

**SEED BACTERIZATION AND BIOCHAR AMENDMENT FOR  
OKRA-AMARANTHUS CROPPING SEQUENCE IN  
ONATTUKARA SANDY PLAINS**

**By  
HARSHITHA S.  
(2023-11-039)**

**THESIS**

**Submitted in partial fulfilment of the  
requirements for the degree of**

**MASTER OF SCIENCE IN AGRICULTURE**

**Faculty of Agriculture  
Kerala Agricultural University**



**DEPARTMENT OF AGRONOMY  
COLLEGE OF AGRICULTURE  
VELLAYANI, THIRUVANANTHAPURAM – 695 522  
KERALA, INDIA  
2026**

**DECLARATION**

I, hereby declare that this thesis entitled "**Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani

Date: 27/01/2026



**Harshitha S.**

(2023-11-039)

**CERTIFICATE**

Certified that this thesis entitled “Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains” is a record of research work done independently by Ms. Harshitha S. (2023-11-039) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani

Date: 27.01.2026



**Dr. Atul Jayapal**

(Major Advisor, Advisory Committee)

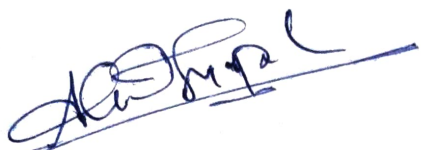
Assistant Professor (Agronomy)

College of Agriculture, Vellayani

Thiruvananthapuram – 695 522

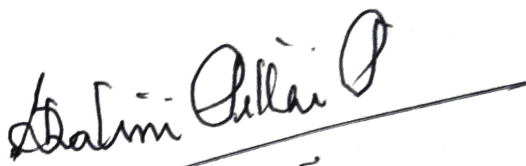
## CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Harshitha S. (2023-11-039), a candidate for the degree of Master of Science in Agriculture with major in Agronomy, agree that the thesis entitled “**Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains**” may be submitted by Ms. Harshitha S. (2023-11-039) in partial fulfilment of the requirement for the degree.



**Dr. Atul Jayapal**

(Major Advisor, Advisory Committee)  
Assistant Professor (Agronomy)  
College of Agriculture, Vellayani  
Thiruvananthapuram – 695 522



**Dr. Shalini Pillai P.**

Professor and Head (Agronomy) and  
Associate Director of Research, RARS (SZ)  
College of Agriculture, Vellayani  
Thiruvananthapuram – 695 522



**Dr. Anith K. N.**

Professor (Microbiology)  
Director of Research  
Kerala Agricultural University  
Thrissur – 680 656



**Dr. Mini V.**

Associate Professor (SSAC) and  
Project Director and Head  
ORARS, Kayamkulam  
Alappuzha – 690 502

## ACKNOWLEDGEMENT

*I extend my profound gratitude to the **Gods** for their constant grace, guidance, and protection throughout this work. Without such blessings, the successful completion of this research would not have been possible.*

*I express my deepest gratitude to my Major Advisor, **Dr. Atul Jayapal**, Assistant Professor, Department of Agronomy, for his invaluable guidance, continuous support, and insightful advice, which greatly shaped the direction and quality of this research. His understanding, encouragement, and motivation have been a constant source of inspiration throughout my academic and professional journey. I am particularly thankful for his willingness to clarify even my seemingly little doubts without hesitation, making me feel valued and supported at every stage. His unwavering belief in my abilities transformed my perspective, from once doubting the idea of pursuing further studies to aspiring to become a passionate researcher and scholar. The exceptional patience he extended to me is truly commendable, and I feel privileged to have been under his mentorship. For all his guidance, generosity, and faith in my potential, I extend my heartfelt gratitude.*

*I sincerely extend my gratitude towards **Dr. Shalini Pillai P.**, Professor and Head, Department of Agronomy; **Dr. Anith K. N.**, Professor (Microbiology) and Director of Research, KAU and **Dr. Mini V.**, Associate Professor (SSAC), ORARS, Kayamkulam, the members of my Advisory Committee, for their timely advice, insightful comments and valuable suggestions, which greatly enhanced the quality of my research work.*

*I express my heartfelt thanks and respect to all the faculty members of the **Department of Agronomy** for their constant encouragement and support throughout my coursework. I also wish to express my sincere gratitude to the faculty members of the **Department of Agricultural Microbiology** for their guidance and the facilities extended to me during the coursework.*

*I wish to convey my sincere gratitude to the faculty members, **Dr. Poornima Yadav P. I.** and **Mr. Anoop Krishnan**; farm officers, **Angitha chechi**, **Allen chettan** and **Sreyas**; non-teaching staffs, **Rehana chechi**, **Parvathy chechi** and **Bijin chettan**; and the **farm labourers** from ORARS, Kayamkulam, for their wholehearted cooperation and timely assistance in the successful execution of my field experiments and laboratory analysis.*

*I also acknowledge the support provided by non-teaching staffs, **Shibu chettan** and **Pradeep chettan** from the Department of Agronomy and **Vigi chechi** from the Department of Agricultural Microbiology, for their timely help and technical assistance in managing laboratory procedures during the course of my research work.*

*I am grateful to my seniors **Deepthi chechi**, **Sneha chechi**, **Anjali chechi**, **Kavya chechi**, **Amitha chechi**, **Ancy chechi**, **Sujith chettan** and **Surya chechi** for their valuable guidance and willingness to share their knowledge and experience, which greatly helped me during the course of my research.*

*I am extremely grateful to my friends **Anjaly**, **Aliya**, **Nashwa**, **Sana**, **Gouri**, **Athira**, and **Ameesha** for their constant encouragement, understanding, and companionship throughout this journey.*

*I am also thankful to my batchmates **Aparna**, **Gunasundhari**, **Sona**, **Amrutha**, **Gokul**, **Joel**, **Athul**, **Shiyas** and all others for their support and cooperation throughout the course of my study.*

*I am grateful to **Kerala Agricultural University** for providing the contingency grant and to the **Government of Kerala** for the scholarship, both of which were crucial in completing this research work.*

*No words can adequately express my heartfelt regards to my beloved parents. I am deeply indebted to my father, **Narayana Naik P.**, and my mother, **Yogitha C. H.**, for their boundless love, sacrifices, and constant encouragement, which have sustained me throughout this journey. Their unwavering belief in me has given me the strength to overcome challenges. This achievement is as much theirs as it is mine. I am equally grateful to my brother, **Goutham**, for his unwavering support. I am also thankful to have my **cats** by my side, whose comforting presence and playful companionship brought me joy throughout this journey.*

*I am also grateful to **all those whose names are not mentioned** here but have contributed in various ways to the successful completion of this work.*

*Finally, I am grateful to **myself** for the perseverance and self-belief that kept me committed to completing this research. I am equally grateful for the resilience, motivation, and determination that sustained me through the most demanding phases of this journey.*

**Harshitha S.**

**TABLE OF CONTENTS**

<b>Sl. No.</b>	<b>CHAPTERS</b>	<b>Page No.</b>
1	INTRODUCTION	1
2	REVIEW OF LITERATURE	3
3	MATERIALS AND METHODS	18
4	RESULTS	31
5	DISCUSSION	57
6	SUMMARY	72
7	REFERENCES	76
	ABSTRACT	
	APPENDICES	

## LIST OF TABLES

Table No.	Title	Page No.
1a	Mechanical composition of soil of the experimental site	19
1b	Chemical and biological properties of soil before the experiment	19
2	Methods of plant analysis	29
3	Effect of seed bacterization and biochar amendment on the growth attributes of okra	33
4	Effect of seed bacterization and biochar amendment on RGR, CGR, root depth, and root volume of okra	34
5	Effect of seed bacterization and biochar amendment on yield attributes of okra	36
6	Effect of seed bacterization and biochar amendment on yield and harvest index of okra	37
7	Effect of seed bacterization and biochar amendment on quality parameters of okra fruit	39
8	Effect of seed bacterization and biochar amendment on uptake of N, P, and K by okra, kg ha <sup>-1</sup>	41
9	Effect of seed bacterization and biochar amendment on soil parameters after the harvest of okra	42
10	Effect of seed bacterization and biochar amendment on available N, P, and K of soil after the harvest of okra, kg ha <sup>-1</sup>	44
11	Effect of seed bacterization and biochar amendment on microbial population of soil after the harvest of okra, log CFU g <sup>-1</sup> soil	45
12	Residual effect of seed bacterization and biochar amendment on yield attributes of amaranthus	47
13	Residual effect of seed bacterization and biochar amendment on uptake of N, P, and K by amaranthus, kg ha <sup>-1</sup>	48
14	Residual effect of seed bacterization and biochar amendment on soil parameters after the harvest of amaranthus	50
15	Residual effect of seed bacterization and biochar amendment on available N, P, and K in soil after the harvest of amaranthus, kg ha <sup>-1</sup>	51
16	Residual effect of seed bacterization and biochar amendment on microbial population of soil after the harvest of amaranthus, log CFU g <sup>-1</sup> soil	52
17	Effect of seed bacterization and biochar amendment on okra equivalent yield	54
18	Effect of seed bacterization and biochar amendment on economics of cultivation	56

**LIST OF FIGURES**

<b>Sl. No.</b>	<b>Title</b>	<b>Between pages</b>
1	Weather data during the crop season from January – May 2025	19 – 20
2	Layout of the experimental field	21 – 22
3	Effect of seed bacterization and biochar amendment on the height of okra plants	58 – 59
4	Effect of seed bacterization and biochar amendment on number of leaves per plant	58 – 59
5	Effect of seed bacterization and biochar amendment on leaf area index	60 – 61
6	Effect of seed bacterization and biochar amendment on relative growth rate	60 – 61
7	Effect of seed bacterization and biochar amendment on crop growth rate	60 – 61
8	Effect of seed bacterization and biochar amendment on root volume	60 – 61
9	Effect of seed bacterization and biochar amendment on number of fruits per plant	62 – 63
10	Effect of seed bacterization and biochar amendment on fruit yield per plant	62 – 63
11	Effect of seed bacterization and biochar amendment on fruit yield per ha	64 – 65
12	Effect of seed bacterization and biochar amendment on harvest index	64 – 65
13	Effect of seed bacterization and biochar amendment on crude fibre of okra fruits	64 – 65
14	Effect of seed bacterization and biochar amendment on uptake of N, P, and K by okra	64 – 65

15	Effect of seed bacterization and biochar amendment on WHC of soil after the harvest of okra	66 – 67
16	Effect of seed bacterization and biochar amendment on available N, P, and K of soil after the harvest of okra	66 – 67
17	Effect of seed bacterization and biochar amendment on microbial population of soil after the harvest of okra	68 – 69
18	Residual effect of seed bacterization and biochar amendment on uptake of N, P, and K by amaranthus	68 – 69
19	Residual effect of seed bacterization and biochar amendment on available N, P, and K in soil after the harvest of amaranthus	70 – 71
20	Effect of seed bacterization and biochar amendment on economics of cultivation	70 – 71

**LIST OF PLATES**

<b>Sl. No.</b>	<b>Title</b>	<b>Between pages</b>
1	Geographic location of the experimental field	19 – 20
2	Preparation of the experimental field	23 – 24
3	Incorporation of FYM and biochar	23 – 24
4	Intercultural operation in okra	23 – 24
5	General view of okra field	25 – 26
6	Land preparation for sequential crop of amaranthus	25 – 26
7	General view of sequential crop of amaranthus	25 – 26

**LIST OF APPENDICES**

<b>Sl. No.</b>	<b>Title</b>	<b>Appendix No.</b>
1	Weather parameters during the experimental period (January 2025 – May 2025)	I
2	Average cost of inputs and market price of produce	II

### LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations / symbols	Expansion
%	Per cent
₹	Indian rupee
±	Plus-minus sign
°C	Degree Celsius
°E	Degree east
°N	Degree north
ANOVA	Analysis of Variance
BCR	Benefit cost ratio
CD (0.05)	Critical difference at 5 % level
CEC	Cation exchange capacity
CFU	Colony forming units
CGR	Crop growth rate
cm	Centi metre
cm <sup>2</sup>	Square centimetre
cm <sup>3</sup>	Cubic centimetre
cmol (+) kg <sup>-1</sup>	Centimoles of positive charge per kilogram
d <sup>-1</sup>	Per day
DAS	Days after sowing
dS m <sup>-1</sup>	Deci siemens per metre
EC	Electrical conductivity
<i>et al.</i>	Co-workers/ Co-authors
Fig.	Figure
FYM	Farm yard manure
g	Gram
g <sup>-1</sup>	Per gram
h	Hour
ha	Hectare
ha <sup>-1</sup>	Per hectare
IAA	Indole-3-acetic acid
K	Potassium

K <sub>2</sub> O	Potassium oxide
KAU	Kerala Agricultural University
kg	Kilogram
kg ha <sup>-1</sup>	Kilogram per hectare
LAI	Leaf area index
m	Metre
m <sup>2</sup>	Metre square
m <sup>-2</sup>	Per metre square
Max.	Maximum
mg	Milli gram
Min.	Minimum
mL	Milli litre
mm	Milli metre
N	Nitrogen
No.	Number
NS	Not significant
OC	Organic carbon
ORARS	Onattukara Regional Agricultural Research Station
P	Phosphorus
P <sub>2</sub> O <sub>5</sub>	Phosphorus pentoxide
PGPR	Plant growth-promoting rhizobacteria
pH	Potenz hydrogen
POP	Package of practices
RBD	Randomised block design
RDN	Recommended dose of nutrients
RGR	Relative growth rate
SEm	Standard error of mean
t	Tonnes
t ha <sup>-1</sup>	Tonnes per hectare
var.	Variety
<i>viz.</i>	Namely
WHC	Water holding capacity

# *Introduction*

---

## 1. INTRODUCTION

The soil of the Onattukara region has been classified as a problem soil in Kerala primarily due to its sandy loam texture, characterised by high porosity and coarse particles, along with low levels of organic matter and essential nutrients. The soil is acidic in nature, poor in nutrient reserves, and shows low water holding capacity and cation exchange capacity with deficiencies in potassium, calcium, and magnesium (Mini and Mathew, 2015). As a result, agricultural productivity in the region remains a challenge without appropriate soil amendments and water management strategies. Onattukara region follows a cropping system where two crops of rice are followed by sesame/vegetables/pulses. During summer, there is potential for raising a crop of okra followed by a short duration crop of amaranthus. Biochar, a carbon-rich product made by pyrolysis of biomass, has emerged as a viable amendment for such problem soils. Biochar has a lower bulk density, higher porosity and higher water holding capacity, making it a suitable material for water and nutrient management (Punnoose and Anitha, 2015). When incorporated in soil, biochar provides various benefits, like increase in yield, water and nutrient use efficiency and other environmental benefits. Several studies have reported improved crop growth and soil properties upon biochar application. Tender coconut husk is now becoming an agricultural waste in Kerala. Only a fraction of this agro-waste is effectively utilised by composting or using it as mulch in coconut gardens. Biochar produced from tender husk is reported to have several benefits in crop production.

Plant growth-promoting bacteria are a promising alternative to commercial fertilisation. Integration of microbial inoculants such as plant growth-promoting rhizobacteria (PGPR) with biochar enhances soil fertility and crop productivity by preventing fertiliser runoff, leaching, and enhancing moisture retention. *Bacillus pumilus*, thrives in a wide range of environments, promotes growth in several crops and shows resistance to abiotic stresses. *Bacillus amyloliquefaciens* has positive effects on yield of tomato (Gul *et al.*, 2008) and can be suggested as a bio-fertiliser to minimise fertiliser application. *Bacillus velezensis* is known to produce Indole-3-acetic acid (IAA) and siderophores, thereby improving plant growth.

Consequently, the present study was proposed with the following objectives:

- Assessment of seed bacterization and biochar amendment on the growth and yield of okra.
- Analysing the residual effect of treatments on the sequential crop of amaranthus in Onattukara.

# *Review of Literature*

## 2. REVIEW OF LITERATURE

Onattukara region in Kerala has sandy loam soils and is characterised by very low organic matter, low water holding capacity, poor nutrient retention and cation exchange capacities and several nutrient deficiencies. All these factors hinder sustainable crop production. Biochar has gained attention as a promising soil amendment in these areas due to its ability to enhance soil structure, water holding capacity and nutrient retention, and provide a favourable habitat for beneficial microorganisms, ultimately leading to increased crop productivity (Saxena *et al.*, 2013; Punnoose and Anitha, 2015). Plant growth-promoting rhizobacteria (PGPR), especially Bacteria, plays a pivotal role in improving plant growth through mechanisms such as solubilization of nutrients, phytohormone production, and stress tolerance (Kumar *et al.*, 2020; Dobrzynski *et al.*, 2022). The combined use of biochar and PGPR has been reported to enhance soil fertility, uptake of nutrients and crop productivity while reducing leaching losses (Malik *et al.*, 2022). Therefore, a review of existing studies on biochar and *Bacillus* spp. provides a basis for understanding their potential in enhancing the productivity of okra-amaranthus cropping sequence in sandy soil. The literature related to the effect of seed bacterization and biochar on crop growth, yield, and soil properties are presented in this chapter.

