, water holding capacity and microbial activity of soil. Organic matter content of good and healthy soil is reported to be more than 3%. But in Bangladesh soil of most regions has less than 1.0%. For continuous cropping, organic manures applied to the crop fields through cowdung, poultry litter, firm yard manure, oil cake, compost, ash, green manure etc. are insufficient. The declining productivity of soil is mainly attributed to poor soil fertility, low pH, organic matter (OM), cation exchange capacity (CEC), base saturation, available nutrients. Inappropriate use of chemical and organic fertilizers and the lack of improved crop management practices by farmers resulting the reduced yield of okra. Now-a-days, gradual deficiency in soil organic matter and reduced yield of crops are alarming factors and burning issues for the sustainable production system.

In Bangladesh, the yield of okra is very low due to improper management of fertilizers and cultural practices. Soil is the greatest resources of nature and is the only natural medium for plant growth or crop production. But the soil fertility deterioration is the major constrain for sustainable crop production in many countries as well as in Bangladesh. Intensive use of land without proper and balanced use of chemical fertilizers with little or no use of organic matters resulting in severe fertility deterioration of the soils of Bangladesh. With the introduction of modern farming practices, farmers of Bangladesh use chemical fertilizer for their crop production annually averaging 172 kg nutrients ha^{-1} but the average crop removal is about 250 kg ha^{-1} (Islam *et al.*, 2002). So, the integrated application of inorganic and organic fertilizers, usually termed integrated nutrient management, is widely recognized as a way of enhancing yield and improving productivity of the soil and in a sustainable way. Integrated use of chemical fertilizers and some of organic sources such as cowdung, vermicompost, farm yard manure (FYM), biochar that can increase the effectiveness of fertilizers, yield of okra and may improve soil physico-chemical properties. There have been reports that biochar in combination with inorganic fertilizers had shown significant increase in yield of cowpea, maize and peanut etc. (Yamato *et al.,* 2006), paddy (Zhang *et al.,* 2012), spring barley, winter wheat, carrots, spinach, oilseed rape, peas and beetroot (Hammond *et al.,* 2013).

The prices of chemical fertilizers are increasing day by day with the reduction of the qualities of soil properties. Also, a limited number of biochar and residual effects of biochar researches have been conducted in Bangladesh which leads to its scope and opportunities in Bangladesh. That is why this study was conducted to observe the following objectives:

i. To evaluate the effect of reduced doses of chemical fertilizers with residual biochar on the growth and yield of okra;
ii. To study the effect of residual biochar and reduced doses of chemical fertilizers on the postharvest soil properties.

CHAPTER II

REVIEW OF LITERATURE

Okra (*Abelmoschus esculentus* L.) is one of the most important vegetable crops in the world. It is quite widespread in different regions of the world and seems to grow well in tropical and sub- tropical or warm temperate regions. Various works on okra have been done in different regions of the world including Bangladesh. We have scanty information about the effect of biochar and reduced doses of chemical fertilizers on soil properties, growth, and yield response of okra. Therefore, some important research findings relevant to the present study have been reviewed and presented in this chapter:

2.1 Effect of biochar on growth and yield of okra

Reddy *et al.* (2022) conducted a field experiment at Naini Agricultural Institute in Research Farm, Department of Soil Science and Agricultural Chemistry, SHUATS, Prayagraj. In the research trial, the experiment was laid in randomized block design with nine treatments and three replications. The okra was planted at a spacing of 30 cm × 15 cm. Growth parameters were collected on plant height (cm), number of leaves plant^{-1}, number of fruits plant^{-1}, weight of the fruit (g), length of the fruit (cm) and yield of okra fruits (q ha^{-1}). The results revealed that the combination of different treatments showed a significant effect on growth and yield parameters with protein and chlorophyll content of okra. Hence, it was concluded that the combination of NPK and biochar was found to be useful for okra crop in terms of growth and yield parameters under the prevailing conditions of the study area.

Acharya *et al.* (2022) found that biochar blended with goat manure (BM) showed the highest effect on soil fertility and fruit yield of okra. BM (51.8 t ha^{-1}) increased fruit yield by 89% over CK (27.4 t ha^{-1}) and by 88% over F (27 t ha^{-1}). Similarly, cow urine-enriched biochar (BCU) (35 t ha^{-1}) increased fruit yield by 29% and 28% compared to CK and F, respectively. Soil pH, OC, and nutrient availability (total N, available P, and available K) showed a significantly positive relationship with fruit yield. The study suggests that using biochar-based organic fertilizers, such as BCU and BM, could outperform recommended mineral fertilizers (F) and produce higher yields and healthy soils, thereby contributing to mitigating the current food security and environmental concerns of the country.

De *et al.* (2020) conducted a field experiment on okra at the experimental station of the Federal University of Sergipe (UFS), located in the municipality of São Cristovão / SE, Northeast Brazil (about10°55 '46 "S; 37°06' 13"W) in randomized blocks, with 6 treatments (CHB + BSS-coconut husk biochar + biochar of sewage sludge, CHB + RSS-coconut husk biochar + raw sewage sludge, BSS + RSS-biochar of sewage sludge + raw sewage sludge, CHB-coconut husk biochar, BSS-biochar of sewage sludge, WB-without biochar (control). Plant height numbers of fruits plant-1, yield and water use productivity were evaluated. The BSS + RSS and BSS treatments provided better results on okra production and growth characteristics with a 421.15% and 419% productivity increase, respectively, compared to the control treatment. The BSS and BSS + RSS treatments provided better water productivity, with values of 14.5 and 13.3 kilogram produced for each cubic meter of water applied, respectively.

Yakubu *et al.* (2020) examined the combined effect of rice straw biochar and irrigation on yield, water productivity, and phosphorus (P) uptake of okra (*Abelmoschus esculentus* L.) grown on a sandy clay loam soil in the dry season. Biochar was applied at 0, 5, 10 Mg ha^{-1}, and 10 Mg ha^{-1} biochar fortified with P (10 Mg ha^{-1} P) under full irrigation (FI) and deficit irrigation (DI) and replicated in each growing season for three years. Under DI, the 10 Mg ha^{-1} and 10 Mg ha^{-1} (P) biochar treatments significantly ($p < .05$) increased okra fresh fruit yield (Y_{FF}) by 67 and 82% but had no impact on total aboveground biomass yield (Y_{TBM}) in the first growing season. Biochar at 5 Mg ha^{-1} had no impact on okra yield. Okra yield was higher under biochar fortified with P compared to the traditional method of applying P alone, e.g., 30 Mg ha^{-1} (P) produced significantly higher Y_{TBM} than 30 Mg ha^{-1} under DI.

Akpa *et al.* (2019) evaluated a field experiment on the effect of combined application rates of cowdung and biochar on the growth and development of okra. The experiment was conducted at the Research Farm, Nasarawa State University Lafia, Nigeria, during the rainy season of 2018. The experimental design employed was a Randomized Complete Block Design (RCBD) involving 3 levels of cowdung (0, 8 and 12 t ha^{-1}) and 3 levels of biochar (0, 4 and 6 t ha^{-1}) at different combinations. The experiment was replicated three times with a total number of 27 plots. Data were collected on plant height (cm), stem girth, number of leaves and leaves area. The data collected were subjected to statistical analysis of variance. Specifically, T_8 (comprising of 12 t ha^{-1} cow dung and 8 t ha^{-1} biochar) produced the tallest plants at 4 WAP, 6 WAP, 7 WAP and 8 WAP. The treatment T_8 also produced plants with the highest leaves area (119.40 cm^2, 225.49 cm^2, 342.96 cm^2 and 387.00 cm^2) at 5 WAP, 6 WAP, 7 WAP and 8 WAP, respectively. Results obtained from the study showed that combination of cowdung and biochar support good growth and the parameters measured were significantly enhanced at all the sampling periods. It can therefore be recommended that combination of cowdung and biochar at 12 t ha^{-1} and 8 t ha^{-1}, respectively is necessary for effective growth and development of okra.

Onwuka and Nwangwu (2016) investigated the effect of biochar produced from different animal and plant wastes on growth and yield of okra plant. The treatments were a control (without biochar) and biochar produced from animal wastes sources namely; bone waste, cow dung, goat droppings, pig waste and poultry droppings. Others were produced from plant wastes sources namely; cocoa pod, palm bunch, saw dust, rice mill husk, ukpo shell (*Mucuna flagellipes*) and wood shaving. The treatments were applied at the rate of 3 t ha^{-1} (whose equivalent was 86 g) to 10 kg of soil weighed into pots and replicated 4 times in a Completely Randomized Design. The test crop was okra (*Abelmoschus esculenta*) and the effects of the treatments were determined on its top biomass dry matter yield, number of leaves, the height, stem girth at 2, 4, 6 and 8 weeks after planting. Biochar produced from poultry manure feedstock significantly ($p \leq 0.05$) increased the plant height at eight weeks after planting among the animal feedstock biochar. It gave a value of 50.68 cm over that of the control which was 25.8cm. Among the plant feedstocks biochar, the application of ukpo shell (*Mucuna flagellipes*) significantly ($p \leq 0.05$) increased the plant top biomass dry matter yield with a value of 8.1 g pot^{-1} as compared to the control value of 4.4 g pot^{-1}. The top biomass dry matter significantly ($p \leq 0.05$) and correlated positively with number of leaves and plant height. The result showed that among the animal feedstock and plant feedstock biochar, poultry manure and ukpo shell (*Mucuna flagellipes*) respectively improved most of the plant parameters measured.

Bishwoyog *et al.* (2015) showed that number of pod $plant^{-1}$, number of seed pod^{-1} and biomass (t ha^{-1}) were significantly affected by application of biochar of different origin. Application of rice husk biochar had higher effect on number of pod $plant^{-1}$, no of seed pod^{-1}, biomass (t ha^{-1}) and green pod yield (t ha^{-1}).

2.2 Effect of biochar on soil properties

Azman *et al.* (2023) stated that soil fertility can be improved by incorporating organic matter such as biochar and compost. The combined addition of biochar and compost effectively restores soil degradation by enhancing nutrient availability, soil aggregation, and porosity. Nonetheless, many studies mainly concentrated on a single application of biochar and compost as a soil amendment. The biochar samples were prepared from oil palm empty fruit bunch (OPEFB) material at the desired microwave power (450 W) under 1 L min^{-1} of N_2 flow for 10 min. Then, sandy soil was amended with 5 g of sole biochar and compost, as well as a biochar-compost mixture at a ratio of 1:1 for 8-weeks polybag experiment of okra plants. At 4 weeks of the plantation, the physical and chemical soil properties were analyzed. The application of biochar and composts alone and in combination significantly improved soil physicochemical properties and plant growth compared to control soil. The synergetic positive effect of biochar and compost combination resulting lowered soil bulk density with higher soil porosity, moisture content, and nutrients availability.

Dimande *et al.* (2023) studied the effect of bat guano and biochar on okra yield and some soil properties. Bat guano was applied at two rates (5 and 10 t ha^{-1}) just before sowing. It was also applied at the same rates one month before sowing. Biochar was used at two rates (5 and 10 t ha^{-1}) and was applied at sowing. Biochar and guano were mixed at the rates of 1 and 4 t ha^{-1} and 2 and 8 t ha^{-1}, respectively, and applied at sowing. The experiment also used a non-fertilized control. Field trials were arranged in a completely randomized design with three replicates. The treatments that received high rates of guano tended to show significantly higher fruit yields (> 10 t ha^{-1} as the two-year average) in comparison with the control, which showed the lowest average okra fruit yield (6.21 t ha^{-1}). In the guano treatments, the apparent recovery by okra of some important nutrients, such as N, was greater than the amount of the nutrient contained in the guano itself. The use of biochar increased the total organic C in the soil and cation exchange capacity (CEC) compared with the control but did not affect the variables related to plant performance. Overall, the results showed that farmers can benefit from the use of guano in the short term because it releases nutrients, while with the use of biochar, the benefits can arise in the long term by improving the soil properties.

Acharya *et al*. (2022) conducted an experiment potential of biochar-based organic fertilizers on increasing soil fertility, available nutrients, and okra productivity in slightly acidic sandy loam soil. Seven treatments with three replicates were arranged in a completely randomized design (CRD). Three treatments included biochar-blended formulations (i) biochar mixed with mineral NPK fertilizer (BF), (ii) biochar mixed with vermicompost (BV), and (iii) biochar mixed with goat manure (BM); two treatments included biochar enrichment formulations (iv) biochar enriched with cow urine (BCU) and (v) biochar enriched with mineral NPK fertilizer in aqueous solution (BFW), and the remaining two included control treatments; (vi) control (CK: no biochar and no fertilizers) and (vii) fertilized control (F: only recommended NPK fertilizer and no biochar). Mineral NPK fertilizers in BF, BFW, and F were applied at the recommended rate as urea, di-ammonium phosphate (DAP), and muriate of potash (MOP). Organic fertilizers in BV, BM, and BCU treatments were applied in equal quantities. All biochar-amended treatments showed improved soil chemical properties with higher pH, organic carbon, total N, and available P and K compared to the two non-biochar control plots (CK and F).

Adamu and Junaidu (2021) investigate the effect of biochar and supplementary application of micronutrient on soil and growth of okra. Biochar and micronutrient at different rate were considered: control (0%), 4 t ha^{-1} biochar, 16 t ha^{-1} biochar, 4 t ha^{-1} biochar + 1 L ha^{-1} micronutrient, 16 t ha^{-1} biochar + ½ L ha^{-1} micronutrient, 4 t ha^{-1} biochar + ½ L ha^{-1} micronutrient and 16 t ha^{-1} biochar + ½ L ha^{-1} micronutrient. The experiments were laid out and the seven treatments arranged in a randomized complete block design (RCBD) and replicated three times. Biochar was drill into the first 5 cm of the soil. Micronutrient application was first done two (2) weeks after planting, and this was followed weekly. All soil samples collected were analyzed using standard laboratory soil analysis procedures. Results showed that 16 t ha^{-1} biochar significantly ($p < 0.05$) increased the percentage organic carbon, organic matter, cation exchange capacity, nitrogen, and pH of the soil.

De *et al.* (2020) found that all soil chemical characteristics analyzed were modified when the biochar was incorporated into the soil. The results provide valuable insight that okra growers can embrace the use of the combination BSS+RSS and BSS, providing better yields and lower water use in growing this plant.

Riaz *et al.* (2018) conducted an experiment to explore the impacts of sugarcane waste straw biochar on soil characteristics and some agronomic traits of okra. The experiment was carried out with four treatments, i.e., control, sugarcane waste straw biochar (10 t ha^{-1}), farmyard manure (FYM, 10 t ha^{-1}), and chemical fertilizers (NPK; 120:100:80 kg ha^{-1}) having three replications of each treatment. Soil samples were tested for texture, bulk density, particle density, pH, electrical conductivity (EC), organic matter content, nitrate nitrogen (NO_3^--N), and extractable-P. The sugarcane waste straw biochar was characterized for plant major nutrient elements. The impact of various treatments was observed on soils and agronomic traits of okra like plant height, fruit size, fruit length, and yield of okra. Results revealed that sugarcane waste straw biochar expressed higher EC value and noticeable amounts of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and magnesium (Mg). The sugarcane waste straw biochar, in comparison with FYM and NPK, significantly improved the NO_3^--N, extractable-P, OM and EC of the calcareous soil, and reduced the soil bulk density. Furthermore, plant growth and yield parameters were significantly improved under biochar application over the control, FYM and NPK. Overall, sugarcane waste straw biochar proved to be a good alternative to conventional organic and inorganic fertilizers under calcareous soil conditions.

Bishwoyog *et al.* (2015) conducted a field experiment at the Horticulture farm of Paklihawa Campus, Institute of Agriculture and Animal Science, Rupandehi district to observe the effect of biochar from different origin on physio-chemical properties of soil and yield of garden pea (*Pisum sativum* L.). The experiment was laid out in a Randomized Complete Block Design with four replications. A set up constituted of various treatments *viz.* rice husk biochar, poultry manure biochar and sheep manure biochar, farmyard manure biochar and wood biochar along with the control group). Biochar of poultry manure and of sheep manure had almost similar effect on soil nitrogen as of other types of biochar, while higher effect on soil phosphorus and potassium as compared to other biochar. Biochar of sheep manure had higher organic matter content and carbon percentage in soil than all other application of biochar. Application of all types of biochar showed highly significant results on bulk density and particle density. It was found that biochar of rice husk had greater particle density 2.61 g cm^{-3} and all the application had decreased bulk density except that of biochar prepared from wood. Thus, the soil where biochar was applied was used.

Remesh (2008) studied that the use of organic manures particularly biochar are the only option to improve the soil organic carbon for sustenance of soil quality and future productivity.

Chan (2007) conducted an experiment using poultry litter biochar as soil amendments. Two biochars produced from poultry litter under different conditions were tested in a pot trial by assessing the yield of radish (*Raphanus sativus* var. Long Scarlet) as well as the soil quality of a hard setting Chromosol (Alfisol). Four rates of biochar (0, 10, 25, and 50 t ha^{-1}), with and without nitrogen application (100 kg N ha^{-1}) were investigated. Biochar addition to the hard setting soil resulted in significant but different changes in soil chemical and physical properties, including increases in C, N, pH, and available P.

2.3 Effect of chemical fertilizer on growth and yield of okra

Khandaker *et al.* (2017) observed the effects of different application rates of inorganic fertilizers on growth, yield and quality of okra (*Abelmoschus esculentus L.*) under BRIS soil condition. The field experiment was conducted during July, 2014 to April, 2015 at the teaching and research farm of University Sultan Zainal Abidin (UniSZA), Besut Campus, Terengganu. Performance of okra variety Singa 979 was assessed by application of NPK at different rates 0 kg ha^{-1} (control), 150 kg ha^{-1}, 170 kg ha^{-1}, 190 kg ha^{-1} and 210 kg ha^{-1}. The treatments were fitted in a randomized complete block design (RCBD) and replicated thrice. Data collected for growth and yield performances included plant height, number of leaf $plant^{-1}$, leaf area, number of branch $plant^{-1}$, chlorophyll content, photosynthesis rate, transpiration rate, internal CO_2, stomatal conductance, number of flower $plant^{-1}$, number of pod $plant^{-1}$, weight of pod, number of seed pod^{-1} and total soluble solid (TSS) of the pods. Based on the results obtained from this experiment, application of NPK at the rates of 190 kg ha^{-1} and 210 kg ha^{-1} shows the highest growth and yield performance. It is followed by application of 170 kg ha^{-1} and 150 kg NPK ha^{-1} in decreasing manner. No application of NPK showed the lowest growth and yield response. The significance of this research was to study the minimum rate of NPK on the effect on okra ground around the seashore of Terengganu or in BRIS soil.

Choudhary *et al.* (2015) conducted a field experiment at Regional Horticultural Research Station, Navsari Agricultural University, Navsari (Gujarat) during rabi season of 2010 to assess the effect of chemical fertilizers along with biofertilizers on okra in terms of growth and yield. Among the different treatments maximum plant height (96.03 cm), pod weight (11.53 g), girth of pod (4.88 cm), yield $plant^{-1}$ (139.39 g) and yield ha^{-1} (10324.94 kg) were observed in treatment receiving *Azospirillum* 5 kg ha^{-1} + RD NPK. The plants under the treatment of PSB 5 kg ha^{-1} + RD NPK through chemical fertilizers had the highest length of pod (12.03 cm). Whereas the treatment of VAM 15 kg ha^{-1} + 75% P + 100% NK through chemical fertilizers had the highest number of pods $plant^{-1}$ (13.11). The study led to the conclusion that the maximum growth parameters, highest yield and yield attributing characters of okra could be achieved by judicious application of biofertilizers and chemical fertilizers.

Prasad and Naik (2013) conducted an experiment at Horticultural Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia in West Bengal during rabi season of 2007-08 with objectives to find out the suitable combination of biofertilizers (*Azotobacter*, *Azospirillium* and Phosphate Solubilizing Bacteria (PSB) in presence or absence of FYM (15 t ha^{-1}) and two levels of graded NPK fertilizers (80-60-50 and 40-30-25 N, P_2O_5, K_2O kg ha^{-1}) on the growth and fruit yield of okra cv. Arka Anamika (*Abelmoschus esculentus*) and the availability status of N, P and K in soil considering the growth, yield and quality parameters data revealed that significantly minimum height of plant was recorded by the application of PSB + FYM. In respect of plant height at 30 days, plant height at 60 days, number of branches, number of leaves, number of fruits, fruit length, fruit diameter, fruit yield per plot and fruit yield per ha were significantly maximum in the plant receiving 50% recommended dose of fertilizer (RDF) + *Azotobacte*r + *Azospirillum* + PSB + FYM with good yield (196.97 q ha^{-1}) and export fruit quality of okra.

Mubashir *et al.* (2010) evaluated the effects of N on the growth and nitrate accumulation of okra (*Hibiscus esculents* L. cv. *Sabz pari*) and carrot (*Daucus carota* L. cv. T_{29}). Treatments consisted of a control, 100, 150 and 200 kg N ha^{-1}. Significantly higher yields of carrot and okra were recorded at 150 kg N ha^{-1}. Nitrate concentration in both of the crops increased (> 35 to 200%) with increasing N. An excessive nitrate accumulation in both was recorded at 200 kg N ha^{-1}. Okra had 1.7 times higher nitrate accumulation than carrot. Early season okra had a significantly higher nitrate (~10%) than late season. Gross income and profitable return responded quadratically with increasing N. Results suggest that N fertilization of carrot and okra at 150 kg N ha^{-1} is optimum for economical yields with less accumulation of nitrate in vegetables.

2.4 Effect of chemical fertilizer on soil properties

Adekiya *et al.* (2019) conducted an experiment on the impact of different green manures and NPK 15-15-15 fertilizer on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus*). The experiment each year consisted of four green manure (GM) types of Pawpaw (*Carica papaya* L.) leaves, Neem (*Azadirachta indica*) leaves, Moringa (*Moringa oleifera*) leaves, and Mesquite (*Prosopis africana*) Taubert leaves, NPK 15-15-15 fertilizer and a control. The six treatments were arranged in a randomized complete block design with four replications. Application of GMs reduced soil bulk density and increased soil organic matter (OM), N, P, K, Ca, Mg, growth and yield of okra compared with the control. NPK fertilizer did not reduce soil bulk density and increase soil OM, but did increase soil N, P, K, Ca, Mg, growth and yield of okra compared with the control.

Gupta *et al*. (2019) conducted a field experiment to investigate the effect of organic manures *viz.* vermicompost and farmyard manure (FYM) in combination with inorganic fertilizers on yield, nutrient uptake by okra (*Abelmoschus esculentus* L.) and on soil biochemical properties in inceptisol for consecutive two years. The treatments were: T_1 = control; T_2 = 100% NPK alone; T_3 = 100% NPK + 5 t FYM ha^{-1}; T_4 = 100% NPK + 10 t FYM ha^{-1}; T_5 = 100% NPK + 5 t vermicompost ha^{-1}; T_6 = 100% NPK + 10 t vermicompost ha^{-1}. The highest yield of okra was recorded under T_6 during both the years. The treatments with the same quantity of vermicompost recorded higher yield in comparison to FYM. Application of vermicompost @ 10 t ha^{-1} (T_6) also increased N uptake over 100% NPK alone (T_2) by 64 and 68% by okra during both the consecutive years, respectively. The corresponding increase in P uptake was 108 and 88% whereas in case of K, it was 85 and 128%. The highest soil available N, P and K content was observed with T_6, as 300, 27.7 and 340 kg ha^{-1}. The treatment T_6 also increased organic carbon content over 100% NPK treated plots (T_2) by 61%.

Agbede *et al*. (2019) carried out a field experiments were during 2015 and 2016 cropping seasons to compare impacts of GM and NPK (15:15:15) fertilizer on soil properties, growth, fruit yield, mineral, lycopene and vitamin C contents of tomato (*Lycopersicon esculentum*). GMs were composed by green tender stems and leaves of pawpaw (*Carica papaya* L.), neem (*Azadirachta indica*), moringa (*Moringa oleifera*) or gliricidia (*Gliricidia sepium*) and applied at 5 Mg $ha^{−1}$, whereas NPK was applied at 300 kg $ha^{−1}$ and there was a no fertilizer plot (control). Application of GMs reduced soil bulk density and increased soil OM, N, P, K, Ca, Mg, growth, number of fruits and fruit yield of tomato compared with the control. NPK fertilizer had no effect on soil bulk density and soil OM, but it increased soil fertility and tomato yield as compared with the control. When comparing treatments, the highest tomato yield and best cost: benefit ratio were obtained with gliricidia as GM. The GMs and NPK fertilizer increased mineral, lycopene and vitamin C contents in tomato fruits and the highest K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents in tomato fruits were found with moringa as GM. Our results revealed that GM has potential to improve soil properties, tomato yield and quality, being an alternative for cropping management.

Shahbaz *et al*. (2019) investigated the growth response and yield production of okra fertilized with various combinations of bioslurry and nitrogen fertilizer. The experiment was planned according to randomized complete block design with 3 replications. Bioslurry was analyzed for its composition and was applied at the rate of 600 kg ha^{-1} along with 50%, 75%, and 100% of the recommended dose of N fertilizer for the production of okra. Phosphorus and potassium fertilizers were added according to recommended rates ha^{-1}. Compared to inorganic N alone, the application of bioslurry alongside NPK fertilizers applied at reduced rates significantly increased the okra fruit yield as a consequence of 14%, 31% enhanced plant height, 12% - 14% additional branches per plant, and 25% - 36% more fruits per plant. Moreover, bioslurry improved root length by 13% - 45%, which resulted in an increased N uptake by plants and improved N use efficiency. Their results also suggested that the application of bioslurry alongside reduced rates of N fertilizer is a viable strategy for the sustainable production of okra, especially under semiarid climatic conditions.

Abbas *et al*. (2019) examined the effect of different forms of fertilizers (organic and inorganic) on the yield and physiochemical attributes of okra (*Abelmoschus esculentus*). This experiment was laid out in the field area of soil and water testing laboratory for research, Bahawalpur in growing seasons from July to October of 2017. Treatments were arranged in two factorial Completely Randomized Block Design (CRBD) fashion with three replications and six treatments. Treatments are arranged as control T_1 (without fertilizer + no poultry manure + no compost), T_2 (NPK full dose of 150 kg ha^{-1} N, 75 kg ha^{-1} P and 60 kg ha^{-1} K), T_3 (full dose of poultry manure @ 30 t ha^{-1}), T_4 (50% NPK + 50% poultry manure *i.e.*, 75 kg ha^{-1} N, 37.5 kg ha^{-1} P and 30 kg ha^{-1} K + 15 t ha^{-1} PM), T_5 (full dose compost @ 30 t ha^{-1}), T_6 (50% NPK+ 50% compost i.e. 75 kg ha^{-1} N, 37.5 kg ha^{-1} P and 30 kg ha^{-1} K + 15 t ha^{-1} compost). Plants growth and yield parameters were determined like the total number of leaves $plant^{-1}$, plant height, fruit length, root and shoot dry weight, fresh fruit weight, the total number of fruits $plant^{-1}$, fruit yield and total yield increase. No significant increase was observed in the yield and growth of okra under control and full NPK fertilizer treatment. Application of organic fertilizers like poultry manure and compost as well as its mixture with full NPK considerably increase the growth and total yield attributes of okra.