### 2.1 EFFECT OF BIOCHAR ON CROP AND SOIL

#### 2.1.1 Effect of Biochar on Growth Attributes

Plant growth due to the effect of biochar varies with soil, type of biochar, crops grown, fertiliser application and cultivation system. Cong *et al.* (2023) had reported that the application of biochar in sandy soils had significantly increased the height, root biomass, stems and leaves, of maize compared to the control. On the contrary, Gairhe *et al.* (2024) opined that the application of biochar obtained from different feedstocks had no significant increase in plant height of okra. Vikram (2024) reported that application of tender coconut husk biochar on okra at 5 t ha<sup>-1</sup> along with 5 t ha<sup>-1</sup> farm yard manure (FYM) and 100 per cent recommended dose of fertilisers (RDF) had significantly increased the growth attributes like height of the plant, number of leaves per plant, root depth and root volume compared to control plants. Madaki *et al.* (2025)

had also observed taller plants, with higher number of leaves, and leaf area in okra applied with rice husk biochar.

Higher number of branches per plant and leaves per plant was observed in amaranthus supplied with biochar along with the recommended dose of NPK (Punnoose and Anitha, 2017). Anwar *et al.* (2021) found that the sole application of wheat straw biochar on okra increased the plant height by 30 per cent and root length by 23 per cent compared to the control. Biochar loaded with nitrogen and biofertiliser produced the highest leaf area index (LAI), total dry matter, and crop growth rate (CGR) in wheat (Khan *et al.*, 2021). Similarly, Khan *et al.* (2022) reported that in maize, the combined application of biochar (36 t ha<sup>-1</sup>) and straw mulch had increased the plant height, stem diameter, leaf area index, number of leaves per plant, dry weight and CGR. Sikdar *et al.* (2023) also observed an increased number of leaves per plant, leaf length, plant fresh weight, and stem diameter when tea waste biochar were applied on okra. The combined application of NPK fertiliser (at 60 kg N ha<sup>-1</sup>) and biochar derived from cocoa pod husk (at 5 t ha<sup>-1</sup>) produced taller plants and number of leaves in okra (Oluleye *et al.*, 2023).

### **2.1.2 Effect of Biochar on Yield Attributes**

Application of tender coconut husk biochar at 20 t ha<sup>-1</sup> along with PGPR (2%) and NPK fertiliser had significantly improved the pod length by 20.31 per cent, pod girth by 36.84 per cent, pod weight by 18.04 per cent, and the number of pods per plant by 30.77 per cent in yard long bean (Dainy, 2015). Timilsina *et al.* (2020) observed that biochar (at 2 t ha<sup>-1</sup>) combined with the RDF had increased the curd yield in cauliflower to about 37 per cent. Acharya *et al.* (2022) reported that the combined application of goat manure and biochar had significantly improved the yield attributes, such as fruit weight by 32.4 per cent, the number of fruits by 70 per cent and total fruit yield by 89 per cent in okra. According González-Pernas *et al.* (2022), biochar (at 10 t ha<sup>-1</sup>) had significantly increased the average fresh weight of radishes by 35.4 per cent, lettuce by 98.1 per cent, tomatoes by 24.8 per cent, and sweet peppers by 35.2 per cent.

Significantly higher numbers of pods per plant, pod length, individual pod weight, pod diameter, and pod weight per plant were observed for okra grown in sandy soils that was amended with sugarcane bagasse biochar (Sikdar *et al.*, 2023). Gairhe *et al.*

(2024) also obtained significant improvement in the size and yield of okra with biochar obtained from ashoka leaf. Vikram (2024) reported that the application of biochar obtained from tender coconut husk, along with FYM and 100 per cent RDF significantly increased yield parameters of okra, such as fruit yield per plant, fruit yield per ha and harvest index compared with control plants. Similarly, Madaki *et al.* (2025) recorded higher number of fruits, greater fruit length and width, and increased fruit weight in okra plants supplemented with rice husk biochar. The application of biochar derived from aquatic weed has been found to increase the number of fruits per plant and fruit weight in okra (Munir *et al.*, 2025).

### **2.1.3 Effect of Biochar on Quality Parameters**

Kamalraj *et al.* (2017) reported an increased composition of carbohydrate, ash, and fibre content in okra fruits which were supplemented with biochar. Increased crude fibre content was also observed due to the application of sugarcane bagasse biochar in tomato (Usman *et al.*, 2023). Vikram (2024) had also reported significant increase in crude fibre content in okra fruits due to the application of tender coconut husk biochar along with FYM and 100 per cent RDF.

Nagula (2017) observed significantly higher total soluble solids and vitamin C in bananas due to the application of tender coconut husk biochar along with 75 per cent soil test-based RDF. The application of biochar produced from bamboo was found to increase the ascorbic acid content and soluble solids in tomato when compared to the control (Suthar *et al.*, 2018). Similar observations on increased vitamin C content were also reported in cucumber (Ali *et al.*, 2020), tomato (Obadi *et al.*, 2024), and ash gourd (Li *et al.*, 2024a) following the application of biochar.

### **2.1.4 Effect of Biochar on Uptake of N, P, and K**

Dainy (2015) observed that applying tender coconut husk biochar in combination with NPK fertiliser had enhanced nitrogen uptake in yard-long bean, increasing it from 51.19 kg ha<sup>-1</sup> to 105.50 kg ha<sup>-1</sup>. Similar results were observed by Peng *et al.* (2021), where the combined application of biochar at 6 t ha<sup>-1</sup> and fertiliser promoted nitrogen uptake in maize by 15 per cent, which may be attributed to improved nitrogen retention

in the soil. Cong *et al.* (2023) also observed increased N uptake in maize as a result of single application of wheat straw biochar.

Jabin (2022) reported an increased uptake of P by ginger in shoot, root and rhizome due to the application of paddy husk biochar at 30 t ha<sup>-1</sup>. Phares *et al.* (2022) had also observed significantly increased P uptake in maize due to the combined application of corn cob biochar and NPK fertilisers. Oluleye *et al.* (2023) found that the application of cocoa pod husk biochar produced 139 per cent increase in P uptake by okra. Vikram (2024) opined that the uptake of P by okra could be increased with the application of tender coconut husk biochar.

The application of tender coconut husk biochar enhanced K uptake in yard long bean by 194.17 per cent compared to the control (Dainy, 2015). Similarly, Syuhada *et al.* (2016) observed an increased uptake of K by corn due to the application of biochar derived from oil palm empty fruit bunch. Oluleye *et al.* (2023) found that the combined application of cocoa pod husk biochar and NPK fertiliser significantly increased K uptake in okra plants by 87 per cent compared to the control.

### **2.1.5 Effect of Biochar on Soil Parameters**

Application of biochar at 30 t ha<sup>-1</sup> along with NPK was found to increase WHC from 30.89 per cent to 48.78 per cent compared to the control (Dainy, 2015). Similar findings were also reported by Nagula (2017), where an increase in the WHC from 24.3 per cent to 38.18 per cent was observed due to the application of biochar along with 75 per cent doses of NPK. Jabin and Rani (2023) observed an increase in WHC and decrease in bulk density of soil with increasing doses of paddy husk biochar.

The experiential findings by Ali *et al.* (2022) showed that, application of cassava straw biochar along with nitrogen fertiliser had significantly improved the soil pH and soil organic carbon compared to the sole application of N. Masulili *et al.* (2025) opined that significantly higher values for soil pH, CEC and OC were observed when rice husk biochar was applied in combination with NPK fertilisers in ginger. Munir *et al.* (2025) also reported an increased soil EC and WHC with the application of aquatic weed biochar compared to the control in okra.

Gao *et al.* (2021) reported that applying biochar at 20 t ha<sup>-1</sup> on soybean significantly improved organic carbon, total N, available P, and available K in the soil. Application of biochar with goat manure in okra was found to enhance total N, available P and K compared with the control plots (Acharya *et al.*, 2022). Oluleye *et al.* (2023) found that the combined application of cocoa pod husk biochar at 5 t ha<sup>-1</sup> and NPK fertiliser on okra resulted in increased available N by 75 per cent, P by 6 per cent, and K by 161 per cent compared to chemical fertilisation alone. The application of biochar from different feedstocks, *viz.*, rice husk, bamboo, ashoka leaf, coconut husk and sawdust on okra had improved soil properties such as soil N, P and K content (Gairhe *et al.*, 2024). According to Vikram (2024), the application of tender coconut husk biochar with FYM and full nutrition on okra had increased the available N in soil, with no significant effects on available P and available K.

#### **2.1.6 Effect of Biochar on Microbial Population**

Sun *et al.* (2013) reported an increased microbial abundance with an elevated number of bacteria, fungi and actinomycetes in soil supplemented with corncob biochar. Similarly, the application of biochar derived from *Lantana camara* on maize resulted in an increased soil microbial biomass by 27.9 per cent (Masto *et al.*, 2013). An enhanced population of soil bacteria was also found in soil supplemented with wheat straw biochar (Anwar *et al.*, 2021). Gao *et al.* (2021) found that the application of rice straw biochar showed no significant changes in the abundance and diversity of soil bacteria, while the abundance of soil fungi increased with biochar application. In contrast, biochar amendment mixed with nitrogen fertiliser on rice has been shown to promote soil beneficial bacterial groups, including *Acidobacteria*, *Actinobacteria*, *Proteobacteria*, *Verrucomicrobia*, *Bacteroidetes*, *Gemmatimonadetes*, and *Planctomycetes*, while decreasing the relative abundance of major fungal phyla such as *Ascomycota*, *Basidiomycota*, *Chytridiomycota*, and *Rozellomycota* (Ali *et al.*, 2022).

#### **2.2 EFFECT OF *Bacillus pumilus* ON CROP AND SOIL**

*Bacillus pumilus* is a spore forming bacterium known for its strong resistance to environmental stresses such as drought, low nutrient availability, irradiation, and oxidative stress (Nicholson *et al.*, 2000). It produces several gibberellins (Joo *et al.*,

2005), which promote plant growth, especially when used along with nitrogen fertilisers (Win *et al.*, 2018). Due to its resilience and ability to inhabit diverse environments, *B. pumilus* is considered a promising plant growth-promoting bacterium and an alternative to commercial fertilisers (Dobrzynski *et al.*, 2022).

### **2.2.1 Effect of *Bacillus pumilus* on Growth Attributes**

Application of *Bacillus pumilus* through seed treatment had consistently led to enhanced plant growth in several crops. In lentil, *B. pumilus* inoculation led to an increase in plant height and biomass (Siddiqui *et al.*, 2007). Soybean seeds treated with the *B. pumilus* Rs3 exhibited an increased plant height by 16 per cent, number of leaves by 21 per cent, and leaf area by 59 per cent relative to the untreated control (Stefan *et al.*, 2010). Masood *et al.* (2020) observed that inoculating tomato seedlings with *B. pumilus* increased plant height by 16 per cent, fresh weight by 27 per cent, dry weight by 35 per cent and root biomass. Similarly, Patani *et al.* (2023) found that tomato seeds treated with *B. pumilus* showed an increase in root length, shoot length, leaf area, shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight against untreated plants.

Ngo *et al.* (2019) reported that inoculation of rice seedlings with *B. pumilus* TUAT1 enhanced plant height, biomass, crown root formation and elongation, which might be attributed to enhanced production of auxin. Liu *et al.* (2020) had also observed enhanced root parameters, including increased number, length, surface area, and volume in rice treated with *B. pumilus*. The inoculation of maize seedlings with *B. pumilus* was also found to enhance number of leaves by 42 per cent, leaf and root length by 40 per cent, shoot length by 39 per cent and plant fresh weight by 34 per cent over control plants (Shahzad *et al.*, 2021).

### **2.2.2 Effect of *Bacillus pumilus* on Yield Attributes**

The inoculation of cauliflower seed with *B. pumilus* along with phosphorus fertilisation was found to improve yield attributes such as curd diameter, curd depth and curd weight (Dipta *et al.*, 2016). Seed treatment of bell pepper with a PGPR consortium comprising *Bacillus pumilus* and *B. subtilis* resulted in 379 per cent increase in yield compared to the uninoculated control (Kaushal *et al.*, 2019). Katsenios *et al.* (2021)

opined that tomato plants inoculated with *Bacillus pumilus* exhibited increased mean fruit weight and total yield per plant by 27 per cent compared to the untreated control. Umamaheswari *et al.* (2022) opined that seed treatment of okra with *Bacillus pumilus* (IIHR Bp-2), along with the application of FYM enriched with the same strain, significantly increased yield (28.22 t ha<sup>-1</sup>) compared to the control (21.57 t ha<sup>-1</sup>).

### **2.2.3 Effect of *Bacillus pumilus* on Quality Parameters**

Stefan *et al.* (2010) reported that soybean plants treated with *B. pumilus* Rs3 produced beans containing 66 per cent more soluble protein compared to uninoculated controls. The application of a bacterial consortium consisting of *Bacillus pumilus* had significantly enhanced the nutritional composition of amaranth grains, such as an increase in crude protein, crude fibre, dry matter, fat, and carbohydrate content (Pandey *et al.*, 2018).

### **2.2.4 Effect of *Bacillus pumilus* on Uptake of N, P, and K**

In rice, root colonisation by *B. pumilus* was found to enhance phosphorus absorption (Liu *et al.*, 2020). *B. pumilus* inoculation was found to improve the N uptake in tomato (Masood *et al.*, 2020) and K uptake in wheat (Nawaz *et al.*, 2020). Similar findings have also been documented in maize, where *B. pumilus* inoculation enhanced the protein content and potassium levels compared to the control (Shahzad *et al.*, 2021). Patani *et al.* (2023) also found that tomato seeds treated with *B. pumilus* showed higher leaf K and P concentrations, which might be due to nutrient solubilization by bacteria.

### **2.2.5 Effect of *Bacillus pumilus* on Soil Parameters**

Dipta *et al.* (2016) reported that seed treatment of cauliflower with *B. pumilus* increased available N by 21.5 per cent, P by 55 per cent and K by 26.4 per cent. However, no significant effects were observed in soil pH, EC, or organic carbon. In contrast, Win *et al.* (2020) observed that the use of *B. pumilus* TUAT-1 in forage rice cultivation resulted in decreased total C, exchangeable K and available P relative to the untreated control. Kumar *et al.* (2021) opined that inoculation of soil with *B. pumilus* JPVS11 significantly lowered the EC of soil compared to non-inoculated soil, while an enhancement was observed in soil OC and essential nutrients such as N, P and K.

### 2.2.6 Effect of *Bacillus pumilus* on Microbial Population

Masood *et al.* (2019) reported that inoculation of rapeseed with *B. pumilus* had resulted in increased soil bacterial populations by four to five times over the untreated control. Similarly, Kumar *et al.* (2021) observed an enhanced population of bacteria, fungi, and actinomycetes in soil where rice seedlings were treated with *B. pumilus* JPVS1. Furthermore, the application of *B. pumilus* T208 was found to effectively change the soil bacterial and fungal community structures and improve stability of microbial networks in rice cultivated soils (Nan *et al.*, 2025).

## 2.3 EFFECT OF *Bacillus amyloliquefaciens* ON CROP AND SOIL

*Bacillus amyloliquefaciens* is a Gram-positive, spore-forming bacterium that produces a variety of secondary metabolites (Chen *et al.*, 2009) and enzymes such as chitinase, which play important roles in microbial antagonism against pathogens (Niazi *et al.*, 2014). It is widely recognised as a potential PGPR capable of thriving under stressed environmental conditions, effectively colonising the plant rhizosphere, and contributing to biofertilisation and biocontrol applications in agriculture (Luo *et al.*, 2022).

### 2.3.1 Effect of *Bacillus amyloliquefaciens* on Growth Attributes

Studies have demonstrated that inoculation with *B. amyloliquefaciens* significantly enhances plant growth parameters across various crops. Qin *et al.* (2017) reported that inoculation with *B. amyloliquefaciens* enhanced growth parameters such as leaf area, shoot length, and fresh weight in cucumber seedlings, while Jamal *et al.* (2018) observed significant improvement in plant biomass, plant height, and number of flowers per plant in pepper following the applications of the same species. Enhanced growth attributes due to *B. amyloliquefaciens* is reported in tomato (Samaras *et al.*, 2018; Abdallah *et al.*, 2018).