Gupta *et al*. (2019) stated that the application of FYM @ 10 t ha^{-1} (T_4) recorded 15 and 17% increase in fruit yield of okra over 100% NPK (T_2) during 2012 and 2013, respectively, whereas vermicompost @ 10 t ha^{-1} (T_6) recorded 33 and 34% increased fruit yield. Furthermore, yield of okra obtained with 5 t vermicompost ha^{-1} plus 100% NPK (T_5) during both the years was at par with that received under 10 t FYM ha^{-1} plus 100% NPK (T_4) demonstrating superiority of vermicompost over FYM.

Sharma *et al*. (2019) conducted a field experiment at Plasticulture Farm, CTAE, MPUAT Udaipur to investigate the effect of chemical fertilizer scheduling on growth and yield performance of okra (*Abelmoschus esculentus* L.) under Sensor Based Automated Drip and Conventional Drip System. In this study four fertigation scheduling treatments of chemical fertilizer were taken. Recommended dose of chemical fertilizer N: P_2O_5:K_2O, 60:30:30 kg ha^{-1} were supplied through different chemical fertilizers like Urea, Urea Ammonium Phosphate (UAP) and Sulphate of potash (SOP) during the crop period. In this study the 40% and 60% of total recommended doses of fertilizer were applied during initial plus development stage and mid stage of crop growth respectively. The result revealed that the higher plant height and number of branch $plant^{-1}$ in fustigation treatments T_2 may be attributed to continuous supply and consequent availability of plant nutrients in the root zone during development and mid stage of crop growth. The highest pod yield of okra found under treatment T_2 with a value of 11 t ha^{-1}, in which fertigation of NPK at recommended dose (60:30:30 kg NPK ha^{-1}) in equal splits through water soluble chemical fertilizers at 4-day interval under sensor based automated drip system. It may be found because of that, under T_2 treatment (fertigation in equal splits through water soluble chemical fertilizers at 4-day interval) nutrient supplied through continuous fertigation till late stage of crop growth. Fertilizer use efficiency was also found higher in sensor-based drip irrigation treatments it was probably due to less leaching of irrigation water with chemical fertilizer because of frequent irrigation as $plant^{-1}$ need. In this study phosphorus and potassium were supplied to okra crop through chemical fertilizers UAP and SOP respectively, because of that there was no precipitate of fertilizers was observed during mixing.

Thingujam U *et al*. (2016) conducted a pot experiment was conducted in the net house of the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh to evaluate the influence of phosphorus (P) and sulfur (S) on major nutrient contents and their uptake by brinjal (cv. BARI brinjal-8) during the period from October, 2011 to May, 2012. The experiment was laid out in a completely randomized design with 12 treatments and 3 replications using four levels of P (0, 30, 60 and 90 kg P ha^{-1}) and three levels of S (0, 15 and 30 kg S ha^{-1}) along with the basal doses of urea, muriate of potash, boric acid, zinc oxide, cowdung and poultry manure. The study revealed that major nutrient contents and their uptake were significantly influenced by P and S interactions. They had positive significant effects on major nutrient contents and their uptake. Application of P increased N, P, K, Ca, Mg and S contents and their uptake up to 60 kg ha^{-1} and over the dose the values were reduced or near to control treatment. Similarly, the gradual increases of major nutrient contents and their uptake were found in S application up to 30 kg ha^{-1}. Among the treatments the combination of P @ 60 kg ha^{-1} and S @ 30 kg ha^{-1} showed the highest N, P, K, S, Ca and Mg contents and their uptake. The lowest values were found in control treatment.

Hasan *et al.* (2013) conducted a field experiment was carried out at the Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India to study the effects of integrated nutrient management on the nutrient accumulation (dry weight recoveries) in brinjal and plant nutrient status of the post-harvest soil of brinjal under Nadia conditions. The results revealed that the treatment consisting of 75% RDF (RDF *i.e.*, N: P: K: 125: 100: 50) + *Azospirillum* + phosphate solubilizing bacteria (PSB) + Borax @ 10 kg ha^{-1} recorded the highest oxidizable organic carbon (8.049 g kg^{-1}), total nitrogen (1.05 g kg^{-1}), available nitrogen (212.67 g kg^{-1}), available phosphorus (76.20 g kg^{-1}) and available potassium (177.59 g kg^{-1}) in the post- harvest soils of brinjal. On the other hand, 75% RDF+ *Azospirillum* + PSB + $FeSO_4$ @ 50 kg ha^{-1} recorded the highest available iron (26.14 kg ha^{-1}) and the treatment consisting of 75% RDF + *Azospirillum* + PSB+ $ZnSO_4$ @ 25 kg ha^{-1} recorded the highest soil available zinc (7.62 kg ha^{-1}) while 75% RDF + Azo + PSB + Borax @ 10 kg ha^{-1} recorded the highest oxidizable organic carbon (8.049 g kg^{-1}), total nitrogen (1.05 g kg^{-1}), available nitrogen (212.67 g kg^{-1}), available phosphorus (76.20 g kg^{-1}) and available potassium (177.59 g kg^{-1}) in the post-harvest soils of brinjal. On the other hand, 75% RDF + *Azospirillum* + PSB + $FeSO_4$ @ 50 kg ha^{-1} recorded the highest available iron (26.14 kg ha^{-1}) and the treatment consisting of 75% RDF + *Azospirillum* + PSB + $ZnSO_4$ @ 25 kg ha^{-1} recorded the highest soil available zinc (7.62 kg ha^{-1}) while 75% RDF + Azo + PSB + Borax @ 10 kg ha^{-1} recorded the highest available Boron content (0.78 kg ha^{-1}) of the post-harvest soil of Brinjal. Highest brinjal yield (14.96 t ha^{-1}) was supported by the treatment consisting of 75% RDF + *Azospirillum* + PSB + Boron @ 10 Kg ha^{-1}.

2.5 Combined effect of biochar and reduced doses of chemical fertilizer on growth and yield of okra

Sikdar *et al.* (2023) conducted a experiment at the net house of the Department of Agroforestry and Environmental Science, Sylhet Agricultural University, Sylhet to evaluate the influence of tea waste and sugarcane bagasse biochar on the morphology, yield and yield contributing traits of okra (Abelmoschus esculentus) in sandy soil. The experimental setup was arranged following randomized complete block design with three replications under eight treatments. The treatments were: T_0 (CK, Control, no amendment), T_1 (CF, Chemical fertilizers), T_2 (2.5 % TWB (tea waste biochar) + CF), T_3 (5% TWB + CF), T_4 (10% TWB + CF), T_5 (2.5% SBB (sugarcane Bagasse biochar) + CF), T_6 (5% SBB + CF); and T_7 (10% SBB + CF). The results revealed that the different morphological characteristics like plant height (PH), number of leaf plant^{-1} (NLP), leaf length (LL), plant fresh weight (PFW), and stem diameter (SD) showed no significant difference among the treatments. The highest PH (107.33 cm) and RL (70.67 cm) were found in T_0 (CK) whereas the maximum LL (27.33 cm), SD (16.83 mm), and fresh root weight (FRW) (19.67g) were noted in T_3. The maximum number of leaves plant^{-1} (NLP) (20) and PFW (110.67 g) of okra were observed in T_2 and T_6, respectively. In case of total leaf chlorophyll content (TLCC), the maximum value was determined in T_4 (47 µmol m^{-2}), but the treatments were not significantly different from each other. The number of pod plant^{-1} (NPP) (23.7), pod length (PL) (18 cm), individual pod weight (IPW) (18 g), number of seed pod^{-1} (NSP) (45) and pod weight per plant^{-1} (PWP) (425 g) of okra were found to be highest in T_7, followed by T_4 and T_6. The yield and yield contributing characters of okra showed significantly higher value for biochar treatments (T_2 - T_7) over to the control (T_0) and sole chemical fertilizer treatment (T_1). After the cultivation of okra, the highest pH value (7.2) was found in T_7, followed by T_6. The results of this study might contribute to enlarge the prospects of biochar application in the production of okra and other crops in both normal and less fertile soils.

Oluleye *et al.* (2023) conducted a field experiment to evaluate the effectiveness of NPK fertilizer fortified with biochar on the growth and yield performance of okra (*Abelmoschus esculentus* L.) relative to inorganic fertilizer. Treatments involved NPK only applied at 30 and 60 kg N ha^{-1}, NPK at 30 kg N ha^{-1} together with biochar at 2.5 t ha^{-1}, NPK at 60 kg N ha^{-1} together with biochar at 5 t ha^{-1} and a control treatment, without fertilizer or biochar application, laid out in a randomized complete block design with three replications. Growth and yield parameters, plant height, number of leaves, fruit yield, nutrient uptake, post-cropping effects on soil properties were determined. Growth and yields from the treatment with NPK at 60 kg N ha^{-1}, together with 5 t ha^{-1} biochar, were significantly ($p \leq 0.05$) highest, than other treatments, and partial budget analysis indicated highest marginal rate of returns for this treatment.

Gelaye (2023) conducted an experiment to investigate the effect of combined application of organic manure and nitrogen fertilizer rates on yield and yield components of potato. Combined application of nitrogen and organic manure fertilizer improved potato growth parameters and yield components (tuber number, average tuber weight). Tuber quality components such as dry matter and starch contents are also influenced by the combined application of nitrogen and organic manure. With the addition of high amount of organic manure with a certain level of nitrogen, fertilizer also gave the highest volume of marketable and total tuber yield. Based on the report of research works done in different parts of the world at different periods, an average of 31 t ha^{-1} of organic manure and 187.5 kg ha^{-1} of nitrogen fertilizer are the ideal combinations for the optimum yield of potato.

Ibrahim (2022) studied on the efficacy of biochar and NPK fertilizer on soil properties and yield of okra (*Abelmoschus esculentus* L.). A randomized complete block design (RCBD) was used involving four (4) biochar rates (5, 10, 15 and 20 t ha^{-1}) and four (4) NPK (20:10:10) fertilizer rates (0, 100, 150 and 200 kg ha^{-1}) arranged factorially in 4 × 4 treatment combinations. Rice husk was used to make biochar since it was readily available and accessible in the study location. Soil samples were collected at random locations on the field from two depths (0-15 cm and 15-30 cm) for analysis using standard procedure. Data were collected on plant height, number of leaves, number of branches, stem girth, days to 50% flowering, number of fruits $plant^{-1}$, fruit length, the weight of fruits and total yield. The result shows that biochar application at 20 t ha^{-1} produced the highest plant height (67.75 cm), number of leaves (31.42), number of branches (16.00), stem girth (2.44 cm), number of fruit $plant^{-1}$ (72.00), fruit length (14.33 cm), fruit weight (770.17 g) and total yield (855.74 kg ha^{-1}). Similarly, NPK at 200 kg ha^{-1} gave higher plant height (61.08 cm), number of leaves (26.75), number of fruit $plant^{-1}$ (57.00), fruit weight (560.50 g) and total yield (622.78 kg ha^{-1}). The combination of 150 kg ha^{-1} and 200 kg ha^{-1} NPK fertilizer with 20 kg ha^{-1} biochar produced the highest yield (938.89 and 934.45 kg ha^{-1}) of okra which was at par. It can therefore be recommended that farmers in the study area can use biochar at 20 t ha^{-1} and NPK fertilizer at 150 kg ha^{-1} for optimum production of the okra plant.

Adamu and Junaidu (2021) found that the effect of biochar and supplementary application of micronutrient on growth of okra. Data on growth parameters that were collected include plant height, leaf area and stem girth. Data was analyzed using analysis of variance (ANOVA). The result showed that, there is no significant ($p < 0.05$) difference on the vegetative growth parameters of the plant.

Sani *et al.* (2020) conducted an field experiment investigates the efficacy of *Trichoderma* and biochar co-application on tomato productivity, nutritional quality and soil health improvements under reduced N-P-K fertilizer application. The study comprised of five treatments: (i) standard application of N-P-K, (ii) 50% dose of N-P-K (control), (iii) *Trichoderma* + 50% dose of N-P-K, (iv) biochar + 50% dose of N-P-K and (v) biochar + *Trichoderma* + 50% dose of N-P-K. The growth, yield, and antioxidant properties of tomatoes, as well as their mineral composition, were analyzed. The results showed that the combined application of *Trichoderma* and biochar increased the growth attributes positively and produced 101.45% and 11.33% higher yield compared to half dose and standard dose of N-P-K, respectively. The combined application also elicited an increase in mineral contents, total soluble solids as well as bioactive molecules such as lycopene and ascorbic acid, thereby increased the nutritional and functional quality of the tomato fruits. Collectively, *Trichoderma* and biochar improved soil fertility, nutrient uptake and promoted the growth of rhizosphere fungal and bacterial populations, which combined resulted in higher tomato yields, antioxidants, and minerals. Therefore, the co-application of *Trichoderma* and biochar with a 50% dose of N-P-K can be considered an effective technique for the sustainable production of tomato with higher yield and superior quality.

Madan and Sanjeev (2016) investigated the effect of chemical and organic fertilizers on growth, flowering and yield of okra. The findings carried out on okra revealed that the combined application of two nutrients sources chemical fertilizers and organic fertilizer (VC) brought about the best results. It gave better vegetative growth, flowering and more yield of okra by saving 50% chemical fertilizers.

Another field experiment was carried out by Ullah *et al.* (2008) at the Horticultural Farm of Bangladesh Agricultural University (BAU), Mymensingh during the period from December 2004 to April 2005 to evaluate the effect of manures and fertilizers on the yield of brinjal. There were five treatments consisting of organic, inorganic and combined sources of nutrients, of which the combined treatment (60 % organic + 40% inorganic) showed the best performances. The maximum branching (20.1) with the highest number fruits plant^{-1} (15.2), fruit length (14.1 cm) and fruit diameter (4.3 cm) were found combined application of manures and fertilizers. The highest yield (45.5 t ha^{-1}) was also obtained from the combined application of organic and inorganic sources of nutrients. Application of mustard oil cake or poultry manure alone gave better performance compared to only chemical fertilizers. The organic matter content and availability of N, P, K and S in soil were increased by organic matter application. On the other hand, soil pH was increased with chemical application than organic.

2.6 Combined effect of biochar and reduced doses of chemical fertilizer on soil properties

Asri (2022) conducted a field experiment to determine the effects of biochar produced from tomato (*Solanum lycopersicum* L.) plant waste on soil fertility and nutritional status of the lettuce (*Lactuca sativa* L.) plant. For this purpose, the combined effect of five different doses of biochar (0, 10, 20, 30, and 40 t ha^{-1}) and three chemical fertilizers (control, half-dose NPK and full-dose NPK) were investigated. The research was conducted in two cultivation periods. Biochar was applied to the soil just in the first period. In the first period, applications increased electrical conductivity, organic matter content, total N, and concentration of available P, Zn, and Mn, and the exchangeable K and Mg in the soil. Biochar and chemical fertilizer applications positively affected the lettuce plant's N, P, and K concentrations. In the second period, concentrations of the available P, Fe, Zn, Mn, Cu and exchangeable Ca, Mg in soil, as well as the N, P, Ca, Mg, Zn, and Cu concentrations of the plant are higher compared to the first period. It was determined that biochar application alone was not sufficient for the nutrition of the lettuce plants, chemical fertilizers should be used additionally. In lettuce cultivation, half-dose NPK was recommended in addition to 30 t ha^{-1} biochar. As a result, it was determined that biochar produced from tomato plant waste was an effective soil improver material and might be an alternative source of K.

Ofori *et al.* (2021) assessed the effects of poultry litter biochar (PLB) and NPK fertilizer application on soil chemical properties and the yield of cabbage. Twelve treatments (control, 100% NPK, 50% NPK, 2.5 t ha^{-1} PLB, 2.5 t ha^{-1} PLB + 50% NPK, 2.5 t ha^{-1} PLB + 100% NPK, 5 t ha^{-1} PLB, 5 t ha^{-1} PLB + 50% NPK, 5 t ha^{-1} PLB + 100% NPK, 7.5 t ha^{-1} PLB, 7.5 t ha^{-1} PLB + 50% NPK, and 7.5 t ha^{-1} PLB + 100% NPK) were evaluated under field conditions in a randomized block design with three replications. Combined application of PLB and NPK fertilizer improved the soil chemical properties, growth, and yield of cabbage relative to the control and sole PLB treatments. Application of 5 t ha^{-1} PLB + 50% NPK increased the soil pH, soil organic carbon, available phosphorus, and cation exchange capacity by 26.6, 41.4, 296, and 78.7%, respectively, relative to the control. Moreover, 5 t ha^{-1} PLB + 50% NPK increased the cabbage yield by 73% compared with the control.

Karthikeyan *et al.* (2021) conducted a field experiment to evaluate the influence of organic manures *viz.*, Farm Yard Manure (FYM), Vermicompost, Biochar, Biochar composite on soil properties, growth and yield of bhendi, *Abelmoschus esculentus* in *Somayyanur* soil series of Madurai district, Tamil Nadu. The experiment was laid out in randomized block design (RBD) with eleven treatments and three replications during the summer season (March – June) 2021 with the inclusion of inorganic fertilizers based on soil test crop response (STCR) based recommendation. Application of biochar composite (5 t ha^{-1}) along with STCR based NPK (75% STCR) increased the total carbon content in soil by 0.538 %. This, in turn, increased the available nitrogen status to 295 and 244 Kg ha^{-1} at 40 and 70 DAS, respectively. Similarly, the available phosphorous (22.4, 19.3 Kg ha^{-1}) and potassium (344.70, 323.70 Kg ha^{-1}) status also showed a considerable increase with the same treatment. The yield attributes of bhendi *viz.*, fruit length, girth, weight, dry matter production and yield recorded maximum values of 15.23 cm, 6.93 cm, 21.56 g, 11.9 t ha^{-1} and 25.20 t ha^{-1} with the combined application of biochar composite and NPK. The findings revealed that 25 % STCR based NPK could be reduced with the application of 5 t ha^{-1} of biochar composite, which is economically an option besides promoting soil health.

A field experiment was conducted by Singh *et al.* (2019) at Vegetable Research Farm, Department of Horticulture (Vegetable and Floriculture), Bihar Agricultural University, Sabour during *Kharif* season of 2017 to explore the best integration of microbial inoculant, organic and chemical fertilizers with respect to improving physical and biological properties of soil and yield of okra by minimizing yellow vein mosaic virus. The experiment was laid out in randomized block design replicated thrice. The results indicated that the application of 25 % RDN through chemical fertilizer + 75 % RDN through vermicompost + *Azotobacter* + PSB (T_{16}) improved, chemical (pH, EC, O. C, Available N, P, K) and biological (*Azotobacter*, *PSB*, Fungi) properties of the soil, reduced the Per cent disease incidence was of YVMV and enhanced the yield of okra.

Thus, it can be inferred that the nutrient supply through 75% chemical and 25% through Vermicompost along with the use of biofertilizers *(Azotobacter* + PSB) is beneficial for improving the soil health, minimizing the YVMV and increasing the yield of okra.

CHAPTER III

MATERIALS AND METHODS

The experiment was carried out at Soil Science field, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, from November 2022 to January 2023. This contains a brief description of experimental site, soil, climate, planting material**,** treatments, experimental design, land preparation, intercultural operations, harvesting, data recording, collection and preparation of soil samples and the methods for the chemicals as well as statistical analysis.

3.1 Description of the experimental site

3.1.1 Experimental site

The experiment was conducted at Soil Science field, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, from November 2022 to January 2023. Geographically the experimental site was at 25°13' N latitude and 88°23' E longitude with an elevation of 37.5m above the mean of sea level (Appendix-I). The land belongs to the agro-ecological zone of Old Himalayan Piedmont Plain (AEZ-I).

3.1.2 Climate and weather

The experimental area belongs to a subtropical climatic zone. Heavy rainfall, high humidity, high temperature, and a relatively long day period are observed during Kharif season (April-September) and scarce rainfall and low humidity, low temperature, and short-day period during Rabi season (October-March). Weather information regarding air temperature (°C), rainfall (mm), relative humidity (%) at the experimental site during study period are presented in Appendix-II.

3.1.3 Soil

The soil of the experiment field belongs to the Old Himalayan Piedmont Plain (AEZ-1). The soil of the experimental plot was sandy with good drainage capacity. The experimental plot was medium high land with a pH value was 6.52. The soils of the experimental sites were analyzed before sowing of okra. The morphological, physical and chemical characteristics of the initial soil of the experimental field is presented in table 3.1.

Table 3.1 Morphological, physical and chemical characteristics of the research field

A. Morphological characteristics

Morphology	Characteristics
Location	Soil Science Field, HSTU, Dinajpur
AEZ	Old Himalayan Piedmont plain (AEZ-1)
General soil type	Non- calcareous brown floodplain soil
Parent material	Piedmont alluvium
Drainage	Well drained
Flood level	Above flood level

B. Physical characteristics

Sand (%)	45.6
Silt (%)	42.0
Clay (%)	12.4
Textural class	Sandy loam
Particle density (g cm^{-3})	2.0
Bulk density (g cm^{-3})	1.532

C. Chemical characteristics

Treatments	OC (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq 100 g^{-1} soil)	Available S (ppm)
T_1	0.51	0.04	22.11	0.11	8.21
T_2	0.70	0.06	44.50	0.16	14.8
T_3	0.74	0.05	46.23	0.37	16.25
T_4	0.72	0.05	46.03	0.37	15.67
T_5	0.70	0.05	57.26	0.31	12.5
T_6	0.66	0.06	34.22	0.17	12.23
T_7	0.68	0.06	32.56	0.21	18.1
T_8	0.67	0.07	42.60	0.14	13.97
T_9	0.66	0.06	45.90	0.25	13.39
T_{10}	0.67	0.05	35.13	0.20	14.28
T_{11}	0.65	0.05	38.93	0.21	14.47

3.2 Planting material

The crop of the experiment was okra (variety Heera). This variety was used during Rabi season (November to January). Seeds were collected from local market in Dinajpur district.

3.3 Experimental design and treatments

The experiment was laid out in the Randomized Complete Block Design (RCBD) having 11 treatments and 3 replications. The total number of plots was 33. The size of the plot was 1 square meter (1m × 1m). The treatment combinations were as follows:

T_1 = No residual biochar + No chemical fertilizer (Control)

T_2 = 100% Recommended Dose of Fertilizers (RDF)

T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar

T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar

T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched organic fertilizer

T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk Biochar

T_7 = 75 % RDF+ Residual 15 t ha^{-1} Sawdust biochar

T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched organic fertilizer

T_9 = 100% RDF+ Residual 10 t ha^{-1} Rice Husk Biochar

T_{10} = 100 % RDF + Residual 10 t ha^{-1} Sawdust biochar

T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched organic fertilizer

The recommended doses of fertilizer (RDF) for okra cultivation in the experiment were as follows (BARI Krishi Projukti Hatboi):

Fertilizer	Doses (kg ha^{-1})
Urea	150
TSP	100
MOP	150
Gypsum	40

3.4 Layout of the experimental plots

Total number of plots : 33

Individual plot size : 1 m^2 (1m × 1m)

Space between block to block : 50 cm

Space between plot distances : 25 cm

No. of treatment : 11

No. of replication : 3

The layout of the experimental field is shown in the figure 3.4.

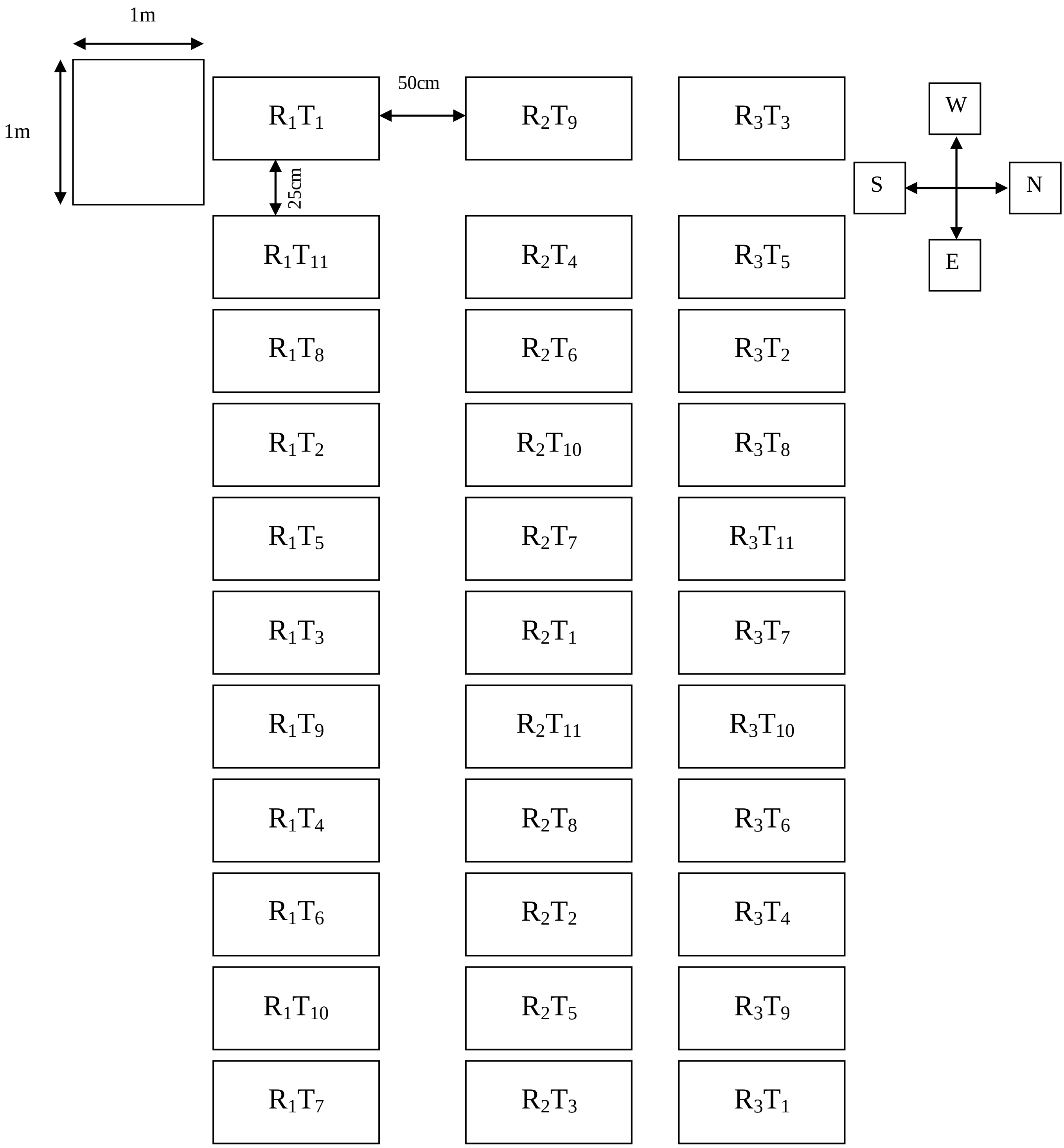


Fig. 3.4: Layout of the experiment

3.5 Biochar and fertilizer application:

Soybean was previously cultivated (mid-March to mid-July) in that land in which biochar application was done according to the above treatments. After that the land was barren for 2 to 3 months. Then the experiment was initially started by land preparation followed by fertilizer application. As there was previously biochar application, so there was a residual effect of biochar in the next crop. That's why, no biochar was used in this experiment, only residual effect was evaluated. In case of fertilizer, TSP, MOP and Gypsum were applied as basal dose during final land preparation except urea. Urea was applied in three split doses at 15, 30 and 45 DAS.