Sheteiwy *et al.* (2021) reported that inoculation of soybean with *B. amyloliquefaciens* exhibited enhanced plant height by 22.53 per cent, leaf area by 14.89 per cent, and fresh weight by 49.76 per cent against control. Similarly, Athira *et al.* (2021) observed increased plant height and branching in chilli following seed biopriming and foliar application of *B. amyloliquefaciens*. Application of

bioformulations containing *B. amyloliquefaciens* and *B. velezensis* also improved plant height, number of leaves per plant, and leaf area of okra (Alexis *et al.*, 2021). Likewise, *B. amyloliquefaciens* inoculation (with 10% concentration) in cucumber has shown a significant increase in biomass, plant height and root length (Ma *et al.*, 2022).

### 2.3.2 Effect of *Bacillus amyloliquefaciens* on Yield Attributes

Gul *et al.* (2008) opined that the application of *B. amyloliquefaciens* increased tomato yield by 8-9 per cent, with treated plants producing heavier fruits and a greater number of fruits compared to control. Similarly, Sheteiwy *et al.* (2021) also observed that soybean seeds inoculated with *B. amyloliquefaciens* showed improved yield attributes, with pod number and 100-seed weight increasing by 35.15 per cent and 16.94 per cent, respectively. Seed bioprimering and foliar application of *B. amyloliquefaciens* were found to enhance fruit numbers and yield than in chilli (Athira *et al.*, 2021). Alexis *et al.* (2021) reported that bioformulations enriched with *B. amyloliquefaciens* and *B. velezensis* significantly increased fruit length, fruit weight (by 48%), and yield (by 94%) of okra compared to untreated controls. Similarly, Sabate and Brandan (2022) also reported that seed inoculation with *B. amyloliquefaciens* B14 had enhanced common bean yield by 18 per cent, with improved yield attributes such as pod number and seeds per pod.

### 2.3.3 Effect of *Bacillus amyloliquefaciens* on Quality Parameters

Qu *et al.* (2016) observed significantly higher vitamin C content in pears following the postharvest treatment with *B. amyloliquefaciens*. Rahman *et al.* (2018) reported that inoculation of strawberry plants with *B. amyloliquefaciens* BChi1 significantly enhanced antioxidant activity, increasing total anthocyanin, carotenoid, flavonoid, and phenolic contents compared to the control. Similarly, *B. amyloliquefaciens* inoculation in bell pepper increased vitamin C content (Cisternas-Jamet *et al.*, 2020), while soil application of the same species in tomato enhanced lycopene content and antioxidant activity with improving fruit quality and nutritional value (Katsenios *et al.*, 2021). In okra, the combined application of *B. amyloliquefaciens* and *B. velezensis* also improved nutritional parameters, such as protein and carbohydrate content, compared to untreated control (Alexis *et al.*, 2021).

#### **2.3.4 Effect of *Bacillus amyloliquefaciens* on Uptake of N, P, and K**

Vinci *et al.* (2018) reported that maize seeds inoculated with *B. amyloliquefaciens* and phosphorus fertilisers showed higher N and P concentrations and uptake compared to uninoculated control. Zafar-ul-Hye *et al.* (2019) found that seed inoculation with *B. amyloliquefaciens* combined with biochar (30 t ha<sup>-1</sup>) significantly increased N, P and K concentrations in wheat grain and shoots. Sheteiwy *et al.* (2021) also observed that inoculation soybean with *B. amyloliquefaciens* enhanced P content by 14.90 per cent and K content by 11.31 per cent in leaves.

#### **2.3.5 Effect of *Bacillus amyloliquefaciens* on Soil Parameters**

Qin *et al.* (2017) observed that the inoculation of *B. amyloliquefaciens* L-S60 on cucumber seedlings could significantly improve the amount of available N, P, and K compared to the control. Jamal *et al.* (2018) further demonstrated that soil inoculation with *B. amyloliquefaciens* Y1 in combination with chemical fertiliser enhanced soil EC, total organic matter, total N, and available P, while decreasing soil pH and CEC. In another study, Sabate and Brandan (2022) found that inoculation of common bean seeds with *B. amyloliquefaciens* B14 significantly improved soil EC by 53 per cent, OC by 93 per cent, total N by 80 per cent and extractable P by 10 per cent compared to the control.

#### **2.3.6 Effect of *Bacillus amyloliquefaciens* on Microbial Population**

Qin *et al.* (2017) observed that *B. amyloliquefaciens* L-S60 modified the structure of the bacterial community in the cucumber rhizosphere, promoting beneficial species associated with improved mineral availability and enhanced seedling growth. Similarly, Jamal *et al.* (2018) found that soil inoculation with *B. amyloliquefaciens* Y1 increased the total bacterial population, including chitinase-producing and thermophilic bacteria, along with higher *B. amyloliquefaciens* counts. Sabate and Brandan (2022) opined that inoculation of soil with *B. amyloliquefaciens* B14 had significantly enhanced populations of *Gliocladium* spp. (by 33%), *Trichoderma* spp. (by 42%), actinomycetes (by 63%), and *Pseudomonas* spp. (by 58%) compared to the untreated control, and also enhanced bacterial and fungal gene abundance, indicating a positive shift in microbial community structure.

## 2.4 EFFECT OF *Bacillus velezensis* ON CROP AND SOIL

*Bacillus velezensis* is a Gram-positive, endospore-forming, aerobic bacterium characterised by its high enzyme-producing capacity, high stress resistance, diverse secondary metabolites, with broad-spectrum antibacterial action, and notable efficacy against pathogens. It can promote plant growth and suppress pathogenic infections under both abiotic and biotic stress conditions. Owing to these characteristics, *B. velezensis* is extensively used in agriculture and holds significant practical value (Zhong *et al.*, 2024).

### 2.4.1 Effect of *Bacillus velezensis* on Growth Attributes

Chen *et al.* (2019) reported that *B. velezensis* LDO2 promoted peanut growth by increasing plant height, root length, and seedling dry weight. Similarly, Dhouib *et al.* (2019) observed that soil drenching of tomato plants with *B. velezensis* C2 had significantly enhanced height of plant and the number of leaves per plant compared to untreated controls. Medeiros and Bettiol (2021) further observed that coating tomato seeds with *B. velezensis* AP-3 markedly improved growth parameters, such as plant height, stem diameter, and aboveground dry weight (by 114%) and root dry weight (by 163%) compared to the control plants.

Hasan *et al.* (2022) reported that root drenching of cotton plants with *B. velezensis* HNH9 resulted in an increased shoot fresh weight and dry weight (by 84.45% and 66.21% respectively), root fresh weight by 49.73 per cent, and root dry weight by 61.9 per cent. Similarly, Wang *et al.* (2022a) opined that cucumber seedlings treated with *B. velezensis* SX13 showed notable improvements in shoot length (by 57.08%), leaf area (by 26.54%) and dry matter accumulation, along with enhanced root volume, surface area and root length. Li *et al.* (2024b) also observed that inoculation of vermiculite-based growing media with *B. velezensis* YXDHD1-7 significantly enhanced tomato growth attributes, plant height by 26.21 per cent, root surface area by 152.65 per cent, and total root length by 194.45 per cent over the control.

### 2.4.2 Effect of *Bacillus velezensis* on Yield Attributes

Balderas-Ruíz *et al.* (2021) reported that application of *B. velezensis* 83 significantly enhanced tomato productivity, with treated plants producing more yield

(4.5 kg per plant) and fruits per plant (79) compared to control (3.3 kg per plant and 63 fruits, respectively). Similarly, Wang *et al.* (2022a) opined that cucumber seedlings treated with *B. velezensis* SX13 showed yield increases of 25.96 to 35.89 per cent over untreated plants. Chen *et al.* (2022) also observed that root irrigation of grape plants with *B. velezensis* GUMT319 improved yield parameters, such as increased size, firmness, and higher 100-fruit weight than the control. Similar reports on increased berry yield per plant were also observed in strawberry with the application of *B. velezensis* (Chebotar *et al.*, 2022; Hong *et al.*, 2022). Lv *et al.* (2025) found that application of microbial fertiliser enriched with *B. velezensis* (30 kg ha<sup>-1</sup>) on soybean improved 100-grain weight by 9.05 per cent, individual grain weight by 13 per cent and individual pod weight by 7.05 per cent, with an overall yield increase by 13.84 per cent.

#### **2.4.3 Effect of *Bacillus velezensis* on Quality Parameters**

Ilmiah *et al.* (2021) found that applying goat manure along with *B. velezensis* B-27 to snake fruit (*Salacca zalacca*) produced the highest antioxidant activity and increased flavonoid and total phenolic contents. Similarly, Wang *et al.* (2022a) reported that *B. velezensis* SX13 treatment in cucumber seedlings had significantly improved fruit quality, with higher levels of vitamin C, organic acids, free amino acids, reducing sugars, soluble proteins, and soluble sugars compared to the control. Chen *et al.* (2022) also observed that root irrigation of grape plants with *B. velezensis* GUMT319 enhanced fruit quality, resulting in a higher sugar: acid ratio and vitamin C content than in untreated plants.

#### **2.4.4 Effect of *Bacillus velezensis* on Uptake of N, P, and K**

Choub *et al.* (2021) reported that application of *B. velezensis* CE100 culture broth on walnut trees significantly enhanced N uptake by 32 per cent and P uptake by 36 per cent compared to the control. The treatment of quinoa seeds with *B. velezensis* QA2 improved plant P uptake by 41.17 per cent compared to the untreated control (Mahdi *et al.*, 2022). Enhanced N uptake and accumulation in rice was also observed by Chen *et al.* (2024) due to the inoculation of *B. velezensis* SQR9 VCs. Cheng *et al.* (2025) also observed increased N content in soybean with the application of *Bacillus velezensis* 20507.

#### 2.4.5 Effect of *Bacillus velezensis* on Soil Parameters

Lu *et al.* (2020) reported that treatment of Chinese cabbage with *B. velezensis* S3-1 reduced total N, C, and P contents in the soil. Similarly, Chen *et al.* (2022) opined that root irrigation of grape plants with *B. velezensis* GUMT319 modified soil physicochemical parameters, such as increased soil pH and decreased N and available K levels compared to the control. Shi *et al.* (2022) also demonstrated that inoculation of peach trees with *B. velezensis* YH-20 significantly enhanced available N by 22.42 per cent, P by 36.28 per cent, while decreasing soil pH. Ma *et al.* (2025) reported that application of *B. velezensis* SQR9 amended biofertiliser on pear trees significantly increased soil OC by 10.9 per cent and available P by 1.4 times compared to the control, along with enhanced levels of N and available K. Inoculation of cucumber plants with *B. velezensis* GHt-q6 was found to enhance available P by 16 per cent, available K by 48 per cent and organic matter by 33 per cent over the control (Liu *et al.*, 2025). Le *et al.* (2025) further demonstrated that supplementation of coral sand soil with *B. velezensis* TSD5 had significantly improved soil aggregation and water retention capacity.

#### 2.4.6 Effect of *Bacillus velezensis* on Microbial Population

Shi *et al.* (2022) observed that inoculation of peach trees with *B. velezensis* YH-20 resulted in significant modification in the soil microbial community compared to the control which were not inoculated. Ma *et al.* (2025) also observed that the application of a *B. velezensis* SQR9 enriched biofertiliser on pear trees activated beneficial rhizosphere bacteria such as *Streptomyces*, *Mycobacterium*, and *Ureibacillus*, which likely contributed to higher soil organic matter, while no significant changes were recorded in the rhizosphere fungal community. Liu *et al.* (2025) also reported that cucumber plants irrigated with *B. velezensis* GHt-q6 ( $10^8$  CFU mL<sup>-1</sup>) significantly increased bacterial populations in the rhizosphere but reduced actinomycete and fungal counts compared to the control.

## 2.5 EFFECT OF BIOCHAR AND PGPR ON SEQUENTIAL CROP

The biochar application generally increases crop yields and improves soil quality in sequential cropping systems. Frimpong *et al.* (2021) reported that the one-time application of corn cob biochar at  $10 \text{ t ha}^{-1}$ , along with NPK fertilisers in a maize-okra-cassava sequence, resulted in higher maize and okra yields and lower cassava yields compared to the control. A study by Nimbalkar *et al.* (2023) revealed that in a soybean-wheat cropping sequence, the one-time application of biochar at  $10 \text{ t ha}^{-1}$ , along with 75 per cent of full nutrients for both crops, produced higher grain yields for both crops compared to those obtained with the full RDF. The BCR was also found to be higher for this treatment at 2.32. Wijitkosum *et al.* (2025) examined the effects of a one-time application of cassava stem biochar in maize over five successive cropping cycles. Their findings revealed increases in kernel biomass, soil CEC, organic matter, and total N and available P up to the second crop, followed by a decline from the third cycle onward.

Trabelsi *et al.* (2012) reported that in a bean-potato cropping sequence, the inoculation of common bean with PGPR significantly enhanced the yield of potato compared to the uninoculated control.

## 2.6 EFFECT OF BIOCHAR AND PGPR ON ECONOMICS OF CULTIVATION

Application of biochar derived from tender coconut husk ( $20 \text{ t ha}^{-1}$ ) along with PGPR and NPK fertiliser on yard long bean recorded a higher BC ratio of 1.56, which can be considered as the economically viable treatment (Dainy, 2015). Nagula (2017) recorded a higher BCR of 2.38 and net returns of ₹ 6,89,336  $\text{ha}^{-1}$  when banana plants were supplemented with biochar ( $10 \text{ kg plant}^{-1}$ ), combined with 75 per cent of the soil test-based fertiliser recommendation. Similarly, Jabin (2022) recorded a higher net income of ₹ 8,48,667  $\text{ha}^{-1}$  with a BCR of 1.88 for ginger, which was provided with coconut frond biochar along with NPK fertilisers. The partial budget analysis for okra by Oluleye *et al.* (2023) revealed that the application of cocoa pod husk resulted in a higher marginal rate of return, which indicated the economic advantage of adding biochar to mineral fertiliser in okra production. Vikram (2024) also reported higher net

return (₹ 1,54,292 ha<sup>-1</sup>) and BCR (1.78) for okra production with the incorporation of tender coconut husk biochar.

Umamaheswari *et al.* (2022) reported higher BCR of 1.93 in okra that were treated with *Bacillus pumilus* and FYM enriched with the same strain. Zhang *et al.* (2023) reported that the co-application of PGPR and biochar increased net income from dry pepper by 9.77-41.58 per cent in the first year and 11.20-21.43 per cent in the second year.

# ***Materials and Methods***

### 3. MATERIALS AND METHODS

The study entitled ‘Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains’ was carried out at the Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram and Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam, during the year 2023-2025. The objective of the experiment was to assess the effect of seed bacterization and biochar amendment on the growth and yield of okra and to analyse the residual effect of treatments on the sequential crop of amaranthus in Onattukara. In the first part of the study, bacterized okra seeds were raised in soils amended with biochar and growth and yield of okra were assessed. In the second part of the study, the residual effect of treatments were studied on the sequential crop of amaranthus. The materials used and the methods followed for the conduct of research work are described in this chapter.

#### 3.1 SITE OF EXPERIMENTAL FIELD

The field experiment was conducted in the wetlands of the Instructional Farm attached to Onattukara Regional Agricultural Research Station, Kayamkulam, Kerala. The experimental area is situated at 9.177°N latitude and 76.517°E longitude, and an altitude of 3.05 m above mean sea level. The geographic location is given in Plate 1.

##### 3.1.1 Soil

The soil in the experimental site was coarse-textured and loamy sand in nature, belonging to the taxonomic family of Loamy Skeletal Kaolinitic Isohyperthermic Ustic Quartzipsamments. The important physico-chemical properties of the soil and methods adopted for analysis are presented in Table 1a and Table 1b. Rating was given as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2024).