3.6 Land preparation

The land was prepared by spading several times and made a fine tilth condition. The plots units were made by laddering. Each block was divided into eleven plots as treatments with raised bound around. The unit plot size was $1m^2$ (1m × 1m). The distance between two blocks and two plots was 50 cm and 25 cm, respectively.

3.7 Seed sowing

Okra seeds were sown in the field at 10th November. Seed to seed spacing was maintained at 40 cm and row to row distance maintained 60 cm.

3.8 Intercultural operations

Intercultural operations were done as and when necessary to ensure normal growth of plant which are given below:

3.8.1 Weeding

The experimental plots were monitored, and weeding was done several times.

3.8.2 Irrigation

The plots were irrigated by the water pump whenever necessary.

3.8.3 Insect and pest control

The okra plants were infected with fungal diseases along with attack of aphids. To rescue the plants from this attack, several doses of fungicide and pesticides were applied. The experimental field was treated with Imitaf 20SL @ 2.5 ml. 10 L^{-1} water; Aristomil 55 EC@ 80ml. 20L^{-1} water; Rovlal 50 WP@ 20 ml. 10 L^{-1} for 3 times at 7days interval.

3.9 Procedure of data collection

As per objectives of the study the following data were collected:

- Plant height
- Number of fruits
- Length of fruits
- Weight of fruits
- Diameter of fruits
- Fresh weight of plants
- Dry weight of plants
- Root length
- Fresh weight of roots
- Dry weight of roots

3.9.1 Plant height

The plant height was recorded from the sample plants in centimeters from the ground level to the leaf at the top from the three tagged plant of each plot at 15 DAS, 30 DAS, 45 DAS, 60 DAS and 75 DAS and mean was calculated.

3.9.2 Number of fruits

The fruit number of okra plants were counted from the fruiting period to harvesting and mean was calculated.

3.9.3 Length of fruits

Length of fruits was measured after harvesting of each fruit and mean was calculated.

3.9.4 Weight of fruits

Weight of fruits was measured after harvesting of each fruit and mean was calculated.

3.9.5 Diameter of fruits

Diameter of fruits was measured after harvesting of each fruit and mean was calculated.

3.9.6 Fresh Weight of plant

Fresh weight of plants was measured after harvesting and mean was calculated.

3.9.7 Dry weight of plants

The plants were oven dried; the weight of plants was measured manually and mean was calculated.

3.9.8 Root length

The length of roots was measured after harvesting and mean was calculated.

3.9.9 Fresh weight of roots

Fresh weight of roots was measured after uprooting the plants and mean was calculated.

3.9.10 Dry weight of roots

Dry weight of roots was measured after oven drying the roots and mean was calculated.

3.10 Collection of soil sample

3.10.1 Initial soil sample

The initial soil sample was collected before land preparation from the plough depth layer (0-15 cm). 10 samples were taken by means of an auger from 10 locations covering the whole experimental plot and mixed thoroughly to make a composite sample. The composite sample was air dried, grinded and sieved through a 20 mesh sieve and stored in a plastic bag for physical and chemical analysis.

3.10.2 Post harvest soil sample

After harvesting the crop, samples were collected from each plot at 0-15 cm depth. The soil samples were air dried, grinded and sieved through a 20 mesh sieve. Prepared soil samples were stored in plastic bags for chemical analysis only.

3.11 Analysis of soil sample

The chemical properties of initial and post-harvest soil samples were analyzed in the laboratory of the Department of Soil Science, HSTU, Dinajpur. The soil chemicals properties *viz.*, pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and available sulfur were determined. Soil samples analysis were as follows:

3.11.1 Soil pH

Soil pH was determined using a glass electrode pH meter at 1:2.5, soil-water ratio. The suspension was allowed to stand for one hour with occasional shaking before determination (Jackson, 1967).

3.11.2 Organic matter (OM) content

Soil organic carbon content was determined volumetrically by wet oxidation method using $K_2Cr_2O_7$ and H_2SO_4 mixture and $FeSO_4$ solution was used for titration as outlined by Jackson (1967). The organic matter content was calculated by multiplying the percent organic carbon with Bemmelen factor of 1.724 (Piper, 1950).

3.11.3 Total nitrogen (N)

Soil N was determined was determined by Micro-Kjeldahl method (Bremner and Mulvaney, 1982). The Soil sample (1.0 g) was digested with 3 ml concentrated H_2SO_4 and 1.1 g catalyst mixture (K_2SO_4:$CuSO_4$. 5 H_2O: Se powder in a ratio 100:10:1). N was estimated by distillation with 40% NaOH followed titration distillate trapped in H_3BO_3 indicator solution with 0.01 N (Page *et al.,* 1989).

3.11.4 Available phosphorus (P)

Available P was extracted from the soil with 0.5 M sodium bicarbonate solution pH 8.5 (Olsen *et al.,* 1954). P in the extract was then determined by developing blue color with $SnCl_2$ reduction of phosphomolybdate complex and color intensity was measured calorimetrically at 660 nm wavelength (Page *et al.,* 1989).

3.11.5 Exchangeable potassium (K)

Exchangeable K was determined by the ammonium acetate extraction method using a flame photometer as described by Page *et al.*, (1989).

3.11.6 Available sulfur (S)

Available S was determined by extraction the soil sample with $CaCl_2$. The S content in the extract was estimated and the intensity of turbid was measured by spectrophotometer at 420 nm wavelength.

3.12 Statistical analysis

The data were presented as the mean value. Statistix 10 software was used to perform statistical analysis. One-way analysis of variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) was performed to determine significant differences among treatments. The values of $p < 0.05$ were considered as significant.

CHAPTER IV

RESULTS AND DISCUSSION

The results obtained from the present study are systematically presented in this episode under different captions following necessary discussion by taking proper support of the previous findings of the published works of others as accessible and the established scientific principles as well. Moreover, six tables have been added in this chapter to clarify the findings. Furthermore, three appendices have been included at the end of the thesis for further information as needed to highlight the findings.

4.1 Plant height

Significant variation was observed in plant height of okra at 15 DAS, 30 DAS, 45 DAS, 60 DAS and 75 DAS due to different level of residual biochar and reduced doses of chemical fertilizer application ($p < 0.01$) represented in table 4.1. At 15 DAS, the highest plant height (21.0 cm) was observed in T_8 treatment when 75% RDF and Residual 15 t ha^{-1} Biochar enriched OF applied which was statistically parallel to T_9 treatment (20.0 cm) and T_5 (19.5 cm). The lowest plant height (12.7 cm) was observed in T_1. At 30 DAS, the maximum plant height (29.8 cm) was noticed in T_5 treatment when 50% RDF and Residual 20 t ha^{-1} Biochar enriched OF applied which was statistically identical to T_6 treatment (29.3 cm), T_8 (28.8 cm), T_{10} (27.2 cm), T_4 (26.6 cm), T_3 (26.1 cm), and T_9 (26.1 cm) and minimum (17.06 cm) was found in T_1. At 45 DAS, the tallest plant height (48.7 cm) was recorded from T_{11} treatment when 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF applied which was closely followed by the T_8 (47.8 cm), T_{10} (47.03 cm), T_6 (46.4 cm), T_9 (45.3 cm), T_7 (44.7 cm) and T_5 (43.6 cm) treatment. On the other hand, the lowest plant height (27.7 cm) was observed in T_1 (control) which were statistically akin to T_2 (33.4 cm). At 60 DAS, the maximum plant height (57.0 cm) was observed in both T_{11} and T_{10} treatment when 100% RDF and Residual 10 t ha^{-1} biochar enriched OF (T_{11}) and 100 % RDF and Residual 10 t ha^{-1} Sawdust biochar (T_{10}) applied which alike to T_9 treatment (54.6 cm), T_8 (54.0 cm) and T_7 (54.0 cm) and the minimum plant height (34.8 cm) was perceived in T_1 (control) which was statistically akin to T_2 (39.6 cm). At 75 DAS, the topmost plant height (74.2 cm) was mentioned in T_{10} treatment when 100 % RDF and Residual 10 t ha^{-1} Sawdust biochar applied which was statistically same to T_{11} treatment (73.5 cm), T_9 (71.4 cm), T_7 (70.0 cm) and T_8 (70.0 cm) whereas least plant height (47.6 cm) was observed in T_1 (control) which was statistically akin to T_2 (50.4

cm). Among all the treatments T_{11} treatment was best of using 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF. Biochar ensure the physical condition of soil and it helped in good water holding capacity and good aeration in soil. So, the plant got maximum nutrition from the soil and healthy plant was grown with maximum production. Consistent result was found by Ibrahim (2018) that biochar application at 20 t ha^{-1} produced the highest plant height (67.75 cm).

4.2 No. of fruits $plant^{-1}$ of okra

A statistically significant variation was recorded in number of fruit $plant^{-1}$ of okra due to effect of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.2. The maximum number of fruit $plant^{-1}$ (16.6) was observed in T_{11} treatment when 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF applied which was statistically parallel to T_{10} (15.6) and T_9 (15.0) on the contrary minimum number of fruit $plant^{-1}$ (8.0) was found in T_1 (control). Contradictory result was found by Nosiru *et al.* (2012) that biochar application at 20 t ha^{-1} produced the highest number of fruit $plant^{-1}$ (72.0) because malvaceae crops do not bear fruits during winter and seasonal variation.

4.3 Marketable fruits weight $plant^{-1}$ and fruits weight $plot^{-1}$ of okra

Application of different level of residual biochar and reduced doses of chemical fertilizer responded significantly on the marketable fruit weight $plant^{-1}$ and fruit weight $plot^{-1}$ of okra ($p < 0.01$) shown in table 4.2. The highest marketable fruit weight $plant^{-1}$ (197.8 g) was obtained from T_{11} treatment when 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF applied which was closely similar to T_{10} (187.3 g) and lowest marketable fruit weight $plant^{-1}$ (36.9 g) was from T_1 (control). The maximum fruit weight $plant^{-1}$ (1.18 kg) was found in the treatment T_{11} when 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF applied which was statistically identical to T_{10} (1.12 kg). The minimum fruit weight $plant^{-1}$ (0.22 kg) was found in T_1 (control). Choudhary *et al*. (2015) found pod weight (11.53 g) and yield $plant^{-1}$ (139.39 g) which similar to my result.

4.4 Fruit length (cm) and fruit breadth (cm)

Insignificant variation was observed in fruit breadth of okra due to different level of residual biochar and reduced doses of chemical fertilizer application ($p > 0.05$) but significant variation was found in fruit length ($p < 0.01$) represented in table 4.3. The maximum fruit length (11.3 cm) was observed in T_{11} treatment when 100% RDF and Residual 10 t ha^{-1}

Biochar enriched OF applied which was identical to T_{10} treatment (10.5 cm). The minimum fruit length (6.6 cm) was observed in T_1 (control). The maximum fruit breadth (5.0 cm) was observed in T_2, T_{10} and T_{11} treatment which was statistically parallel to T_5 (4.8 cm), T_7 (4.7 cm), T_3 (4.6 cm), T_8 (4.6 cm), T_9 (4.3 cm) and T_6 (4.2 cm). The lowest fruit breadth (4.0 cm) was observed in T_1 and T_4 which was statistically parallel to T_6 (4.2 cm), T_9 (4.3 cm), T_8 (4.6 cm), T_3 (4.6 cm) and T_7 (4.7 cm). Ibrahim (2018) carried out a field experiment and showed that biochar application at 20 t ha^{-1} produced the highest fruit length of 14.33 cm.

4.5 Fresh shoot biomass $plant^{-1}$ and dry shoot biomass $plant^{-1}$ of okra

In case of fresh fruit biomass $plant^{-1}$ and dry shoot biomass $plant^{-1}$ of okra significant variation was observed due to of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) represented in table 4.3. The maximum fresh shoot biomass $plant^{-1}$ (181.5 g) was observed in T_{11} treatment when 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF applied which was statistically parallel to T_9 (177.0 g), T_{10} (176.4 g), T_8 (174.3 g), T_7 (170.8 g) and T_6 (161.4 g). The minimum fresh shoot biomass $plant^{-1}$ (96.6 g) was observed in T_1 (control) which was statistically akin to T_3 (111.3 g), T_4 (116.7 g) and T_5 (188.3 g). The highest dry shoot biomass $plant^{-1}$ (30.8 g) was noticed in T_{11} treatment when 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF applied which was nearly similar to T_9 (30.09 g), T_{10} (29.9 g), T_8 (29.6 g), T_7 (29.04 g) and T_6 (27.4 g). The lowest dry shoot biomass $plant^{-1}$ (16.4 g) was observed in T_1 (control) which was statistically akin to T_4 (19.8 g) and T_3 (18.9 g). Mengfei *et al.* (2023) found the same result.

Table 4.1: Effect of residual biochar with reduced doses of chemical fertilizers on plant height of okra at different days after sowing (DAS)

Treatments	Plant height (cm)				
	PH (15 DAS)	PH (30 DAS)	PH (45 DAS)	PH (60 DAS)	PH (75 DAS)
T_1	12.7 e	17.1 d	27.7 e	34.8 f	47.6 g
T_2	17.0 d	23.4 c	33.4 de	39.6 ef	50.4 fg
T_3	17.5 cd	26.1 abc	39.1 cd	44.4 de	55.3 ef
T_4	17.5 cd	26.6 abc	41.3 bc	48.0 cd	59.5 de
T_5	19.5 ab	29.8 a	43.6 abc	50.4 bc	62.3 cd
T_6	19.0 bc	29.3 a	46.4 ab	50.4 bc	66.5 bc
T_7	17.0 d	24.5 bc	44.7 abc	54.0 ab	70.0 ab
T_8	21.0 a	28.8 ab	47.8 ab	54.0 ab	70.0 ab
T_9	20.0 ab	26.1 abc	45.3 abc	54.6 ab	71.4 ab
T_{10}	18.5 bcd	27.2 abc	47.0 ab	57.0 a	74.2 a
T_{11}	18.2 bcd	26.6 abc	48.7 a	57.0 a	73.5 a
SEM	0.605	1.5	2.2	1.7	2.1
LS	**	**	**	**	**
CV	5.8	10.03	9.2	5.9	5.7

The data was presented as the mean value. PH=Plant Height; *= 5% Level of Significance; **= 1% Level of Significance; NS= Non-significant; CV= Coefficient of Variance.