Table 1a. Mechanical composition of soil of the experimental site

Fraction	Content in soil (%)	Method
Sand	85.65	Bouyoucos Hydrometer method (Bouyoucos, 1962)
Silt	5.03	
Clay	9.32	
Textural class	Loamy sand	

Table 1b. Chemical and biological properties of soil before the experiment

Parameters	Content	Rating	Methods
Water holding capacity (%)	32.61	-	Keen-Raczkowski box method (Piper, 1966)
Soil reaction (pH)	5.96	Moderately acid	pH meter (1:2.5 soil water ratio) (Jackson, 1973)
EC (dS m <sup>-1</sup> )	0.15	Normal	Conductivity meter (1:2.5 soil water ratio) (Jackson, 1973)
CEC (cmol (+) kg <sup>-1</sup> )	2.44	-	Ammonium saturation using neutral normal ammonium acetate and distillation (Jackson, 1973)
Organic carbon (%)	0.62	Medium	Walkley and Black rapid titration method (Jackson, 1973)
Available N (kg ha <sup>-1</sup> )	267.61	Low	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha <sup>-1</sup> )	78.03	High	Bray colorimetric method (Jackson, 1973)
Available K (kg ha <sup>-1</sup> )	208.80	Medium	Neutral normal ammonium acetate extraction and estimation using flame photometry (Jackson, 1973)
Bacteria (log CFU g <sup>-1</sup> soil)	7.21		Serial dilution and plating on nutrient Agar medium (Atlas and Parks, 1993)
Fungi (log CFU g <sup>-1</sup> soil)	4.78		Serial dilution and plating on Martin's Rose Bengal Agar medium (Martin, 1950)
Actinomycetes (log CFU g <sup>-1</sup> soil)	5.87		Serial dilution and plating on Ken Knight's Agar medium (Cappuccino and Sherman, 1996)



Plate 1. Geographic location of the experimental field

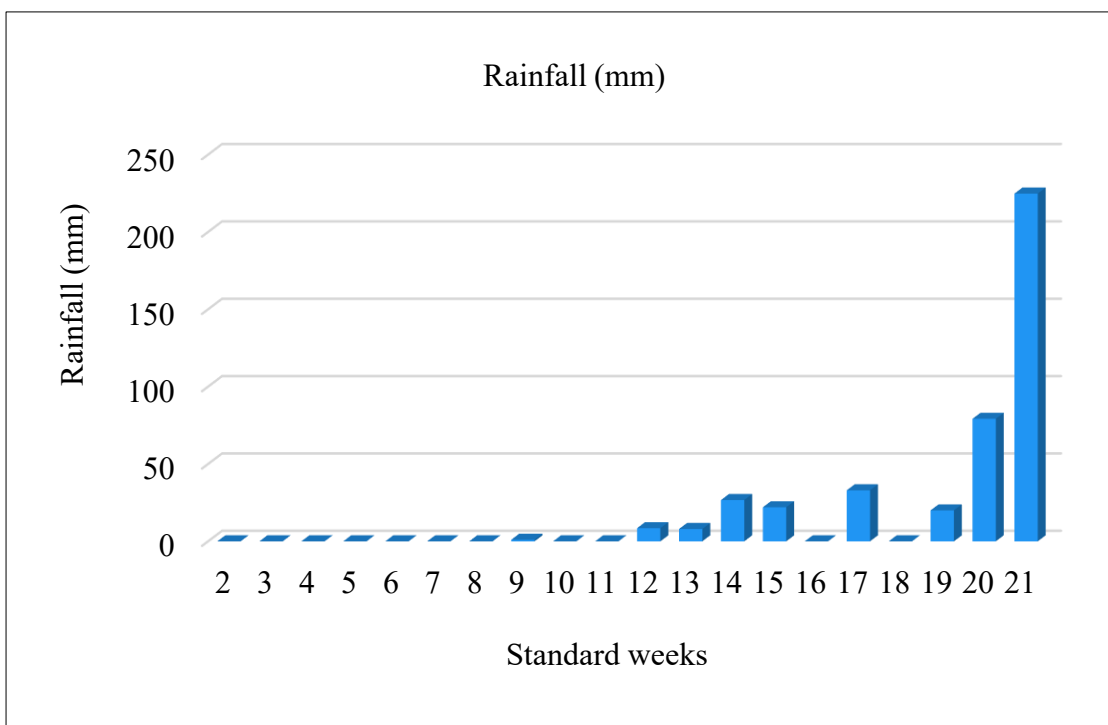
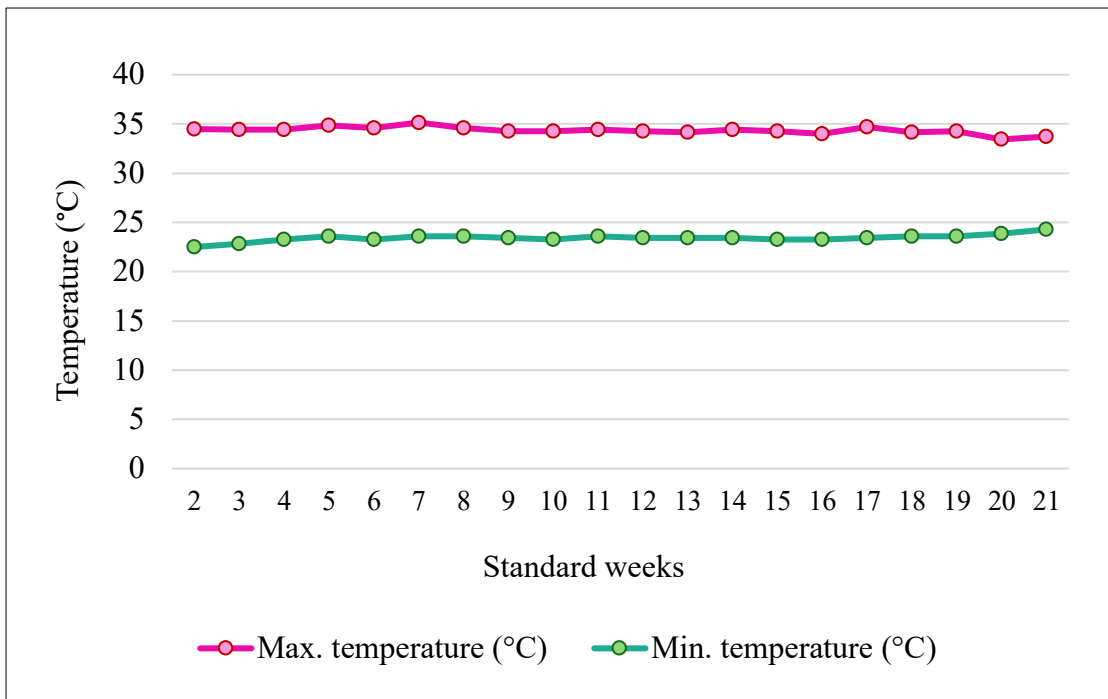


Fig. 1 Weather data during the crop season from January – May 2025

### **3.1.2 Climate and Season**

The field experiment was conducted during January to May 2025. The Onattukara region generally experiences a tropical humid climate. The monthly data of weather parameters *viz.* rainfall, maximum temperature and minimum temperature during the cropping period were collected from the Meteorological Observatory stationed at ORARS, Kayamkulam, Kerala. The data is presented in Fig. 1 and Appendix I.

### **3.1.3 Cropping History of the Field**

The experimental area was an open wetland that was previously cropped with rice var. Bhagya.

## **3.2 MATERIALS**

### **3.2.1 Experiment I: Seed Bacterization and Biochar Amendment on Growth and Yield of Okra**

The experiment was carried out to assess the effect of seed bacterization and biochar amendment on the growth and yield of okra in Onattukara.

#### ***3.2.1.1 Bacterial Isolates***

Bacterial isolates of *Bacillus pumilus* VLY 17, *Bacillus amyloliquefaciens* VLY 24, and *Bacillus velezensis* PCSE 10 were obtained from the Department of Agricultural Microbiology, College of Agriculture, Vellayani and were tested for their impact on the growth and yield of okra.

#### ***3.2.1.2 Crop and Variety***

The crop used for the field experiment was okra. Okra var. Varsha Uphar was used as the first crop. Varsha Uphar, a high yielding and yellow vein mosaic resistant variety of okra, which was derived from the cross of Lam selection x Parbhani Kranti. The seeds were purchased from Instructional Farm, ORARS, Kayamkulam.

#### ***3.2.1.3 Biochar***

The tender coconut husk biochar used in the experiment was prepared at ORARS, Kayamkulam, as per the procedure mentioned under ‘methods’ in this chapter.

#### ***3.2.1.4 Manures and Fertilisers***

The manure that was used in the experiment was farmyard manure (FYM). The recommended dose of N, P and K were supplied as urea (46% N), rajphos (20% P<sub>2</sub>O<sub>5</sub>) and muriate of potash (60% K<sub>2</sub>O).

### **3.2.2 Experiment II: Assessing the Residual Effect of Seed Bacterization and Biochar Amendment on Growth and Yield of Amaranthus**

The residual effect of seed bacterization and biochar amendment applied to okra was assessed by raising a bulk crop of amaranthus.

#### ***3.2.2.1 Crop and Variety***

For sequentially cropped amaranthus, the var. KAU Vaika was used. KAU Vaika, released from College of Agriculture Vellayani, Kerala, is a high yielding (35 t ha<sup>-1</sup>) multi-cut late flowering amaranthus variety with a long vegetative growth period and has red-coloured stems and leaves. The seeds of KAU Vaika were purchased from the Department of Vegetable Science, College of Agriculture, Vellayani, Kerala.

#### ***3.2.2.2 Manures and Fertilisers***

For sequentially cropped amaranthus, no fertilisers were applied.

### **3.3 METHODS**

#### **3.3.1 Experiment I: Seed Bacterization and Biochar Amendment on Growth and Yield of Okra**

##### ***3.3.1.1 Experimental Design and Layout for Okra***

The experiment for assessing the effect of seed bacterization and biochar amendment on the growth and yield of okra was laid out in Randomized Block Design (RBD). The layout of the experimental field is given in Fig. 2. The details of the experiment are given below.

Design	: RBD
Treatments	: 8
Replications	: 3



$R_1$	$R_2$	$R_3$
$T_6$	$T_4$	$T_8$
$T_5$	$T_3$	$T_1$
$T_8$	$T_1$	$T_2$
$T_1$	$T_6$	$T_7$
$T_7$	$T_8$	$T_5$
$T_3$	$T_2$	$T_6$
$T_2$	$T_7$	$T_3$
$T_4$	$T_5$	$T_4$

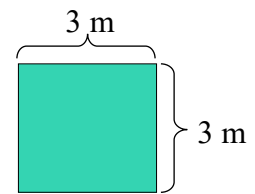


Fig. 2 Layout of the experimental field

Total no. of plots : 24  
 Plot size : 3 m x 3 m  
 Spacing : 60 cm x 30 cm

### ***3.3.1.2 Details of Treatments***

T<sub>1</sub> – FYM 20 t ha<sup>-1</sup> + 100% RDN (KAU POP)  
 T<sub>2</sub> – 5 t ha<sup>-1</sup> biochar + 5 t ha<sup>-1</sup> FYM + 100% RDN  
 T<sub>3</sub> – T<sub>1</sub> + Seed treatment with *Bacillus pumilus* VLY 17  
 T<sub>4</sub> – T<sub>1</sub> + Seed treatment with *Bacillus amyloliquefaciens* VLY 24  
 T<sub>5</sub> – T<sub>1</sub> + Seed treatment with *Bacillus velezensis* PCSE 10  
 T<sub>6</sub> – T<sub>2</sub> + Seed treatment with *Bacillus pumilus* VLY 17  
 T<sub>7</sub> – T<sub>2</sub> + Seed treatment with *Bacillus amyloliquefaciens* VLY 24  
 T<sub>8</sub> – T<sub>2</sub> + Seed treatment with *Bacillus velezensis* PCSE 10

The seeds were treated as per the procedure mentioned in 3.3.3.2.

## **3.3.2 Experiment II: Assessing the Residual Effect of Seed Bacterization and Biochar Amendment on Growth and Yield of Amaranthus**

### ***3.3.2.1 Layout for Sequentially Cropped Amaranthus***

Following the harvest of okra, the experimental plots were used for raising a bulk crop of amaranthus (var. KAU Vaika).

### **3.3.3 Details of Cultivation for Okra**

#### ***3.3.3.1 Preparation of Experimental Field***

The experimental area was periodically cropped with rice. After the harvest of rice, a primary tillage was done, and the main field was cleared of weeds. The stubbles were removed, and the clods in the soil were broken down. Lime at 1 t ha<sup>-1</sup> was uniformly added in the experimental site and incorporated into the soil along with secondary tillage. The whole experimental area was divided into 24 plots as per the design, each having a plot size of 3 m x 3 m (Plate 2).

### **3.3.3.2 Seed Bacterization**

Each of the endospore-forming endophytic bacterial isolates was heavily cross streaked on nutrient agar plates and incubated for 48 h at room temperature. The bacterial suspension was obtained by drenching the culture plates with 10 mL sterile distilled water under aseptic conditions (Anith *et al.*, 2003). The seeds of okra were surface sterilised using one per cent aqueous solution of sodium hypochlorite for three minutes. They were then washed three times with sterile distilled water to remove remaining sodium hypochlorite. Then the seeds were blot dried with sterile tissue paper. The surface sterilised seeds were sprayed with the respective bacterial suspension using sterile spray bottles and were kept overnight for drying. These bacterized seeds were then packed and sown immediately in the field.

### **3.3.3.3 Preparation of Biochar**

Tender coconut husks were collected from local markets from Onattukara region and were sun dried to reduce the moisture content. A customised kiln (having internal dimensions of 1.4 m x 1.5 m x 0.75 m) was used for controlled pyrolysis. The biochar produced was crushed manually and incorporated into the soil as per the treatments during land preparation.

### **3.3.3.4 Seeds and Sowing**

The bacterized seeds of okra, as per treatments, were sown directly in the main field in lines at a spacing of 60 cm x 30 cm.

### **3.3.3.5 Application of Manures and Fertilisers**

Well decomposed FYM, along with biochar, were applied as per treatments in the plots during land preparation (Plate 3). The RDN for okra were applied at 110:35:70 kg N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O ha<sup>-1</sup> (KAU, 2024). The fertilisers were given in split doses as half N, full P, full K (as basal) and the remaining half of the N as top dressing at 30 DAS.

### **3.3.3.6 Irrigation**

At the initial stages of growth, sufficient moisture was ensured for germination. The crops were irrigated as and when required till harvest.



Plate 2. Preparation of the experimental field



Plate 3. Incorporation of FYM and biochar



Plate 4. Intercultural operation in okra

### ***3.3.3.7 After Cultivation***

After sowing, a uniform population was maintained in all plots by gap filling in okra and thinning in amaranthus. Intercultural operations like weeding and earthing up for okra were done at 15 DAS and 30 DAS (Plate 4).

### ***3.3.3.8 Harvest***

Okra was ready for harvest on the 56<sup>th</sup> day after sowing. A total of nine harvests were taken as and when required.

## **3.3.4 Details of Cultivation for Amaranthus**

### ***3.3.4.1 Preparation of Experimental Field***

After the harvest of okra, the plants were uprooted, stubbles were cleared and the plots were made ready for sowing amaranthus (Plate 6).

### ***3.3.4.2 Seeds and Sowing***

The seeds of amaranthus were broadcasted as per treatments and were raised as a sequential crop.

### ***3.3.4.3 Application of Manures and Fertilisers***

The sequential crop of amaranthus was raised without any manuring.

### ***3.3.4.4 Irrigation***

Adequate soil moisture was maintained during the initial growth stages to ensure germination, and subsequent irrigations were provided as required throughout the crop growth period until harvest.

### ***3.3.4.5 After Cultivation***

For amaranthus, one weeding was done at 30 days after sowing.

### ***3.3.4.6 Harvest***

The sequentially cropped amaranthus was harvested at 40 DAS.

### 3.4 BIOMETRIC OBSERVATIONS

The outer row of each plot was left out as a border row. From the net plot, five plants were selected at random and were tagged as observational plants.

#### 3.4.1 Observations in Okra

##### 3.4.1.1 Growth and Growth Attributes

The growth characters *viz.*, plant height and number of leaves per plant, were recorded from five observational plants from each plot at monthly intervals up to harvest. The root depth and root volume were calculated at harvest.

###### 3.4.1.1.1 Plant Height

The height of the plant was measured from the ground level (base of the plant) to the terminal bud (tip of the growing point) at monthly intervals. The average was calculated and expressed in cm.

###### 3.4.1.1.2 Number of Leaves per Plant

The number of functional leaves of observational plants were counted at monthly intervals, and the average was calculated.