In the column figures having a similar letter(s) do not differ significantly at 5% level of significance.

Treatment combinations were as follows
T_1 = No residual biochar + No chemical fertilizer, T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched OF , T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk Biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched OF, T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk Biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched OF.

Table 4.2: Effect of residual biochar with reduced doses of chemical fertilizers on no. of fruits plant^{-1}, marketable fruit weight plant^{-1} and fruit weight plot^{-1}

Treatments	No. of fruits plant^{-1}	Marketable fruit weight plant^{-1} (g)	Fruit weight plot^{-1} (kg)
T_1	8.0 e	36.9 h	0.22 h
T_2	14.0 bcd	149.1 c	0.89 c
T_3	12.1 d	74.8 g	0.45 g
T_4	13.0 cd	81.2 fg	0.49 fg
T_5	14.4 bc	82.2 fg	0.49 fg
T_6	14.3 bc	93.7 ef	0.57 ef
T_7	14.5 bc	104.7 e	0.62 e
T_8	14.0 bcd	123.6 d	0.74 d
T_9	15.0 abc	180.0 b	1.08 b
T_{10}	15.6 ab	187.3 ab	1.12 ab
T_{11}	16.6 a	197.8 a	1.18 a
SEM	0.724	5.00	0.03
LS	**	**	**
CV	9.09	7.2	7.2

The data was presented as the mean value. *= 5% Level of Significance; **= 1% Level of Significance; NS= Non-significant; CV= Coefficient of Variance.

In the column figures having a similar letter(s) do not differ significantly at 5% level of significance.

Treatment combinations were as follows

T_1 = No residual biochar + No chemical fertilizer (Control), T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched OF , T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk Biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched OF, T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk Biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched OF.

Table 4.3: Effect of residual biochar and reduced doses of chemical fertilizer on fruit length, fruit breadth, fresh shoot biomass plant $^{-1}$ and dry shoot biomass plant $^{-1}$ of okra

Treatments	Fruit length (cm)	Fruit breadth (cm)	Fresh shoot biomass plant^{-1} (g)	Dry shoot biomass plant^{-1} (g)
T_1	6.6 e	4.0 b	96.6 c	16.4 c
T_2	9.7 bc	5.0 a	125.4 b	21.3 b
T_3	8.3 d	4.6 ab	111.3 bc	18.9 bc
T_4	9.0 cd	4.0 b	116.7 bc	19.8 bc
T_5	8.8 cd	4.8 a	118.3 bc	20.1 bc
T_6	9.6bc	4.2 ab	161.4 a	27.4 a
T_7	9.5 bc	4.7 ab	170.8 a	29.04 a
T_8	9.8 bc	4.6 ab	174.3 a	29.6 a
T_9	10.1 b	4.3 ab	177.0 a	30.09 a
T_{10}	10.5 ab	5.0 a	176.4 a	29.9 a
T_{11}	11.3 a	5.0 a	181.5 a	30.8 a
SEM	0.360	0.277	7.8	1.3
LS	**	NS	**	**
CV	6.6	10.4	9.2	9.2

The data was presented as the mean value. *= 5% Level of Significance; **= 1% Level of Significance; NS= Non-significant; CV= Coefficient of Variance.

In the column figures having a similar letter(s) do not differ significantly at 5% level of significance.

Treatment combinations were as follows

T_1 = No residual biochar + No chemical fertilizer (Control), T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched OF, T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk Biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched OF, T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk Biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched OF.

4.6 Root length (cm)

In root length of okra significant variation was observed for the effect of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.4. In T_4 treatment he maximum root length (8.7 cm) was observed when 50% RDF and Residual 20 t ha^{-1} Sawdust biochar applied which was statistically parallel to T_3 (8.4) and T_5 (8.3) and T_1 (control) showed minimum root length (6.3 cm). Biochar promotes root growth by increasing soil K availability Cui *et al.* (2021) which is similar to my result.

4.7 Fresh root weight (g) and dry root weight (g)

Results from the Table (4.4) showed the significant variation in fresh root weight (g) and dry root weight (g) of okra due to the effect of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$). The maximum fresh root weight (5.7 g) was observed in T_3 treatment when 50% RDF and Residual 20 t ha^{-1} Rice Husk biochar applied on the contrary minimum (2.7 g) was from T_1 (control). Again, the maximum dry root weight (0.630 g) was observed in T_3 treatment when 50% RDF + Residual 20 t ha^{-1} Rice husk biochar applied and minimum (0.304 g) was found in T_1 (control). As for plant growth, slight increase induced by biochar was found in root weight, while shoot weight significant increased with biochar application at 7 and 10 DAS (Gibson, 2000).

4.8 Effect of residual biochar with reduced doses of chemical fertilizer on post-harvest soil

4.8.1 pH

There was a significant variation observed in pH as soil properties due to application of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.5. The topmost value of pH (7.31) was remarked in T_5 treatment because Biochar enriched OF tends to increase the soil pH compared to other biochar and lowest pH (6.21) was found in T_1 (control). The increasing order of pH was organized as followed T_1 (6.21) < T_2 (6.40) < T_{11} (6.70) < T_9 (6.83) < T_7 (6.85) <T_{10} (6.91) < T_8 (7.10) ~ T_4 (7.10) < T_3 (7.11) < T_6 (7.18) < T_5 (7.31). Biochar with its alkaline nature increases the soil pH and increases crop yield, alleviating the acid stress (Cornelissen *et al*. 2018).

4.8.2 Organic carbon (%)

Organic carbon showed a significant variation as soil properties due to application of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) which presented in table 4.5. The highest OC (0.64%) was observed in T_4 and T_5 treatment because biochar enriched OF and sawdust biochar contain more OC compared to other biochar and T_1 (control) mentioned the lowest OC (0.38%)). The increasing order of OC was T_1 (0.38) < T_2 (0.47) < T_9 (0.51) < T_{10} (0.53) < T_{11} (0.56) ~ T_7 (0.56) ~ T_6 (0.56) < T_8 (0.58) < T_3 (0.59) < T_5 (0.64) ~ T_4 (0.64). Soil organic carbon was found significantly higher in the biochar-amended soils compared to non-biochar (control) soil (Pandit, 2018).

4.8.3 Organic matter (%)

Significant variation was noted in OM as soil properties due to application of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.5. T_4 and T_5 treatment showed the most OM (1.11%) contained because biochar enriched OF and sawdust biochar contain more OC compared to other biochar whereas T_1 (control) contained least OM (0.66%). The increasing order of OM was T_1 (0.66) < T_2 (0.79) < T_9 (0.89) < T_{10} (0.92) < T_{11} (0.96) ~ T_7 (0.96) ~ T_6 (0.96) <T_8 (0.99) < T_3 (1.00) <T_5 (1.11) ~ T_4 (1.11). The combined application of crop residue and biochar reduced the turnover rate of soil organic matter by 2–5 times compared to the control no-biochar soil by Cheng *et al*. (2017).

4.9 Total N, available P, exchangeable K and available S of post- harvest soil

4.9.1 Total N

Significant variation was observed in soil properties containing total N, available P, exchangeable K and available S due to application of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.6. The highest total N content (0.058%) was found in T_5 treatment because biochar enriched organic fertilizer contain more nitrogen compared to other biochar and lowest total N content (0.022%) was from T_1 (control). The increasing order of total N content was T_1 (0.022) < T_9 (0.029) ~ T_2 (0.029) < T_{11} (0.036) ~ T_6 (0.036) ~ T_{10} (0.036) < T_8 (0.044) ~ T_7 (0.044) < T_4 (0.051) ~ T_3 (0.051) < T_5 (0.058). Soil nitrogen (N) has been found higher due to reduced leaching losses and retention of nitrogen in the pores of the biochar by Martisen *et al*. (2015).

4.9.2 Available P

Available P content in the post- harvest soil was influenced significantly in soil properties due to application of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.6. The highest available P content (34.96 ppm) was observed in T_4 treatment because sawdust biochar containd more phosphorus compared to other biochar. The lowest available P content (9.68 ppm) was found in T_1 (control). The increasing order of available P content is T_1 (9.68) < T_2 (12.45) < T_9 (13.43) < T_{10} (13.55) < T_{11} (13.79) < T_7 (18.56) < T_6 (20.33) <T_8 (21.93) < T_5 (32.61) <T_3 (33.37) < T_4 (34.96). Pandit (2018) reported that soil available P was found significantly higher in the biochar-amended soils compared to non-biochar (control) soil.

4.9.3 Exchangeable K

The exchangeable K content of the post-harvest soil was influenced significantly in soil properties due to application of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.6. The utmost exchangeable K content (0.306 meq 100 g^{-1} soil) was remarked in T_5 treatment because biochar enriched OF make more K available for plant compared to other biochar. On the other hand, lowest exchangeable K content (0.159 meq 100 g^{-1} soil) was from T_1 (control). The increasing order of K content was T_1 (0.159) < T_9 (0.193) < T_2 (0.198) < T_{10} (0.200) < T_{11} (0.205) < T_7 (0.218) < T_8 (0.222) <T_6 (0.232) < T_4 (0.271) <T_3 (0.281) < T_5 (0.306). Pandit (2018) reported that the soil exchangeable K was found significantly higher in the biochar-amended soils compared to non-biochar (control) soil.

4.9.4 Available S

There was a significant variation observed in soil properties containing available S due to application of different level of residual biochar and reduced doses of chemical fertilizer ($p < 0.01$) shown in table 4.6. The highest available S content (15.82 ppm) was observed in T_4 treatment because sawdust biochar contain more S compared to other biochar. The lowest available S content (6.57 ppm) was found in T_1 (control). The increasing order of S was T_1 (6.57) < T_2 (9.72) < T_9 (10.60) < T_{10} (11.57) < T_{11} (12.09) ~ T_6 (12.09) < T_7 (12.35) < T_8 (13.40) < T_5 (15.12) < T_3 (15.57) < T_4 (15.82).

Table 4.4: Effect of residual biochar with reduced doses of chemical fertilizers on root length, fresh root weight and dry root weight of okra

Treatments	Root length (cm)	Fresh root weight (g)	Dry root weight (g)
T_1	6.3 e	2.7 j	0.304 j
T_2	7.3 d	3.0 i	0.333 i
T_3	8.4 ab	5.7 a	0.630a
T_4	8.7 a	5.3 b	0.583 b
T_5	8.3 ab	5.1 bc	0.561 bc
T_6	7.9 bcd	4.9 cd	0.546 cd
T_7	8.0 bc	4.7 de	0.524 de
T_8	8.0 bc	4.5 e	0.502 e
T_9	7.8 dbc	4.2 f	0.465 f
T_{10}	7.5 cd	3.4 h	0.374 h
T_{11}	7.6 cd	3.9 g	0.431 g
SEM	0.089	0.089	0.01
LS	**	**	**
CV	4.8	3.5	3.5

The data was presented as the mean value. *= 5% Level of Significance; **= 1% Level of Significance; NS= Non-significant; CV= Coefficient of Variance.

In the column figures having a similar letter(s) do not differ significantly at 5% level of significance.

Treatment combinations were as follows

T_1 = No residual biochar + No chemical fertilizer (Control), T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched OF , T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched OF, T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched OF.

Table 4.5: Effect of residual biochar with reduced doses of chemical fertilizers on pH, organic carbon and organic matter of post- harvest soil

Treatments	pH	OC (%)	OM (%)
T_1	6.21 h	0.38 h	0.66 h
T_2	6.40 g	0.47 g	0.79 g
T_3	7.11 c	0.59 b	1.00 b
T_4	7.10 c	0.64 a	1.11 a
T_5	7.31 a	0.64 a	1.11 a
T_6	7.18 b	0.56 d	0.96 d
T_7	6.85 e	0.56 d	0.96 d
T_8	7.10 c	0.58 c	0.99 c
T_9	6.83 e	0.51 f	0.89 f
T_{10}	6.91 d	0.53 e	0.92 e
T_{11}	6.70 f	0.56 d	0.96 d
SEM	0.017	0.002	0.005
LS	**	**	**
CV	3.5	0.93	0.93

The data was presented as the mean value. *= 5% Level of Significance; **= 1% Level of Significance; NS= Non-significant; CV= Coefficient of Variance.

In the column figures having a similar letter(s) do not differ significantly at 5% level of significance.

Treatment combinations were as follows

T_1 = No residual biochar + No chemical fertilizer (Control), T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched OF, T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched OF, T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched OF.

Table 4.6: Effect of residual biochar with reduced doses of chemical fertilizer on total N, available P, exchangeable K and available S of post- harvest soil

Treatments	Total N (%)	Available P (ppm)	Exchangeable K (meq 100/ g soil)	Available S (ppm)
T_1	0.022 f	9.68 i	0.159 j	6.57 h
T_2	0.029 e	12.45 h	0.198 h	9.72 g
T_3	0.051 b	33.37 b	0.281 b	15.57 ab
T_4	0.051 b	34.96 a	0.271 c	15.82 a
T_5	0.058 a	32.61 c	0.306 a	15.12 b
T_6	0.036 d	20.33 e	0.232 d	12.09 de
T_7	0.044 c	18.56 f	0.218 f	12.35 d
T_8	0.044 c	21.93 d	0.222 e	13.40 c
T_9	0.029 e	13.43 g	0.193 i	10.60 f
T_{10}	0.036 d	13.55 g	0.200 h	11.57 e
T_{11}	0.036 d	13.79 g	0.205 g	12.09 de
SEM	0.001	0.193	0.001	0.199
LS	**	**	**	**
CV	3.5	1.6	0.81	2.8

The data was presented as the mean value. *= 5% Level of Significance; **= 1% Level of Significance; NS= Non-significant; CV= Coefficient of Variance.