###### 3.4.1.1.3 Leaf Area Index (LAI)

The leaf area of okra was measured at monthly intervals till harvest. The linear method was used for finding the leaf area, and the value was expressed in cm<sup>2</sup>.

$$\text{Leaf area} = L \times B \times K \times n$$

Where L and B are the length and breadth of the leaf in cm, K is the constant value (0.62) (Musa and Usman, 2016), and n is the number of leaves per plant. LAI was calculated using the formula given below (Watson, 1947).

$$\text{LAI} = \frac{\text{Leaf area of plant (cm}^2\text{)}}{\text{Land area occupied by plant (cm}^2\text{)}}$$



Plate 5. General view of okra field



Plate 6. Land preparation for sequential crop of amaranthus



Plate 7. General view of sequential crop of amaranthus

#### 3.4.1.4 Relative Growth Rate

Plant dry weights from five observational plants were recorded at 15 days intervals between 30-45 DAS, 45-60 DAS and 60-75 DAS and were used to calculate RGR using the formula given by Evans (1972).

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

Where  $W_1$  and  $W_2$  are dry weights (g) of plants at time  $T_1$  and  $T_2$  (days), respectively. The values are expressed as  $\text{g g}^{-1} \text{d}^{-1}$ .

#### 3.4.1.5 Crop Growth Rate

Plant dry weights were recorded at 15 days intervals between 30-45 DAS, 45-60 DAS and 60-75 DAS by uprooting five observational plants and oven drying at 70 °C. CGR was calculated using the following formula given by Watson (1958).

$$\text{CGR} = \frac{W_2 - W_1}{(T_2 - T_1) \times S}$$

Where  $W_1$  and  $W_2$  are dry weights of plants at time  $T_1$  and  $T_2$ , respectively.  $S$  is the land area in  $\text{m}^2$ . The values are expressed as  $\text{g m}^{-2} \text{d}^{-1}$ .

#### 3.4.1.1.6 Root Depth

At final harvest, the observational plants were dug out using a spade without breaking the roots and washed carefully with water to remove adhering soil. The root depth was measured as the length of the taproot from the base of the plant to the tip of the root from the observational plants, and its mean was calculated and expressed in cm.

#### 3.4.1.1.7 Root Volume

Root volume was measured by the method suggested by Musick *et al.* (1965). The roots were immersed in a measuring cylinder containing a known volume of water. The increase in the volume of water was calculated and expressed in  $\text{cm}^3$ .

### ***3.4.1.2 Yield and Yield Attributes***

#### *3.4.1.2.1 Days to 50 per cent Flowering*

Days to 50 per cent flowering were recorded by counting the number of days from sowing to 50 per cent flowering in each plot, and the mean was calculated.

#### *3.4.1.2.2 Number of Fruits per Plant*

Fruits obtained from each observational plant at different harvest were counted, and the average was worked out.

#### *3.4.1.2.3 Length of Fruits*

The fruits obtained from five observational plants of all treatments (after each harvest) were used to find out the length of the fruits. Fruit length was measured from the tip of the fruit to the stalk end, and the mean was calculated and expressed in cm.

#### *3.4.1.2.4 Girth of Fruit*

The fruits obtained from five observational plants of all treatments (after each harvest) were used to find out the girth of the fruits. The girth (diameter) of the fruits were measured at the midpoint using a scale and thread. The average girth was then calculated and expressed in cm.

#### *3.4.1.2.5 Individual Fruit Weight*

The fruits obtained from five observational plants of all treatments (after each harvest) were used to find out the weight of the fruits. The weights were measured, and the average was then worked out and expressed in g.

#### *3.4.1.2.6 Fruit Yield per Plant*

The weight of fruits harvested from each observational plants were recorded after each harvest. After the final harvest, the total weight of the fruits obtained from the observational plants of each plot was worked out, averaged and expressed in g.

#### *3.4.1.2.7 Fruit Yield per Hectare*

Fruit weight from each harvest from the net plot area was recorded and pooled to compute yield in terms of kg per plot, and was converted into t ha<sup>-1</sup>.

#### *3.4.1.2.8 Harvest Index*

The harvest index was assessed using the formula proposed by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

### **3.4.2 Observations in Amaranthus**

#### *3.4.2.1 Yield per Plant*

Amaranthus was harvested at 40 DAS. The yield obtained from each observational plant was recorded, and the average yield was then worked out and expressed in g.

#### *3.4.2.2 Yield per Hectare*

The fresh weight of amaranthus from the net plot area was recorded and pooled to compute yield in terms of kg plot<sup>-1</sup>, and was converted into t ha<sup>-1</sup>.

### **3.5 QUALITY PARAMETERS OF OKRA FRUIT**

#### **3.5.1 Vitamin C**

The vitamin C content of the fruits was estimated as per the volumetric method proposed by Sadasivam and Manickam (1996), and it was expressed in mg per 100 g fresh weight.

#### **3.5.2 Crude Fibre**

The crude fibre content of the fruits was determined as per the method suggested by Sadasivam and Manickam (1996) and expressed in percentage.

### 3.6 MICROBIAL ANALYSIS OF SOIL

The total count of bacteria, fungi, and actinomycetes (log CFU g<sup>-1</sup> soil) in the soil samples were determined by serial dilution and plating on specific media. Bacteria were grown in nutrient Agar medium (Atlas and Parks, 1993), fungi in Martin's Rose Bengal Agar (Martin, 1950), and actinomycetes in Ken Knight's Agar medium (Cappuccino and Sherman, 1996).

### 3.7 CHEMICAL ANALYSIS

#### 3.7.1 Plant Analysis

The observational plants from each plot of okra and amaranthus were collected separately, chopped, sun dried, and oven dried to a constant weight. Samples were crushed and powdered to pass through a 0.5 mm mesh, and 0.2 g samples were taken, digested, and the nutrient content was estimated as per standard procedures (Table 2). For okra, fruits and haulm were separately analysed.

$$\text{Nutrient uptake by crop (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Dry matter (kg ha}^{-1}\text{)}}{100}$$

Table 2. Methods of plant analysis

Parameters	Method
N	Modified micro Kjeldahl method (Jackson, 1973)
P	Nitric-perchloric acid digestion (9:4) and Vanadomolybdo-phosphoric yellow colour method using a spectrophotometer (Jackson, 1973)
K	Nitric-perchloric acid digestion (9:4) and flame photometry method (Jackson, 1973)

#### 3.7.2 Soil Analysis

The composite soil samples from the field before the start of the experiment and soil samples from each plot after the harvest of okra and sequentially cropped amaranthus were collected. The samples were cleaned off stubbles and

plant debris and air dried. It was then passed through a 2 mm sieve and analysed for physicochemical properties (Table 1). For organic carbon estimation, the soil samples were passed through a 0.2 mm sieve.

### 3.8 OKRA EQUIVALENT YIELD

The yield of the sequential crop amaranthus was converted into equivalent yield of okra based on the price of the produce, and the okra equivalent yield of cropping sequence was calculated using the following formula (Reddy and Reddy, 2016).

$$\text{Okra equivalent yield} = \text{Okra yield} + \left( \frac{\text{Yield of amaranthus} \times \text{Price of amaranthus}}{\text{Price of okra}} \right)$$

### 3.9 ECONOMIC ANALYSIS

#### 3.9.1 Net Income

After computing the cost of cultivation and gross income, the net returns obtained were found out using the formula:

$$\text{Net income (₹ ha}^{-1}\text{)} = \text{Gross income} - \text{Cost of cultivation}$$

#### 3.9.2 Benefit Cost Ratio (BCR)

B:C ratio of the treatments was calculated using the formula

$$\text{BCR} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

The cost of cultivation and gross income incurred for okra and amaranthus were combined and used for computing BCR.

### 3.10 STATISTICAL ANALYSIS

The data were statistically analysed by applying the technique of analysis of variance (ANOVA) for Randomised Block Design. The analysis was carried out using GRAPES statistical software developed by the Department of Agricultural Statistics, College of Agriculture, Vellayani (Gopinath *et al.*, 2020).

# *Results*

---

## 4. RESULTS

The study entitled ‘Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains’ was carried out with the objectives to assess the effect of seed bacterization and biochar amendment on the growth and yield of okra and to analyse the residual effect of treatments on the sequential crop of amaranthus in Onattukara. This study was conducted during 2023-2025. This chapter presents the findings from the statistically analysed data collected during the study.

### 4.1 SEED BACTERIZATION AND BIOCHAR AMENDMENT ON THE GROWTH AND YIELD OF OKRA

#### 4.1.1 Growth Attributes

The growth attributes of okra are depicted in Table 3 and Table 4.

##### 4.1.1.1 Height of the Plant

The height of the okra plants were observed at 30 DAS, 60 DAS, and 90 DAS (Table 3). At 30 DAS, the treatment T<sub>8</sub> resulted in significantly taller plants (20.10 cm) and was found to be on a par with treatment T<sub>7</sub> (19.87 cm), T<sub>4</sub> (19.83), and T<sub>2</sub> (18.03 cm). The treatment T<sub>1</sub> recorded significantly shorter plants (15.67 cm). At 60 DAS, the treatment T<sub>7</sub> recorded significantly taller plants (94.20 cm) and was found to be on a par with treatments T<sub>8</sub> (87.73 cm) and T<sub>3</sub> (84.63 cm). Shorter plants were recorded from the treatment T<sub>1</sub> (77.63 cm). No significant difference in height was observed at 90 DAS for the treatments.

##### 4.1.1.2 Number of Leaves per Plant

The effect of treatments on the number of leaves per plant was observed at 30 DAS, 60 DAS and 90 DAS (Table 3). The number of leaves per plant increased with the age of the crop till 60 DAS, and then it was found to decline. However, treatments could not produce significant difference in number of leaves per plant at 30 DAS and 90 DAS. At 60 DAS, the treatment T<sub>7</sub> recorded significantly higher number of leaves per plant (23.73) and was found to be on a par with the treatments T<sub>4</sub> (22.47), T<sub>3</sub> (22.27),

T<sub>8</sub> (22.07), T<sub>6</sub> (21.73), and T<sub>5</sub> (21.20). The lowest number of leaves per plant were recorded from the treatment T<sub>1</sub> (16.80).

#### **4.1.1.3 Leaf Area Index (LAI)**

The effect of treatments on the leaf area index was observed at 30 DAS, 60 DAS and 90 DAS (Table 3). In general, like the number of leaves per plant, leaf area index of the crop also increased with the age of the crop till 60 DAS, which was then found to decline till harvest. At 60 DAS, the treatment T<sub>7</sub> produced significantly higher leaf area index (3.21) compared to T<sub>1</sub> (1.96) and was found to be on a par with the treatments T<sub>4</sub> (2.94), T<sub>8</sub> (2.93), T<sub>6</sub> (2.89), and T<sub>3</sub> (2.86).

#### **4.1.1.4 Relative Growth Rate (RGR)**

The RGR was recorded at 15 days intervals between 30-45 DAS, 45-60 DAS, and 60-75 DAS (Table 4). At 30-45 DAS, significantly higher RGR was observed for the treatment T<sub>7</sub> (0.100 g g<sup>-1</sup> d<sup>-1</sup>), which was also found on a par with the treatments T<sub>5</sub> (0.093 g g<sup>-1</sup> d<sup>-1</sup>), T<sub>8</sub> (0.093 g g<sup>-1</sup> d<sup>-1</sup>), T<sub>6</sub> (0.090 g g<sup>-1</sup> d<sup>-1</sup>), and T<sub>1</sub> (0.083 g g<sup>-1</sup> d<sup>-1</sup>). At 45-60 DAS, the relative growth rate was significantly higher in T<sub>7</sub> (0.137 g g<sup>-1</sup> d<sup>-1</sup>) and was found to be on a par with the treatment T<sub>8</sub> (0.120 g g<sup>-1</sup> d<sup>-1</sup>). No significant difference due to treatments were observed during 60-75 DAS.

#### **4.1.1.5 Crop Growth Rate (RGR)**

The crop growth rate of the plants were also observed at 15 days intervals between 30-45 DAS, 45-60 DAS, and 60-75 DAS (Table 4). The crop growth rate was found to be increasing with the age of crop till harvest. Between 30-45 DAS and 60-75 DAS, there was no significant difference between the treatments. At 45-60 DAS, significantly higher crop growth rate was found in T<sub>5</sub> (14.44 g m<sup>-2</sup> d<sup>-1</sup>), which was comparable with the treatments T<sub>6</sub> (14.26 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>7</sub> (13.33 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>4</sub> (13.27 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>3</sub> (13.15 g m<sup>-2</sup> d<sup>-1</sup>), and T<sub>8</sub> (12.34 g m<sup>-2</sup> d<sup>-1</sup>). The lowest value was found for the treatment T<sub>2</sub> (7.71 g m<sup>-2</sup> d<sup>-1</sup>).

Table 3. Effect of seed bacterization and biochar amendment on the growth attributes of okra

Treatments	Height of the plant (cm)			Number of leaves per plant			Leaf Area Index (LAI)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	15.67 <sup>b</sup>	77.63 <sup>b</sup>	84.10	7.87	16.80 <sup>b</sup>	15.20	0.41	1.96 <sup>d</sup>	1.53
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	18.03 <sup>ab</sup>	81.90 <sup>b</sup>	88.50	8.40	16.93 <sup>b</sup>	14.93	0.61	2.35 <sup>cd</sup>	1.66
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	16.93 <sup>b</sup>	84.63 <sup>ab</sup>	90.40	8.73	22.27 <sup>a</sup>	15.47	0.60	2.86 <sup>abc</sup>	1.71
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	19.83 <sup>a</sup>	80.00 <sup>b</sup>	89.63	9.07	22.47 <sup>a</sup>	15.53	0.70	2.94 <sup>ab</sup>	1.74
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	16.17 <sup>b</sup>	79.13 <sup>b</sup>	84.40	7.67	21.20 <sup>a</sup>	15.80	0.46	2.61 <sup>bc</sup>	1.84
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	16.77 <sup>b</sup>	78.80 <sup>b</sup>	91.50	8.53	21.73 <sup>a</sup>	14.80	0.54	2.89 <sup>abc</sup>	1.70
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	19.87 <sup>a</sup>	94.20 <sup>a</sup>	99.37	8.93	23.73 <sup>a</sup>	15.73	0.59	3.21 <sup>a</sup>	1.87
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	20.10 <sup>a</sup>	87.73 <sup>ab</sup>	97.00	9.33	22.07 <sup>a</sup>	16.07	0.63	2.93 <sup>ab</sup>	1.79
SEm (±)	0.82	3.37	3.92	0.42	0.90	0.93	0.09	0.19	0.15
CD (0.05)	2.49	10.22	NS	NS	2.71	NS	NS	0.56	NS

DAS- Days after sowing; FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par; Data were obtained from a total of 15 plants (five randomly selected plants in each of the three replications).

Table 4. Effect of seed bacterization and biochar amendment on RGR, CGR, root depth, and root volume of okra

Treatments	Relative Growth Rate (RGR) (g g <sup>-1</sup> d <sup>-1</sup> )			Crop Growth Rate (CGR) (g m <sup>-2</sup> d <sup>-1</sup> )			Root depth (cm)	Root volume (cm <sup>3</sup> )
	30-45 DAS	45-60 DAS	60-75 DAS	30-45 DAS	45-60 DAS	60-75 DAS		
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	0.083 <sup>ab</sup>	0.103 <sup>bc</sup>	0.053	1.61	8.15 <sup>b</sup>	12.53	17.87	21.93 <sup>e</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	0.053 <sup>c</sup>	0.100 <sup>c</sup>	0.060	1.24	7.71 <sup>b</sup>	13.89	17.43	33.93 <sup>d</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>pumilus</i> VLY 17	0.050 <sup>c</sup>	0.107 <sup>bc</sup>	0.040	1.67	13.15 <sup>a</sup>	13.58	18.00	53.00 <sup>ab</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>amyloliquefaciens</i> VLY 24	0.060 <sup>bc</sup>	0.117 <sup>bc</sup>	0.043	1.67	13.27 <sup>a</sup>	14.82	16.80	47.33 <sup>bc</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>velezensis</i> PCSE 10	0.093 <sup>a</sup>	0.117 <sup>bc</sup>	0.043	2.35	14.44 <sup>a</sup>	16.79	16.83	60.00 <sup>a</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>pumilus</i> VLY 17	0.090 <sup>a</sup>	0.117 <sup>bc</sup>	0.047	2.22	14.26 <sup>a</sup>	16.67	18.37	43.33 <sup>bcd</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>amyloliquefaciens</i> VLY 24	0.100 <sup>a</sup>	0.137 <sup>a</sup>	0.047	1.60	13.33 <sup>a</sup>	14.63	19.10	60.53 <sup>a</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>velezensis</i> PCSE 10	0.093 <sup>a</sup>	0.120 <sup>ab</sup>	0.050	1.85	12.34 <sup>a</sup>	15.19	19.13	39.27 <sup>cd</sup>
SEm (±)	0.008	0.006	0.004	0.22	0.81	1.16	0.75	3.46
CD (0.05)	0.02	0.02	NS	NS	2.45	NS	NS	10.51

DAS- Days after sowing; FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par; Data were computed separately from observations obtained from a total of 15 plants (five randomly selected plants in each of the three replications).

#### ***4.1.1.6 Root Depth***

The effect of treatments on root depth is (at harvest) depicted in Table 4. Rooting depth of okra could not vary significantly in response to the treatments.

#### ***4.1.1.7 Root Volume***

The significant effect of treatments on root volume (at harvest) is depicted in Table 4. Among the treatments, T<sub>7</sub> resulted in significantly higher root volume (60.53 cm<sup>3</sup>) and was found to be on a par with the treatments T<sub>5</sub> (60.00 cm<sup>3</sup>) and T<sub>3</sub> (53.00 cm<sup>3</sup>). The lowest root volume was recorded in control (T<sub>1</sub>) with a volume of 21.93 cm<sup>3</sup>.

### **4.1.2 Yield Attributes and Yield**

The yield and yield attributes of okra are depicted in Table 5 and Table 6.

#### ***4.1.2.1 Days to 50 per cent Flowering***

The days to 50 per cent flowering (Table 5) did not show significant variation. In general, plants in all the treatments reached 50 per cent flowering between 41-45 DAS.

#### ***4.1.2.2 Number of Fruits per Plant***

Table 5 depicts the effect of treatments on the number of fruits per plant. Significantly higher number of fruits per plant were recorded in the treatment T<sub>8</sub> (30.00), which was found to be on a par with T<sub>7</sub> (29.00). The lowest number of fruits was recorded from T<sub>1</sub> (20.00).

#### ***4.1.2.3 Length of Fruits***

The effect of treatments on the length of fruit was not significant (Table 5).

#### ***4.1.2.4 Girth of Fruit***

The girth of the fruit was also not found to be significant (Table 5).

Table 5. Effect of seed bacterization and biochar amendment on yield attributes of okra

Treatments	Days to 50 per cent flowering	Number of fruits per plant	Length of fruits (cm)	Girth of fruit (cm)	Individual fruit weight (g)
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	44.00	20.00 <sup>b</sup>	14.53	6.56	22.54
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	43.33	22.00 <sup>b</sup>	14.92	6.41	20.88
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	44.67	22.00 <sup>b</sup>	15.08	6.56	23.37
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	44.33	23.00 <sup>b</sup>	14.98	6.51	21.35
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	43.33	23.00 <sup>b</sup>	15.50	6.91	23.12
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	43.67	24.00 <sup>b</sup>	14.77	6.49	23.09
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	43.33	29.00 <sup>a</sup>	15.06	6.72	21.64
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	41.67	30.00 <sup>a</sup>	14.81	6.63	23.12
SEm (±)	0.79	1.30	0.21	0.19	0.86
CD (0.05)	NS	3.937	NS	NS	NS

DAS- Days after sowing; FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par; Data were obtained from a total of 15 plants (five randomly selected plants in each of the three replications).

Table 6. Effect of seed bacterization and biochar amendment on yield and harvest index of okra

Treatments	Fruit yield per plant (g)	Fruit yield ha <sup>-1</sup> (t)	Harvest Index
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	442.33 <sup>c</sup>	10.24 <sup>c</sup>	0.69 <sup>abc</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	511.00 <sup>bc</sup>	11.12 <sup>bc</sup>	0.72 <sup>a</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	478.00 <sup>bc</sup>	11.08 <sup>bc</sup>	0.60 <sup>d</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	518.67 <sup>b</sup>	12.01 <sup>b</sup>	0.63 <sup>cd</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	510.33 <sup>bc</sup>	11.84 <sup>bc</sup>	0.64 <sup>bcd</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	480.00 <sup>bc</sup>	11.82 <sup>bc</sup>	0.62 <sup>d</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	608.00 <sup>a</sup>	14.09 <sup>a</sup>	0.70 <sup>ab</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	607.33 <sup>a</sup>	14.07 <sup>a</sup>	0.71 <sup>a</sup>
SEm (±)	24.78	0.57	0.022
CD (0.05)	75.17	1.74	0.066

FYM- Farm yard manure; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par; Data were obtained from a total of 15 plants (five randomly selected plants in each of the three replications).

#### **4.1.2.5 Individual Fruit Weight**

The treatments did not produce any significant effects on individual fruit weight of okra (Table 5).

#### **4.1.2.6 Fruit Yield per Plant**

The effect of treatments on fruit yield per plant is given in Table 6. Among the treatments, treatment T<sub>7</sub> recorded significantly higher fruit yield per plant (608.00 g) and was found to be on a par with T<sub>8</sub> (607.33 g). Lower yield per plant was obtained for the treatment T<sub>1</sub> (442.33 g).

#### **4.1.2.7 Fruit Yield per Hectare**

Table 6 depicts the fruit yield per hectare of okra as influenced by the treatments. Significantly higher yield per hectare was recorded by the treatment T<sub>7</sub> (14.09 t ha<sup>-1</sup>) and was found to be on a par with the treatment T<sub>8</sub> (14.07 t ha<sup>-1</sup>). The treatment T<sub>1</sub> recorded comparatively lower yield (10.24 t ha<sup>-1</sup>).

#### **4.1.2.8 Harvest Index**

Harvest index was significantly influenced by the treatments (Table 6). The treatment T<sub>2</sub> recorded a significantly higher harvest index of 0.72 and was found to be on a par with the treatments T<sub>8</sub> (0.71), T<sub>7</sub> (0.70) and T<sub>1</sub> (0.69).

### **4.1.3 Quality Parameters**

The effect of treatments on the quality parameters *viz.*, vitamin C and crude fibre of okra is shown in Table 7.

#### **4.1.3.1 Vitamin C**

The effect of treatments on Vitamin C in okra was not significant (Table 7).

#### **4.1.3.2 Crude Fibre**

The effect of treatments on crude fibre of okra is presented in Table 7. Significantly higher crude fibre content was observed for the treatment T<sub>7</sub> (16.03%) and was found to be on a par with the treatments T<sub>5</sub> (15.01%) and T<sub>4</sub> (14.81%). Lower crude fibre content was recorded for the treatment T<sub>1</sub> (12.31%).

Table 7. Effect of seed bacterization and biochar amendment on quality parameters of okra fruit

Treatments	Vitamin C (mg 100 g <sup>-1</sup> Fresh weight)	Crude fibre (%)
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	14.21	12.31 <sup>e</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	16.80	12.57 <sup>de</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>pumilus</i> VLY 17	15.50	13.93 <sup>bcd</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>amyloliquefaciens</i> VLY 24	11.63	14.81 <sup>abc</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>velezensis</i> PCSE 10	15.50	15.01 <sup>ab</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>pumilus</i> VLY 17	14.21	13.45 <sup>cde</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>amyloliquefaciens</i> VLY 24	18.09	16.03 <sup>a</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>velezensis</i> PCSE 10	14.21	14.11 <sup>bc</sup>
SEm (±)	1.85	0.48
CD (0.05)	NS	1.46

FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par.

#### **4.1.4 Plant Analysis**

The effect of treatments on nutrient uptake by okra is presented in Table 8.

##### ***4.1.4.1 Nitrogen Uptake***

The treatment T<sub>7</sub> had significantly increased the N uptake (82.31 kg ha<sup>-1</sup>) in okra (Table 8). This was found to be on a par with the treatment T<sub>8</sub> (79.75 kg ha<sup>-1</sup>). Lower N uptake was recorded for the treatment T<sub>1</sub> (44.33 kg ha<sup>-1</sup>).

##### ***4.1.4.2 Phosphorus Uptake***

The P uptake in okra was significantly influenced by the treatments (Table 8). Significantly higher P uptake was observed for the treatment T<sub>6</sub> (15.68 kg ha<sup>-1</sup>) and was found to be on a par with the treatments T<sub>7</sub> (15.54 kg ha<sup>-1</sup>), T<sub>5</sub> (15.28 kg ha<sup>-1</sup>), T<sub>4</sub> (15.09 kg ha<sup>-1</sup>) and T<sub>8</sub> (14.74 kg ha<sup>-1</sup>). Lower P uptake of 10.52 kg ha<sup>-1</sup> was recorded for the treatment T<sub>1</sub>.

##### ***4.1.4.3 Potassium Uptake***

The uptake of K in okra was significantly influenced by the treatments (Table 8). Significantly higher K uptake was recorded for the treatment T<sub>7</sub> (76.24 kg ha<sup>-1</sup>) and was found to be on a par with the treatments T<sub>4</sub> (75.29 kg ha<sup>-1</sup>), T<sub>6</sub> (74.36 kg ha<sup>-1</sup>), T<sub>8</sub> (73.55 kg ha<sup>-1</sup>), and T<sub>3</sub> (61.55 kg ha<sup>-1</sup>). The lowest value of 42.75 kg ha<sup>-1</sup> which was recorded in T<sub>1</sub> treatment.

#### **4.1.5 Soil Analysis**

The data on soil parameters recorded following the experiment are summarised in Table 9 and Table 10.

##### ***4.1.5.1 Soil Reaction (pH)***

The effect of treatments on soil pH (Table 9) was not significant.

##### ***4.1.5.2 Electrical Conductivity (EC)***

The electrical conductivity of the soil (Table 9) did not vary significantly among the treatments.

Table 8. Effect of seed bacterization and biochar amendment on uptake of N, P, and K by okra, kg ha<sup>-1</sup>

Treatments	N	P	K
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	44.33 <sup>e</sup>	10.52 <sup>b</sup>	42.75 <sup>d</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	51.31 <sup>de</sup>	10.91 <sup>b</sup>	50.61 <sup>cd</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	57.55 <sup>cd</sup>	11.62 <sup>b</sup>	61.55 <sup>abc</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	73.97 <sup>b</sup>	15.09 <sup>a</sup>	75.29 <sup>ab</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	58.73 <sup>cd</sup>	15.28 <sup>a</sup>	59.38 <sup>bc</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	62.02 <sup>c</sup>	15.68 <sup>a</sup>	74.36 <sup>ab</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	82.31 <sup>a</sup>	15.54 <sup>a</sup>	76.24 <sup>a</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	79.75 <sup>ab</sup>	14.74 <sup>a</sup>	73.55 <sup>ab</sup>
SEm (±)	2.7	1.0	5.3
CD (0.05)	8.19	3.0	16.0

FYM- Farm yard manure; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par.

Table 9. Effect of seed bacterization and biochar amendment on soil parameters after the harvest of okra

Treatments	Soil reaction (pH)	EC (dS m <sup>-1</sup> )	CEC (cmol (+) kg <sup>-1</sup> )	Water holding capacity (%)	Organic carbon (%)
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	5.95	0.19	2.67	32.72 <sup>c</sup>	0.73
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	6.01	0.19	3.04	38.44 <sup>a</sup>	0.72
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	5.94	0.22	2.84	34.36 <sup>abc</sup>	0.68
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	5.88	0.22	2.85	33.65 <sup>bc</sup>	0.76
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	5.93	0.21	2.84	34.27 <sup>abc</sup>	0.69
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	6.01	0.22	2.94	37.63 <sup>ab</sup>	0.71
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	5.99	0.20	2.96	38.06 <sup>ab</sup>	0.74
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	6.01	0.21	2.97	38.61 <sup>a</sup>	0.75
SEm (±)	0.04	0.01	0.13	1.46	0.032
CD (0.05)	NS	NS	NS	4.44	NS

FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; EC- Electrical conductivity; CEC- Cation exchange capacity; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par.

#### **4.1.5.3 Cation Exchange Capacity (CEC)**

The effect of treatments on CEC (Table 9) was not significant.

#### **4.1.5.4 Water Holding Capacity (WHC)**

Water holding capacity of the soil after harvest was significantly influenced by the treatments (Table 9). The treatment T<sub>8</sub> recorded the significantly higher water holding capacity of 38.61 per cent and remained at par with the treatments T<sub>2</sub> (38.44%), T<sub>7</sub> (38.06%), T<sub>6</sub> (37.63%), T<sub>3</sub> (34.36%), and T<sub>5</sub> (34.27%). Lower water holding capacity was found in T<sub>1</sub> (32.72%).

#### **4.1.5.5 Organic Carbon**

The organic carbon content of soil after the harvest of okra was not significantly influenced by the treatments (Table 9).

#### **4.1.5.6 Available Nitrogen**

Table 10 depicts the available N status of soil after the harvest of okra. The treatments had significant influence on the available N in soil. Among the treatments, the treatment T<sub>8</sub> recorded significantly higher available N (276.14 kg ha<sup>-1</sup>) and was statistically comparable with T<sub>6</sub> (260.21 kg ha<sup>-1</sup>), T<sub>7</sub> (254.89 kg ha<sup>-1</sup>) and, T<sub>4</sub> (244.27 kg ha<sup>-1</sup>). The lowest available nitrogen content was observed in T<sub>3</sub> (201.79 kg ha<sup>-1</sup>).

#### **4.1.5.7 Available Phosphorus**

There was no significant difference among treatments for available phosphorus content in soil after the harvest of okra (Table 10).

#### **4.1.5.8 Available Potassium**

There was significant effect for the treatments on available K in soil after the harvest of okra (Table 10). The treatment T<sub>7</sub> recorded a significantly higher available K (188.83 kg ha<sup>-1</sup>) and was found to be on a par with T<sub>8</sub> (178.49 kg ha<sup>-1</sup>), T<sub>4</sub> (170.69 kg ha<sup>-1</sup>) and T<sub>6</sub> (167.52 kg ha<sup>-1</sup>). Significantly lower value was recorded in T<sub>1</sub> (120.92 kg ha<sup>-1</sup>).

Table 10. Effect of seed bacterization and biochar amendment on available N, P, and K of soil after the harvest of okra, kg ha<sup>-1</sup>

Treatments	Available N	Available P	Available K
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	212.41 <sup>cd</sup>	55.51	120.92 <sup>c</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	233.65 <sup>bcd</sup>	62.08	156.05 <sup>b</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	201.79 <sup>d</sup>	66.75	147.17 <sup>bc</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	244.27 <sup>abc</sup>	79.48	170.69 <sup>ab</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	223.03 <sup>bcd</sup>	77.47	148.36 <sup>bc</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	260.21 <sup>ab</sup>	71.98	167.52 <sup>ab</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	254.89 <sup>ab</sup>	85.35	188.83 <sup>a</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	276.14 <sup>a</sup>	86.46	178.49 <sup>ab</sup>
SEm (±)	13.83	6.74	10.74
CD (0.05)	41.96	NS	32.59

FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par.

Table 11. Effect of seed bacterization and biochar amendment on microbial population of soil after the harvest of okra, log CFU g<sup>-1</sup> soil

Treatments	Bacteria	Fungi	Actinomycetes
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	7.11	4.58 <sup>a</sup>	5.84 <sup>ab</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	7.16	4.53 <sup>a</sup>	5.91 <sup>a</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	7.20	4.36 <sup>b</sup>	5.63 <sup>bc</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	7.29	4.31 <sup>bc</sup>	5.72 <sup>abc</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	7.26	4.27 <sup>bc</sup>	5.47 <sup>c</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	7.30	4.05 <sup>d</sup>	5.83 <sup>ab</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	7.26	4.24 <sup>bc</sup>	5.98 <sup>a</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	7.28	4.18 <sup>cd</sup>	5.87 <sup>ab</sup>
SEm (±)	0.05	0.049	0.092
CD (0.05)	NS	0.149	0.278

FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; CFU- Colony forming units; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par.

#### **4.1.6 Microbial Population in the Soil After the Harvest of Okra**

The effect of treatments on the microbial population of soil after the harvest of okra is given in Table 11. The treatment effect on bacterial count was not significant. The fungal population was significantly higher in T<sub>1</sub> (4.58 log CFU g<sup>-1</sup> soil) and was on a par with T<sub>2</sub> (4.53 log CFU g<sup>-1</sup> soil). The actinomycetes count was significantly higher in T<sub>7</sub> (5.98 log CFU g<sup>-1</sup> soil) and was on a par with T<sub>2</sub> (5.91 log CFU g<sup>-1</sup> soil), T<sub>8</sub> (5.87 log CFU g<sup>-1</sup> soil), T<sub>1</sub> (5.84 log CFU g<sup>-1</sup> soil), T<sub>6</sub> (5.83 log CFU g<sup>-1</sup> soil) and T<sub>4</sub> (5.72 log CFU g<sup>-1</sup> soil).