In the column figures having a similar letter(s) do not differ significantly at 5% level of significance.

Treatment combinations were as follows

T_1 = No residual biochar + No chemical fertilizer (Control), T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched OF , T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched OF, T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched OF.

CHAPTER V

SUMMARY AND CONCLUSIONS

The research work was conducted in the research field of the Department of Soil Science, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during November to January 2022 (Rabi season) to study the residual effects of biochar with reduced doses of chemical fertilizers on the soil properties, growth and yield response of okra. The experimental soil belongs to the Old Himalayan Piedmont Plain (AEZ-1). The experiment was laid out in a Randomized Complete Block Design (RCBD). There were eleven (11) treatments with three replications in the experiment. So, the total numbers of plots were 33. The unit plot size was 1m × 1m (1 m^2). The treatments were T_1 = No residual biochar + No chemical fertilizer (Control), T_2 = 100% RDF (Recommended Dose of Fertilizers), T_3 = 50% RDF + Residual 20 t ha^{-1} Rice Husk biochar, T_4 = 50% RDF + Residual 20 t ha^{-1} Sawdust biochar, T_5 = 50% RDF + Residual 20 t ha^{-1} Biochar enriched OF , T_6 = 75% RDF + Residual 15 t ha^{-1} Rice Husk biochar, T_7 = 75 % RDF + Residual 15 t ha^{-1} Sawdust biochar, T_8 = 75% RDF + Residual 15 t ha^{-1} Biochar enriched OF, T_9 = 100% RDF + Residual 10 t ha^{-1} Rice Husk biochar, T_{10} = 100% RDF + Residual 10 t ha^{-1} Sawdust biochar, T_{11} = 100% RDF + Residual 10 t ha^{-1} Biochar enriched OF.

The whole required amounts of TSP, MOP, Gypsum were applied as basal dose during final land preparation and Urea fertilizer applied in 3 split doses. Seeds were sown on the November, 2022 in the field. The crop was allowed to grow until maturity and intercultural operations such as weeding, thinning, gap filling and irrigation were done whenever required in order to support normal growth of the plant. Plot wise growth and yield components were recorded. Soil samples were collected before fertilizers application and after harvest. Initial and post-harvest soil samples were analyzed for physical and chemical properties of soil using the standard methods. The statistical analysis was done by using statistics 10 software. One-way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) was performed to determine significant differences among treatments. The values of $p < 0.05$ were considered as significant.

The result revealed that the growth and yield components such as plant height, number of fruit $plant^{-1}$, marketable fruit weight $plant^{-1}$, fruit weight $plot^{-1}$, fruit length, fresh shoot biomass $plant^{-1}$, dry shoot biomass $plant^{-1}$, root length, fresh root weight, dry root weight except fruit breadth significantly influenced by the different treatments.

At 15 DAS, the highest plant height (21.0 cm) was observed in T_8 treatment. The lowest plant height (12.7cm) was observed in T_1 treatment. At 30 DAS, the highest plant height (29.8 cm) was observed in T_5 treatment when 50% RDF and Residual 20 t ha^{-1} Biochar enriched OF applied which was statistically parallel to T_6 treatment (29.3 cm). The lowest plant height (17.06 cm) was observed in T_1. At 45 DAS, the highest plant height (48.7 cm) was observed in T_{11}. The lowest plant height (27.7 cm) was observed in T_1 (control). At 60 DAS, the highest plant height (57.0 cm) was observed in both T_{11} and T_{10} treatment. The lowest plant height (34.8 cm) was observed in T_1 (control). At 75 DAS, the highest plant height (74.2 cm) was observed in T_{10} treatment when 50% RDF and Residual 10 t ha^{-1} Sawdust biochar applied which was statistically similar to T_{11} treatment (73.5 cm), T_9 (71.4 cm), T_7 (70.0 cm) and T_8 (70.0 cm). The lowest plant height (47.6 cm) was observed in T_1 (control) which was statistically akin to T_2 (50.4 cm). The maximum number of fruit $plant^{-1}$, marketable fruit weight $plant^{-1}$, fruit weight $plot^{-1}$, fruit length, fresh shoot biomass $plant^{-1}$, dry shoot biomass $plant^{-1}$(16.6, 197.8 g, 1.18 g, 11.3 cm, 181.5 g and 30.8 g respectively) was noticed in T_{11} treatment on the contrary least (8.0, 36.9 g, 0.22 g, 6.6 cm, 96.6 g and 16.4 g, respectively) was from T_1 treatment. In fruit breadth insignificant variation was observed. The highest fruit breadth (5.0 cm) was remarked in T_{10} and T_{11} treatments and lowest (4.0 cm) from T_1 and T_4 treatments. The most root length (8.7 cm) from T_4 and lowest (6.3 cm) from T_1. The maximum fresh root weight and dry root weight (5.7 g and 0.630 g) observed in T_3 treatments and lowest (2.7 g and 0.304 g) from T_1 treatment.

Application of biochar with reduced doses of chemical fertilizers resulted in a considerable influence on the properties of the post-harvest soils such as total N content, available P, exchangeable K and available S. In post-harvest soil application of chemical fertilizers gave positive result. The total higher levels of N, available P, exchangeable K and available S (0.058 %, 34.36 ppm, 0.306 meq 100 g^{-1} soil, 15.82, respectively) were found in T_4 and T_5 treatment and lowest (0.022 %, 9.68 ppm, 0.159 meq 100 g^{-1} soil, 6.57 respectively) was in T_1 treatment. Soil pH was highest (7.31) in T treatment and lowest (6.21) was in T_1 treatment. Again, highest OM and OC (1.11 and 0.64) was observed in both T_4 and T_5 treatment whereas lowest (0.66 and 0.38) was found in T_1 treatment.

Considering the overall results of this experiment it was observed that cultivation of okra in the field having residual effect of biochar with using chemical fertilizer gives better yield and growth compared to the field without residual effect of biochar.

Based on the results of the present study, following conclusion and recommendation may be drawn:

Conclusions:

1. The growth and yield contributing characteristics of okra were found significant due to the residual effects of biochar with reduced doses of chemical fertilizers.
2. Application of 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF (T_{11}) was suitable for higher yield (1.18 kg) of okra in AEZ-1.
3. Post-harvest soil properties revealed that the highest nutrient status (N, P, K, S) was found in T_4 and T_5 treatments.

Recommendation:

It can be recommended that farmers in the study area can use 100% RDF and Residual 10 t ha^{-1} Biochar enriched OF for optimum production of the okra plant and further study can be conducted to evaluate more information with this combination in different location.

REFERENCES

Abbas Z, Mubashir M, Riaz U, Javid Z, Ashraf M, Qamar MJ, Zulqadar SA and Mehdi SM. 2019. Combined Impacts of Compost, Poultry Manure and NPK Fertilizers on Yield of Okra Plant (*Abelmoschus esculentus* L.). Pakistan Journal of Agricultural Research. 32(3).

Acharya N, Vista SP, Shrestha S, Neupane N and Pandit NR. 2022. Potential of Biochar-Based Organic Fertilizers on Increasing Soil Fertility, Available Nutrients, and okra Productivity in Slightly Acidic Sandy Loam Soil. Nitrogen 2023. 4: 1–15.

Adamu MB and Junaidu UG. 2021. Effect of biochar and supplementary application of micronutrient on soil and growth of okra in Lafia, Nigeria. International Journal of Environmental Agricultural Biotechnology. 6(1):1-6.

Adeboye OC and Oputa CO. 1996. Effects of galex on growth and fruit nutrient composition of okra (*Abelnurschus esculentus*). Journal of Agriculture. 18(1 and 2): 1-9.

Adekiya AO, Agbede TM, Aboyeji CM, Dunsin O and Ugbe JO. 2019. Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus* L.). Journal of the Saudi Society of Agricultural Sciences. 18(2):218-223.

Agbede TM, Adekiya AO, Ale MO, Eifediyi EK and Olatunji CA. 2019. Effects of green manures and NPK fertilizer on soil properties, tomato yield and quality in the forest-savanna ecology of Nigeria. Experimental Agriculture. 55(5): 793-806.

Akpa AJ, Jayeoba OJ and Dauda WP. 2019. Growth and Development Response of Okra (*Abelmoschus esculentus* L.) to combine Application of Cow Dung and Biochar. International Journal of Agricultural Sciences and Veterinary Medicine. *7*.

Annon.1993. Pod development and germination studies in okra (*Abelmoschus esculentus* L.). Indian Journal Agricultural Science. 41(10): 852-856.

Asri FO. 2022. Effects of biochar and fertilizer application on soil properties and nutrient status of lettuce. Chilean journal of agricultural research. 82(3): 469-483.

Azman NANMN, Khalid PIM, Amin NAS, Zakaria ZY, Zainol MM, Ilham Z, Phaiboonsilpa N and Asmadi M. 2023. Effects of biochar, compost, and composted biochar soil amendments on okra plant growth. Materials Today: Proceedings.

Bailis R, Ezzati M and Kammen DM. 2005. Mortalityand greenhouse gas impacts of biomass and petrolium energy futures in Africa. Science. 308(5718): 98-103.

Bakry AB, Elkramany MF, Elewa TA and Ibrahim OM. 2015. Evaluating the role of Biochar application under two levels of water requirements on wheat production under sandy soil conditions. Global Journal of Advanced Research. 2(2): 411-418.

BBS. 2019. Monthly Statistical Bulletin of Bangladesh. Bangladesh Bureau of Statistics, Ministry of Planning. Government of People's Republic of Bangladesh, Dhaka. 42.

Bishwoyog A, Neupane J, Dhakal SP, Nepal J, Gnyawali B, Timalsina R and Poudel A. 2015. Eeffect of Biochar from Different Origin on Physio-Chemical Properties of Soil and Yield of Garden Pea (*Pisum sativum* L.) at Paklihawa, Rupandehi, Nepal. World Journal of Agricultural Research .3: 129-138.

Bremner JM and Mulvaney CS. 1982. Methods of soil analysis. Nitrogen-Total. Part 2.2nd edition. Agronomony Monographs. 9. ASA and SSSA, Madison. 595-624.

Chan K, Van Zwieten YL, Meszaros I, Downie A and Joseph S. 2007. Using Poultry Litter Biochars as Soil Amendments. Australian Journal of Soil Research. 46:437-444.

Chan KY and Xu Z. 2009. Biochar: Nutrient properties and their enhancement. In: Biochar for environmental management: science and technology. 67-84.

Cheng H, Hill PW, Bastami MS, Jones DL. 2017. Biochar stimulates the decomposition of simple organic matter and suppresses the decomposition of complex organic matter in a sandy loam soil. Global Change Biological Bioenergy. 9: 1110–1121.

Choudhary K, More SJ and Bhanderi DR. 2015. Impact of biofertilizers and chemical fertilizers on growth and yield of okra (*Abelmoschus esculentus* L.). The ecoscan. 9 (1 and 2): 67-70.

Cornelissen G, Jubedah N, Hale SE, Martinsen V, Silvani L and Mulder J. 2018. Fading Positive Effect of Biochar on Crop Yield and Soil Acidity during Five Growth Seasons in an Indonesian Ultisol. Science of the Total Environment. 634: 561–568.

Cui Q, Xia J, Yang H, Liu J and Shao P. 2021. Biochar and effective microorganisms promote Sesbania cannabina growth and soil quality in the coastal saline-alkali soil of the Yellow River Delta, China. Science of the Total Environment. 756: 143801.

De Freitas MI, Lucas AAT and Gonzaga MIS. 2020, May. Biochar and Its Impact on Soil Properties and on the Growth of Okra Plants. In Colloquium Agrariae. ISSN: 1809-8215 16 (2): 29-39.

Dimande P, Arrobas M and Rodrigues MA. 2023. Effect of Bat Guano and Biochar on Okra Yield and Some Soil Properties. Horticulturae. 9(7):728.

Gelaye Y. 2023. Effect of combined application of organic manure and nitrogen fertilizer rates on yield and yield components of potato: A review. Cogent Food and Agriculture. 9(1): 2217603.

Gemede HF. 2015. Nutritional quality and health benefits of okra (*Abelmoschus esculentus*): A review on: Journal of Food Processing and Technology. 6(6):1000458.

Gibson SI. 2000. Plant sugar-response pathways: part of a complex regulatory web. Plant Physiology. 124: 1532-1539.

Gupta R, Swami S and Rai AP. 2019. Impact of integrated application of vermicompost, farmyard manure and chemical fertilizers on okra (*Abelmoschus esculentus* L.) performance and soil biochemical properties. International Journal of Chemical Studies. 7: 1714-1718.

Hammond J, Shackley S, Prendergast Miller M, Cook J, Buckingham S and Pappa VA. 2013. Biochar field testing in the UK: Outcomes and implications for Use. Carbon Manag. 4: 159-170.

Ibrahim II, Yaroson AY, Lawal IH, Idris JA and Goma AA. 2018. Growth and yield characteristics of *Abelmoschus esculentus* L. (Okra). Influenced by application of poultry manure and NPK fertilizers on the Jos Plateau. International Journal Innovative Science Research in Technology. 3(10).