### **4.2 ASSESSING THE RESIDUAL EFFECT OF SEED BACTERIZATION AND BIOCHAR AMENDMENT ON GROWTH AND YIELD OF AMARANTHUS**

#### **4.2.1 Yield Attributes of Amaranthus**

The yield and yield attributes of amaranthus are depicted in Table 12.

##### ***4.2.1.1 Yield per Plant***

The effect of treatments on the yield per plant was not significant (Table 12).

##### ***4.2.1.2 Yield per Hectare***

The treatments could not produce any significant effect on the yield of amaranthus (Table 12).

#### **4.2.2 Plant Analysis**

The effect of treatments on nutrient uptake by amaranthus is depicted in Table 13.

##### ***4.2.2.1 Nitrogen Uptake***

The N uptake by amaranthus is presented in Table 13. The treatment T<sub>7</sub> (22.59 kg ha<sup>-1</sup>) recorded significantly higher N uptake by amaranthus and was on a par with the treatments T<sub>8</sub> (22.26 kg ha<sup>-1</sup>), T<sub>2</sub> (22.07 kg ha<sup>-1</sup>), T<sub>4</sub> (21.21 kg ha<sup>-1</sup>) and T<sub>6</sub> (21.10 kg ha<sup>-1</sup>).

Table 12. Residual effect of seed bacterization and biochar amendment on yield attributes of amaranthus

Treatments	Yield per plant (g)	Yield per ha (kg)
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	39.92	4097
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	41.33	5006
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	39.33	4158
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	52.17	5156
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	48.00	4306
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	53.00	5289
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	49.50	5434
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	53.58	5582
SEm (±)	3.69	365
CD (0.05)	NS	NS

FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Data were obtained from a total of 15 plants (five randomly selected plants in each of the three replications).

Table 13. Residual effect of seed bacterization and biochar amendment on uptake of N, P, and K by amaranthus, kg ha<sup>-1</sup>

Treatments	N	P	K
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	16.86 <sup>b</sup>	3.95 <sup>cd</sup>	16.35 <sup>c</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	22.07 <sup>a</sup>	5.23 <sup>bc</sup>	19.31 <sup>abc</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	16.59 <sup>b</sup>	3.66 <sup>d</sup>	17.22 <sup>bc</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	21.21 <sup>a</sup>	6.64 <sup>ab</sup>	19.83 <sup>ab</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	15.55 <sup>b</sup>	5.12 <sup>bcd</sup>	16.19 <sup>c</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	21.10 <sup>a</sup>	5.53 <sup>b</sup>	22.76 <sup>a</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	22.59 <sup>a</sup>	6.58 <sup>ab</sup>	19.99 <sup>ab</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	22.26 <sup>a</sup>	7.30 <sup>a</sup>	22.09 <sup>a</sup>
SEm (±)	0.59	0.50	1.14
CD (0.05)	1.78	1.52	3.47

FYM- Farm yard manure; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par.

#### ***4.2.2.2 Phosphorus Uptake***

The P uptake by amaranthus is presented in Table 13. The treatment T<sub>8</sub> (7.30 kg ha<sup>-1</sup>) had recorded significantly higher P uptake by amaranthus and was on a par with the treatments T<sub>4</sub> (6.64 kg ha<sup>-1</sup>) and T<sub>7</sub> (6.58 kg ha<sup>-1</sup>).

#### ***4.2.2.3 Potassium Uptake***

The uptake of K in amaranthus was significantly influenced by the treatments (Table 13). Significantly higher K uptake was recorded for the treatment T<sub>6</sub> with 22.76 kg ha<sup>-1</sup> and was found to be on a par with the treatments T<sub>8</sub> (22.09 kg ha<sup>-1</sup>), T<sub>7</sub> (19.99 kg ha<sup>-1</sup>), T<sub>4</sub> (19.83 kg ha<sup>-1</sup>) and T<sub>2</sub> (19.31 kg ha<sup>-1</sup>).

### **4.2.3 Soil Analysis**

The data on soil parameters after the experiment are presented in Table 14 and Table 15.

#### ***4.2.3.1 Soil Reaction (pH)***

The effect of treatments on soil pH (Table 14) was not significant.

#### ***4.2.3.2 Electrical Conductivity (EC)***

The treatments were not found to be significant in terms of EC (Table 14).

#### ***4.2.3.3 Cation Exchange Capacity (CEC)***

The effect of treatments on CEC (Table 14) was not significant.

#### ***4.2.3.4 Water Holding Capacity (WHC)***

There was no significant difference among treatments (Table 14) for WHC.

#### ***4.2.3.5 Organic Carbon***

The organic carbon content in soil after amaranthus was not significantly influenced by the treatments (Table 14).

Table 14. Residual effect of seed bacterization and biochar amendment on soil parameters after the harvest of amaranthus

Treatments	Soil reaction (pH)	EC (dS m <sup>-1</sup> )	CEC (cmol (+) kg <sup>-1</sup> )	WHC (%)	Organic carbon (%)
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	5.35	0.14	2.47	30.87	0.70
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	5.41	0.12	2.78	35.35	0.68
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	5.35	0.15	2.55	30.97	0.65
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	5.29	0.10	2.53	31.67	0.71
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	5.34	0.12	2.58	31.58	0.65
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	5.41	0.10	2.69	34.22	0.66
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	5.40	0.10	2.73	34.31	0.69
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	5.41	0.12	2.74	35.28	0.71
SEm (±)	0.03	0.01	0.15	1.65	0.031
CD (0.05)	NS	NS	NS	NS	NS

FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; EC- Electrical conductivity; CEC- Cation exchange capacity; WHC- Water holding capacity; KAU POP- Kerala Agricultural University Package of Practices.

Table 15. Residual effect of seed bacterization and biochar amendment on available N, P, and K in soil after the harvest of amaranthus, kg ha<sup>-1</sup>

Treatments	Available N	Available P	Available K
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	138.07 <sup>cd</sup>	40.02 <sup>d</sup>	74.03 <sup>e</sup>
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	159.31 <sup>bc</sup>	45.36 <sup>cd</sup>	106.32 <sup>bcd</sup>
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	116.83 <sup>d</sup>	46.03 <sup>cd</sup>	99.52 <sup>d</sup>
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	143.38 <sup>c</sup>	61.42 <sup>ab</sup>	122.07 <sup>ab</sup>
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	138.07 <sup>cd</sup>	57.35 <sup>ab</sup>	105.28 <sup>cd</sup>
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	180.55 <sup>ab</sup>	53.24 <sup>bc</sup>	116.98 <sup>abc</sup>
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	175.24 <sup>ab</sup>	62.38 <sup>a</sup>	128.66 <sup>a</sup>
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	196.48 <sup>a</sup>	61.23 <sup>ab</sup>	125.72 <sup>a</sup>
SEm (±)	8.245	2.74	5.28
CD (0.05)	25.009	8.31	16.01

FYM- Farm yard manure; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices; Treatments with the same letters within a column are statistically at par.

Table 16. Residual effect of seed bacterization and biochar amendment on microbial population of soil after the harvest of amaranthus, log CFU g<sup>-1</sup> soil

Treatments	Bacteria	Fungi	Actinomycetes
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	7.58	4.42	5.80
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	7.58	4.53	5.79
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	7.70	4.53	5.67
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	7.64	4.44	5.84
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	7.60	4.47	5.78
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	7.73	4.40	5.90
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	7.68	4.53	5.78
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	7.67	4.49	5.86
SEm (±)	0.046	0.049	0.042
CD (0.05)	NS	NS	NS

FYM- Farm yard manure; NS- Not significant; RDN- Recommended dose of nutrients; CFU- Colony forming units; KAU POP- Kerala Agricultural University Package of Practices.

#### **4.2.3.6 Available Nitrogen**

Table 15 depicts the data on available N status in soil after the harvest of amaranthus. Among the different treatments, T<sub>8</sub> recorded significantly higher available N content (196.48 kg ha<sup>-1</sup>), which was remained at par with the treatments T<sub>6</sub> (180.55 kg ha<sup>-1</sup>) and T<sub>7</sub> (175.24 kg ha<sup>-1</sup>). Significantly lower available N content was observed in treatment T<sub>3</sub> (116.83 kg ha<sup>-1</sup>).

#### **4.2.3.7 Available Phosphorus**

The effect of treatments on the available P in soil after the harvest of amaranthus is given in Table 15. The treatment T<sub>7</sub> recorded significantly higher available P (62.38 kg ha<sup>-1</sup>). It was found to be on a par with the treatments T<sub>4</sub> (61.42 kg ha<sup>-1</sup>), T<sub>8</sub> (61.23 kg ha<sup>-1</sup>) and T<sub>5</sub> (57.35 kg ha<sup>-1</sup>). Significantly lower value for the treatments were observed in T<sub>1</sub> (40.02 kg ha<sup>-1</sup>).

#### **4.2.3.8 Available Potassium**

Data on the effect of treatments on available potassium after amaranthus are shown in Table 15. The treatment T<sub>7</sub> recorded significantly higher available K (128.66 kg ha<sup>-1</sup>), which was found to be on a par with T<sub>8</sub> (125.72 kg ha<sup>-1</sup>), T<sub>4</sub> (122.07 kg ha<sup>-1</sup>) and T<sub>6</sub> (116.98 kg ha<sup>-1</sup>). Significantly lower values were recorded for the treatment T<sub>1</sub> (74.03 kg ha<sup>-1</sup>).

### **4.2.4 Microbial Population in the Soil After the Harvest of Amaranthus**

The effect of treatments on the microbial population of soil after the harvest of amarathus was not significant (Table 16).

### **4.3 OKRA EQUIVALENT YIELD**

The effect of treatments on the okra equivalent yield is presented in Table 17. The higher okra equivalent yield was obtained with T<sub>8</sub> (18.85 t ha<sup>-1</sup>), followed by T<sub>7</sub> (18.75 t ha<sup>-1</sup>) and T<sub>4</sub> (16.43 t ha<sup>-1</sup>).

Table 17. Effect of seed bacterization and biochar amendment on okra equivalent yield

Treatments	Okra equivalent yield (t ha <sup>-1</sup> )
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	13.75
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	15.41
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>pumilus</i> VLY 17	14.64
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>amyloliquefaciens</i> VLY 24	16.43
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus</i> <i>velezensis</i> PCSE 10	15.53
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>pumilus</i> VLY 17	16.35
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>amyloliquefaciens</i> VLY 24	18.75
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus</i> <i>velezensis</i> PCSE 10	18.85

FYM- Farm yard manure; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices.

#### 4.4 ECONOMICS OF CULTIVATION

The results on the economics of cultivation are presented in Table 18. The highest gross income (₹ 6,59,910 ha<sup>-1</sup>) was recorded for the treatment T<sub>8</sub> (T<sub>2</sub> + Seed treatment with *Bacillus velezensis* PCSE 10), followed by T<sub>7</sub> (₹ 6,56,170 ha<sup>-1</sup>). Net income also followed the same trend. Higher net income was obtained from T<sub>8</sub> (₹ 3,31,265 ha<sup>-1</sup>) followed by T<sub>7</sub> (₹ 3,27,525 ha<sup>-1</sup>). The BC ratio was found to be higher for T<sub>8</sub> (2.01) and T<sub>4</sub> (2.01), followed by T<sub>7</sub> (2.00).

Table 18. Effect of seed bacterization and biochar amendment on economics of cultivation

Treatment	Cost of cultivation (₹ ha <sup>-1</sup> )	Gross income (₹ ha <sup>-1</sup> )	Net income (₹ ha <sup>-1</sup> )	BC Ratio
T <sub>1</sub> – 20 t ha <sup>-1</sup> FYM + 100% RDN (KAU POP)	284245	481310	197065	1.69
T <sub>2</sub> – 5 t ha <sup>-1</sup> biochar + 5 t ha <sup>-1</sup> FYM + 100% RDN	326645	539380	212735	1.65
T <sub>3</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	286245	512540	226295	1.79
T <sub>4</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	286245	575030	288785	2.01
T <sub>5</sub> – T <sub>1</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	286245	543580	257335	1.90
T <sub>6</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus pumilus</i> VLY 17	328645	572370	243725	1.74
T <sub>7</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus amyloliquefaciens</i> VLY 24	328645	656170	327525	2.00
T <sub>8</sub> – T <sub>2</sub> + Seed treatment with <i>Bacillus velezensis</i> PCSE 10	328645	659910	331265	2.01

FYM- Farm yard manure; RDN- Recommended dose of nutrients; KAU POP- Kerala Agricultural University Package of Practices.

# *Discussion*

---

## 5. DISCUSSION

The study entitled ‘Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains’ was carried out at the Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram and Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam, during the year 2023-2025. The results obtained are discussed in this chapter.

### 5.1 SEED BACTERIZATION AND BIOCHAR AMENDMENT ON THE GROWTH AND YIELD OF OKRA

#### 5.1.1 Growth Attributes of Okra

The height of the okra plants was observed at 30 DAS, 60 DAS and 90 DAS (Fig. 3). At 30 DAS, the treatment T<sub>8</sub> recorded significantly taller plants (20.10 cm) and was found to be on a par with treatments T<sub>7</sub> (19.87 cm), T<sub>4</sub> (19.83) and T<sub>2</sub> (18.03 cm). The taller plants in T<sub>8</sub> might be due to the combined effect of seed treatment with *Bacillus velezensis* PCSE 10 and the application of biochar in soil. Chen *et al.* (2019) had also observed enhanced plant height in peanut when inoculated with *Bacillus velezensis*. This significant enhancement in plant height could be due to the ability of the bacteria to solubilise phosphate, produce siderophores, and stimulate plant growth. Tu *et al.* (2025) opined that the genome of *B. velezensis* contains several genes that are associated with plant growth promotion activity (IAA synthesis and mineral phosphate solubilization). Vikram *et al.* (2024a) had reported that tender coconut husk biochar exhibited a water holding capacity of 232.32 per cent, attributed to its high pore space. The ability of tender coconut husk biochar to absorb and hold moisture in sandy loam soils might have contributed to the increased height of okra in T<sub>8</sub>, T<sub>7</sub> and T<sub>2</sub> at 30 DAS. Anwar *et al.* (2021) had also reported a 30 per cent increase in plant height for okra compared to the control with the application of wheat straw biochar. At 60 DAS, the treatment T<sub>7</sub> produced significantly taller plants (94.20 cm) and was found to be on a par with T<sub>8</sub> (87.73 cm) and T<sub>3</sub> (84.63 cm). This might be due to the combined effect of seed treatment with *Bacillus amyloliquefaciens* VLY 24 and the application of biochar in soil. According to Qin *et al.* (2017), inoculation of cucumber seedlings with *Bacillus amyloliquefaciens* significantly increased the shoot length due to the improved N uptake and the ability of the bacterium to solubilise potassium. Tian *et al.* (2023) observed that

*Bacillus amyloliquefaciens* produced growth-promoting compounds (such as IAA and siderophores) as well as phytohormones (cytokinin, zeatin, and abscisic acid), all of which contributed to an increase in plant height. The moisture retaining capacity of biochar might have contributed to the sustained increase in plant height even at 60 DAS, as observed in T<sub>7</sub> and T<sub>8</sub> treatments. Acharya *et al.* (2022) observed significantly taller plants in okra due to the application of biochar. This effect was associated with the ability of biochar to enhance soil fertility through improved nutrient loading and its plant growth-promoting properties. Oluleye *et al.* (2023) also obtained taller okra plants with biochar and NPK fertiliser. No significant difference in height was observed among the treatments during the later stages of growth.