Ibrahim II. 2022. Efficacy of Biochar and NPK Fertilizer on Soil Properties and Yield of Okra (*Abelmoschus esculentus* L.) in Guinea Savanna Region of Nigeria. Journal of Environmental Bioremediation and Toxicology. *5*(1): 6-10.

Islam MA. 2002. Integrated nutrient management with inorganic fertilizers, organic manures and crop residues in wheat-Mungbean-T. aman cropping pattern. M. S. Thesis (Semi-Jan-June) Department of Soil Science., Bangladesh Agricultural University. Mvmensingh.

Jackson ML. 1967. Soil Chemical Analysis. Prentice Hall of India (Pvt.) Limited, New Delhi, India. 41-55.

Julie M. 2010. Guidelines on Practical Aspects of Biochar Application to Field Soil in Various Soil Management Systems. 1-23.

Karthikeyan B, Saliha BB, Kannan P and Vellaikumar S. 2021. Effect of biochar composite and organic sources on soil properties and yield of bhendi (*Abelmoschus esculentus* L.). Journal of Applied and Natural Science.13(4):1198-1205.

Khandaker MM, Nor MF, Dalorima T, Sajili MH and Mat N. 2017. Effect of different rates of inorganic fertilizer on physiology, growth and yield of okra (*'Abelmoschus esculentus'*) cultivated on Bris soil of Terengganu, Malaysia. Australian Journal of Crop Science.11(7): 880-887.

Khetran R Kasi, MA, Agha, SAH Fahmud, S and Ali J .2016. Effect of different doses of NPK fertilizer on growth of okra (*Abelmoschus esculentus* L.). International Journal of Advanced Research in Biological Science. 3 (10):213-218.

Kumar DS, Kumar AP, Kumar KA, Srinivasa Rao, DB and Nadendla R. 2013. A review on: *Abelmoschus esculentus* (okra). International Research Journal of Pharmaceutical and Applied Sciences. 3(4): 129–132.

Lehmann J and Rondon M. 2005. Biochar soil management on highly-weathered soils in the humid tropics. In: N. Uphoff (ed.). Biological Approaches to Sustainable Soil Systems, Boca Raton, CRC Press. 123.

Madan L and Sanjeev K. 2016. Effect of chemical and organic fertilizers on growth, flowering and yield of okra (*Abelmoschus esculentus* L.) cv. Arka Anamica. Agriways. 4(1):69-72.

Maramag R. 2013. Diuretic potential of *Capsicum frutescens* Linn., *Corchorus oliturius* Linn., and *Abelmoschus esculentus* L. Asian Journal of Natural and Applied Sciences.

2(1): 60–69.

Markose BL and Peter KV .1990. Okra. Review of research on vegetable and Tuber crops. Technical Bulletin 16. Kerala Agricultural University Press Mannuthy, Kerala. 109.

Martinsen V, Mulder J, Shitumbanuma V, Sparrevik M, Børresen T and Cornelissen G. 2015. Farmer-led Maize Biochar Trials: Effect on Crop Yield and Soil Nutrients under Conservation Farming. Journal of Plant Nutrition. Soil Science. 177: 681–695.

Mengfei C, Yang H, Xia S, Han Y, Guangling Y, Guangmu T, Shuhuang C, Wanli X and Hongtao J. 2023. Long-term effects of biochar application on the growth and physiological characteristics of maize. Front plant science .14: 218-223.

Mubashir M, Malik SA, Khan AA, Ansari TM, Wright S, Brown MV and Islam KR. 2010. Growth, yield and nitrate accumulation of irrigated carrot and okra in response to nitrogen fertilization. Pakistan Journal of Botany. 42(4): 2513-2521.

Mutezo WT. 2013. Early crop growth and yield responses of maize (*Zea mays*) to biochar applied on soil. International Working Paper Series. 13(3): 50.

Nosiru MO, Banjo JOS and Adedeji TO. 2012. Determinants of Improved Productivity of Okra (*Abelmoschus esculentus*) by farmers in lowland areas of Ogun State, Nigeria. American-Eurasian Journal of Agricultural Environmental Science. 12(12): 1572-1578.

Ofori P, Asamoah G, Amoah B, Agyeman KOA and Yeboah E. 2021. Combined application of poultry litter biochar and NPK fertilizer improves cabbage yield and soil chemical properties. Open Agriculture. 6(1): 356-368.

Olsen SR, Cole CV, Watanable FS and Dean LA. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. United States Department of Agriculture.929.

Oluleye AK, Ogunlade MO and Adewoyin OB. 2023. Response of okra (*Abelmoschus esculentus* L.) to biochar derived from cocoa pod husk and NPK fertilizer. Tropical Agriculture. 100(1): 11-19.

Onwuka MI and Nwangwu BC. 2016. Roles of biochar produced from animal and plant wastes on okra (*Abelmoschus esculenta*) growth in Umudike area of Abia State, Nigeria Journal of Agriculture and Sustainability. 9(2).

Page AL, Miller RH and Keeney DR. 1989. Methods of soil analysis: Part 2 (2nd edition). American Society of Agronomy, Wisconsin, USA.

Pandit NR, Mulder J, Hale SE, Zimmerman R, Pandit BH and Cornelissen G. 2018. Multi-year Double Cropping Biochar Field Trials in Nepal: Finding the Optimal Biochar Dose through Agronomic Trials and Cost-Benefit Analysis. Science of the Total Environment. 637–638: 1333–1341.

Piper CS. 1950. Soil and Plant Analysis. Adelaide University Press, Adelaide, Australia.

Prasad PH and Naik A. 2013. Effect of varying NPK levels and bio-fertilizers on growth and yield of okra (*Abelmoschus esculentus* L.) under sustainable condition. Trends in Biosciences. 6(2): 167-169.

Rashid MM. 1999. Sabji Biggan. Rashid Publishing House, 94, old DOHS, Dhaka1206. 466-470.

Reddy TP, Swaroop N, Thomas T and Barthwal. 2022. Effect of biochar with NPK on morphological parameters and biochemical constituents of okra (Abelmoschus *esculentus*).

Remesh P. 2008. Organic farming research in M.P. organic farming in rain fed agriculture: Central Institute from dry Land agriculture, Hyderabad. 13- 17.

Riaz M, Khan M, Ali S, Khan MD, Ahmad R, Khan MJ and Rizwan M. 2018. Sugarcane waste straw biochar and its effects on calcareous soil and agronomic traits of okra. Arabian Journal of Geosciences. 11: 1-7.

Sani MNH, Hasan M, Uddain, J and Subramaniam S. 2020. Impact of application of Trichoderma and biochar on growth, productivity and nutritional quality of tomato under reduced NPK fertilization. Annals of Agricultural Sciences. 65(1):107-115.

Seth T, Chattopadhyay A, Dutta S, Hazra P and Singh B. 2017. Genetic control of yellow vein mosaic virus disease in okra and its relationship with biochemical parameters. Euphytica. 213: 30.

Shahbaz M, Akhtar MJ, Ahmed W and Wakeel A. 2014. Integrated effect of different N-fertilizer rates and bioslurry application on growth and N-use efficiency of okra (*Hibiscus esculentus* L.). Turkish Journal of Agriculture and Forestry. 38(3):.311-319.

Sharma V, Singh PK, Yadav KK, Lakhawat SS and Bhakar SR. 2019. Effects of chemical fertilizer scheduling on performance of okra (*Abelmoschus esculentus* L.) crop under soil moisture sensor based automated drip and conventional drip irrigation system. International Journal of Chemical Studies. 7(4): 3189-3191.

Sikdar A, Zaman N, Deb S, Chakma N and Sharif MO. 2023. Effect of Co-application of Different Biochars and Inorganic Fertilizers on the Growth and Yield of okra (*Abelmoschus esculentus* L.) in sandy soil. Journal of Agroforestry and Environment. 16(2): 20-27.

Singh BK, Verma RB, Singh M, Sah AK and Kumari M. 2019. Effect of integrated use of bio-inoculants, organic and chemical fertilizers on soil microbial population, soil properties and incidence of pathogens on okra (*Abelmoschus esculentus* L.). Journal of Pharmacognosy and Phytochemistry. 8(6): 1722-1726.

Sorapong B. 2012. Bamija (*Abelmoschus esculentus* L.) kao vazna povrtarska vrsta u svetu *Okra* (*Abelmoschus esculentus* L.) as a valuable vegetable in the world. Ratarstvo i Povrtarstvo. 49(1): 105–112.

Thakur MR and SK Arora. 1986. Okra. In: Vegetable Crops in India, ed. TK Bose and MG Som, Naya Prokash, Calcutta P. 606.

Tindall HD. 1988. Vegetables in the Tropics. MacMillan Education Ltd., London. 325-328.

Ullah MS, Islam MS, Islam MA and Haque T. 2008. Effects of organic manures and chemical fertilizers on the yield of brinjal and soil properties. Journal of the Bangladesh Agricultural University. 6(452-2016-35507).

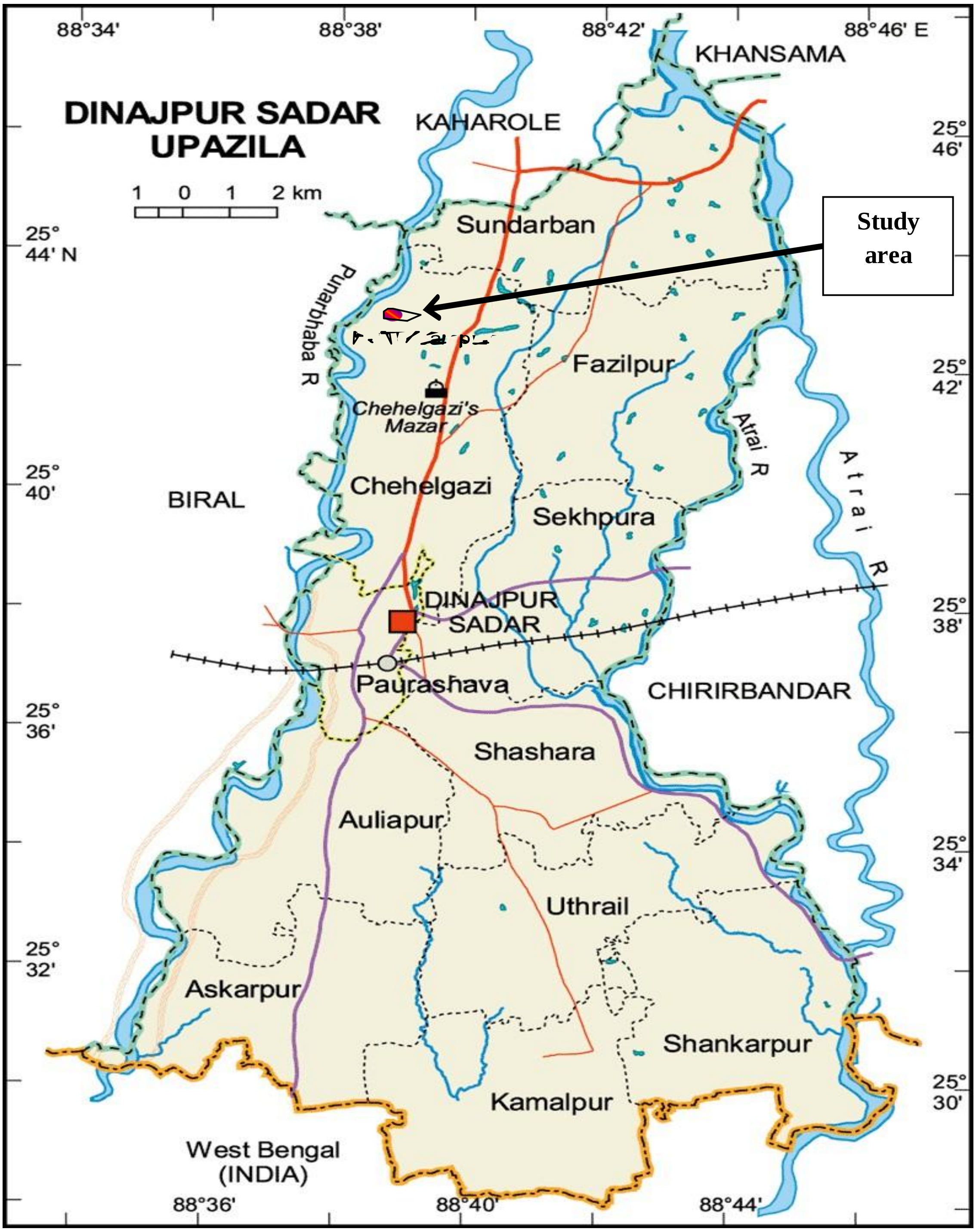
Yakubu A, Danso EO, Arthur E, Kugblenu-Darrah YO, Sabi EB, Abenney-Mickson S, Ofori K and Andersen MN. 2020. Rice straw biochar and irrigation effect on yield and water productivity of okra. Agronomy Journal. 112(4): 3012-3023.

Yamato M, Okimori Y, Wibowo IF, Anshori S and Ogawa M. 2006. Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. Soil Science. Plant Nutrition. 52(4): 489-495.

Zhang A, Liu Y, Pan G, Hussain Q, Li L, Zheng J and Zhang X. 2012. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. Plant and Soil. 351 (1-2): 263-275.

APPENDICES

Appendix I . Location of the experimental site (map of Dinajpur Sadar Upazila showing the research site)



Appendix II: Monthly records of average air temperature, relative humidity, rainfall and sunshine during the experimental period (November 2022 to January 2023)

Month	**Temperature (°C)	*Relative humidity (%)	*Rainfall (mm)	**Sunshine (hrs)
November	24	73.25	4.0	8.5
December	22	72.05	3.2	7.2
January	22	75.62	5.5	8.4

**=Monthly Average,*=Monthly Total

Source: Weather yard, Bangladesh Wheat and Maize Research Institute (BWMRI), Nashipur, Dinajpur

Appendix III: Some photographs during research period