The effect of treatments on the number of leaves per plant was evaluated at monthly intervals till 90 DAS (Fig. 4). In general, the number of leaves per plant was found to increase till 60 DAS; thereafter, it declined. Significant differences among the treatments were observed only at 60 DAS. Similar to the height of the plant at 60 DAS, the number of leaves per plant was also found to be significantly more in T<sub>7</sub> (23.73), which was at par with the treatments T<sub>4</sub> (22.47), T<sub>3</sub> (22.27), T<sub>8</sub> (22.07), T<sub>6</sub> (21.73), and T<sub>5</sub> (21.20). This result revealed that, in general, irrespective of the bacterial strain used, seed treatment significantly increased the number of leaves per plant in okra. Alexis *et al.* (2021) reported a significantly greater number of leaves per plant in okra, treated with *Bacillus amyloliquefaciens*, which was attributed to the rapid degradation of organic matter and the subsequent release of nutrients essential for plant growth. This might be the reason for the significantly higher number of leaves per plant for T<sub>7</sub> and T<sub>4</sub> treatments. Tian *et al.* (2023) had also observed that *Bacillus amyloliquefaciens* produced several growth-promoting metabolites along with phytohormones, all of which contributed to an increased number of leaves per plant. The application of biochar has been reported to raise the soil pH, enhance CEC and make available the soil nutrients to plants (Vikram *et al.*, 2025). The treatments involving biochar application (T<sub>6</sub>, T<sub>7</sub>, and T<sub>8</sub>) exhibited significantly higher uptake of P and K (Table 8), whereas N uptake of okra was significantly higher in the treatments T<sub>7</sub> and T<sub>8</sub>. Hence, the application of biochar might also have contributed to the significantly greater number of leaves per plant in okra for the treatments T<sub>7</sub> and T<sub>8</sub>. Madaki *et al.* (2025) also

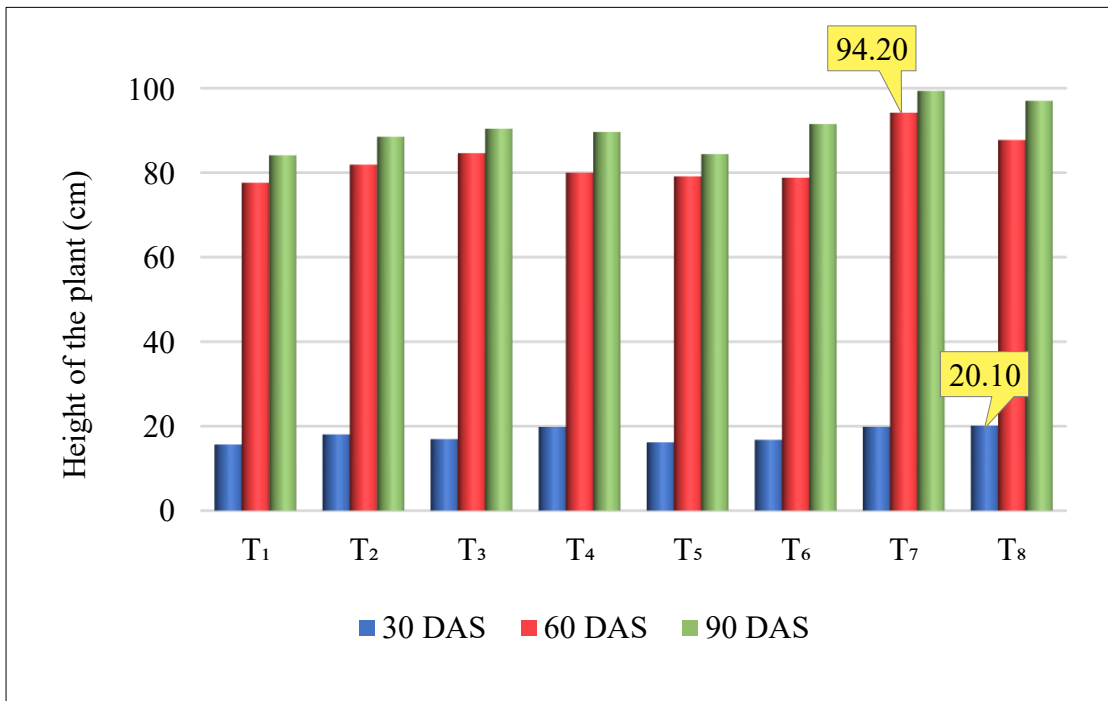


Fig. 3 Effect of seed bacterization and biochar amendment on the height of okra plants

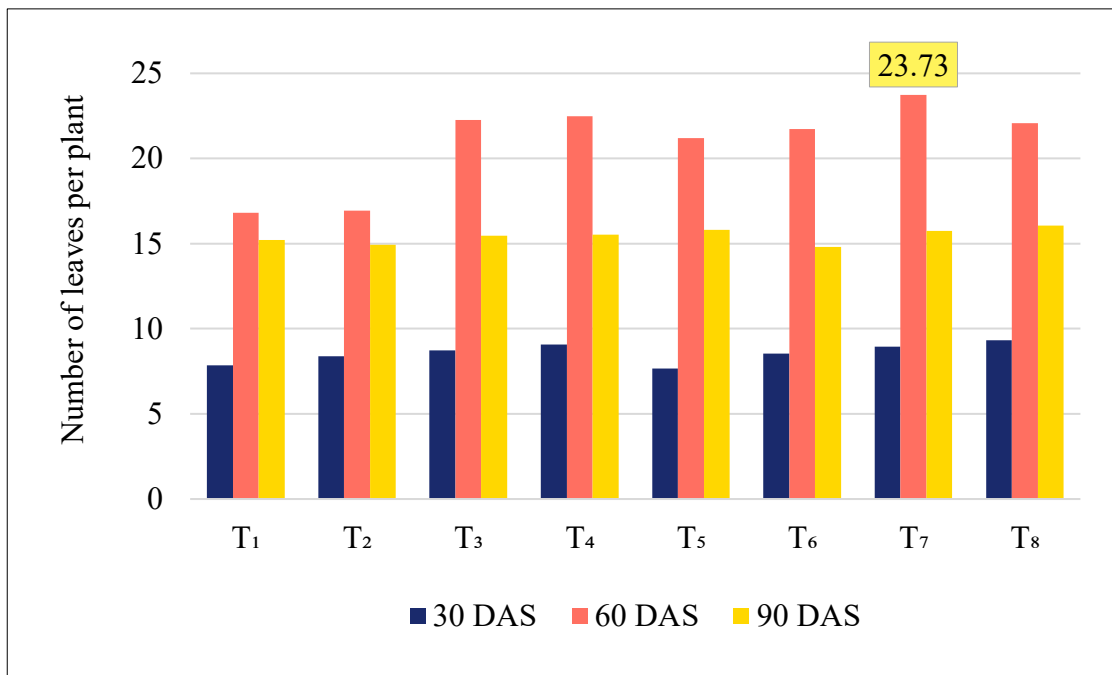


Fig. 4 Effect of seed bacterization and biochar amendment on number of leaves per plant

obtained a significantly greater number of leaves in okra that were applied with rice husk biochar. Punnoose and Anitha (2017) also obtained a greater number of leaves per plant in amaranthus that was supplied with biochar produced from woody wild growth, along with the recommended dose of NPK.

In general, like the number of leaves per plant, the leaf area index of okra also increased with the age of the crop till 60 DAS, which was then found to decline thereafter (Fig. 5). At 60 DAS, the treatment T<sub>7</sub> recorded significantly higher leaf area index (3.21) and was found to be on a par with the treatments T<sub>4</sub> (2.94), T<sub>8</sub> (2.93), T<sub>6</sub> (2.89) and T<sub>3</sub> (2.86). Tian *et al.* (2023) observed that *Bacillus amyloliquefaciens* produces compounds such as IAA and siderophores, along with phytohormones, all of which contribute to an increase in the number of leaves per plant and enhanced leaf area, which in turn increases the leaf area index. Sheteiwiy *et al.* (2021) observed 11-16 per cent increase in leaf area for soybean plants which were inoculated with *Bacillus amyloliquefaciens* and concluded that *B. amyloliquefaciens* had the ability to colonise the roots of plants and promote plant growth. The treatments that included biochar application (T<sub>6</sub>, T<sub>7</sub>, and T<sub>8</sub>) showed significantly higher uptake of P and K (Table 8), while N uptake was significantly increased in okra under treatments T<sub>7</sub> and T<sub>8</sub>. This improved nutrient uptake, particularly in T<sub>7</sub> and T<sub>8</sub>, might have contributed to the significantly higher LAI observed in okra under these treatments. Khan *et al.* (2021) observed that the LAI was found to be significantly higher when biochar loaded with N and biofertilisers was applied in wheat. Sánchez *et al.* (2025) also observed a 25 per cent increase in the number of leaves and 1.8-times higher leaf area index in lettuce due to the application of walnut shell biochar.

The effect of treatments on the relative growth rate of okra was recorded at 15 days intervals, *i.e.*, 30-45 DAS, 45-60 DAS and 60-75 DAS (Fig. 6). In general, similar to the number of leaves per plant, the RGR of plants were also found to increase till 60 DAS, thereafter it declined. Significantly higher RGR was observed at 30-45 DAS for the treatment T<sub>7</sub> (0.100 g g<sup>-1</sup> d<sup>-1</sup>), which was on a par with the treatments T<sub>5</sub> (0.093 g g<sup>-1</sup> d<sup>-1</sup>), T<sub>8</sub> (0.093 g g<sup>-1</sup> d<sup>-1</sup>), T<sub>6</sub> (0.090 g g<sup>-1</sup> d<sup>-1</sup>) and T<sub>1</sub> (0.083 g g<sup>-1</sup> d<sup>-1</sup>). The higher values observed for T<sub>7</sub> might be due to the combined effect of seed treatment with *Bacillus amyloliquefaciens* VLY 24 and soil application of biochar. Shao *et al.* (2014) reported

that *Bacillus amyloliquefaciens* produced the phytohormone IAA, emitted volatile compounds, and secreted various extracellular enzymes, all of which contributed to enhanced plant growth and directly increased the relative growth rate. Biochar in soil is known to increase soil nutrients, pH, porosity, and water availability, which are critical for plant growth. This improved nutrient status directly supports faster root and shoot development, leading to increased dry matter production (Joseph *et al.*, 2021), which might have resulted in higher RGR. Khan *et al.* (2022) also reported an increase in total dry matter production in maize when conditioned with biochar and straw mulch. The same trend was followed for RGR at 45-60 DAS. Significantly higher RGR was observed in T<sub>7</sub> (0.137 g g<sup>-1</sup> d<sup>-1</sup>) and was found to be on a par with the treatment T<sub>8</sub> (0.120 g g<sup>-1</sup> d<sup>-1</sup>). The synergistic effect of biochar and bacteria might have promoted vigorous vegetative growth in okra by significantly enhancing nitrogen uptake in the treatments T<sub>7</sub> and T<sub>8</sub> (Table 8).

The CGR of okra plants were also observed at 15 days intervals between 30-45 DAS, 45-60 DAS and 60-75 DAS (Fig. 7). The CGR was found to be increasing with the age of the crop till harvest. At 45-60 DAS, significantly higher CGR was found in T<sub>5</sub> (14.44 g m<sup>-2</sup> d<sup>-1</sup>), which was comparable with the treatments T<sub>6</sub> (14.26 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>7</sub> (13.33 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>4</sub> (13.27 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>3</sub> (13.15 g m<sup>-2</sup> d<sup>-1</sup>) and T<sub>8</sub> (12.34 g m<sup>-2</sup> d<sup>-1</sup>). This result reveals that, in general, regardless of the bacterial strain applied, seed treatment in okra had significantly increased the CGR of the plant between 45-60 DAS. Among the significantly influencing treatments, for T<sub>5</sub> and T<sub>8</sub>, seed treatment was done using *Bacillus velezensis* PCSE 10. According to Wang *et al.* (2022a), *Bacillus velezensis* has the ability to solubilise both organic and inorganic forms of phosphorus and secrete IAA, which in turn improves the morphological structure, element accumulation, nutrient uptake and utilisation, directly contributing to enhanced biomass of plants. Calzavara *et al.* (2021) had also reported a significantly higher biomass of tree species under nitrogen-deficient conditions, where rhizosphere inoculation with *Bacillus velezensis* ZK enhanced photosynthesis and nitrogen assimilation in plants. Wang *et al.* (2022a) also found that cucumber seedlings treated with *Bacillus velezensis* SX13 showed significant improvements in shoot dry weight by 18.81 per cent, and root dry weight by 21.60 per cent, thereby contributing to an increased CGR of the plants. The

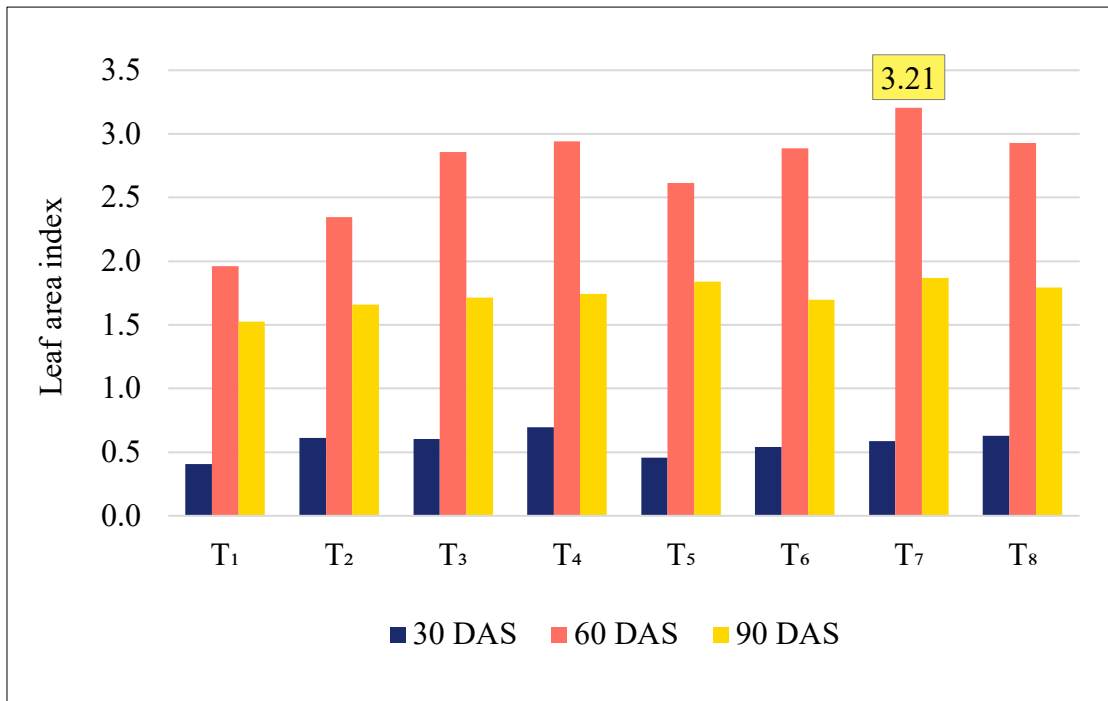


Fig. 5 Effect of seed bacterization and biochar amendment on leaf area index

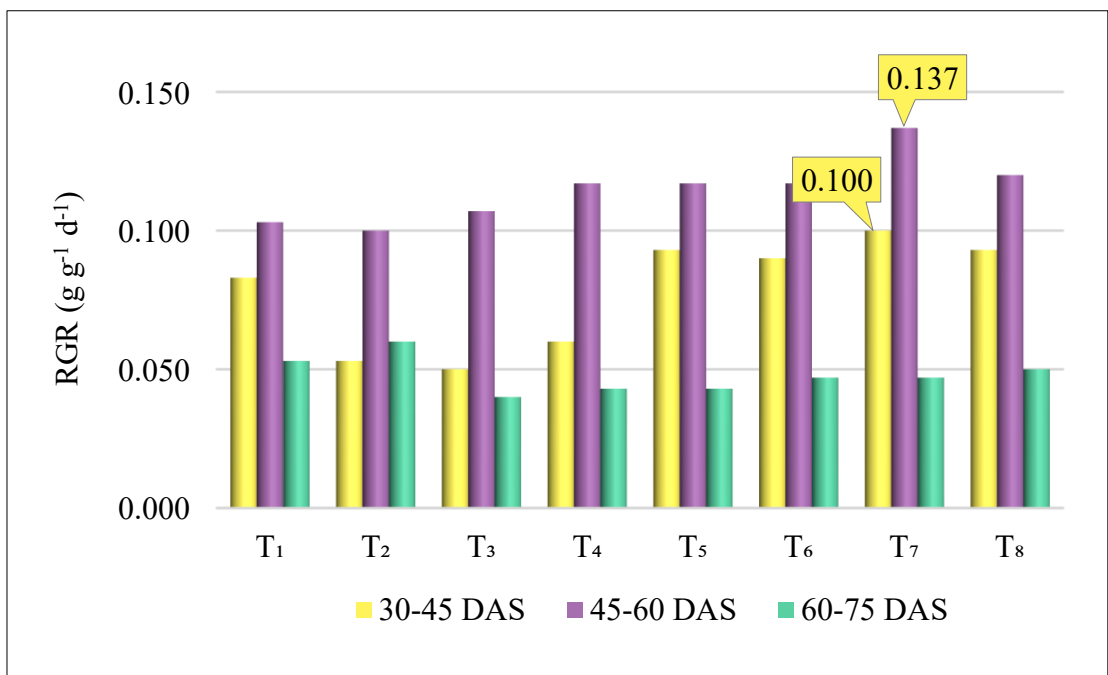


Fig. 6 Effect of seed bacterization and biochar amendment on relative growth rate

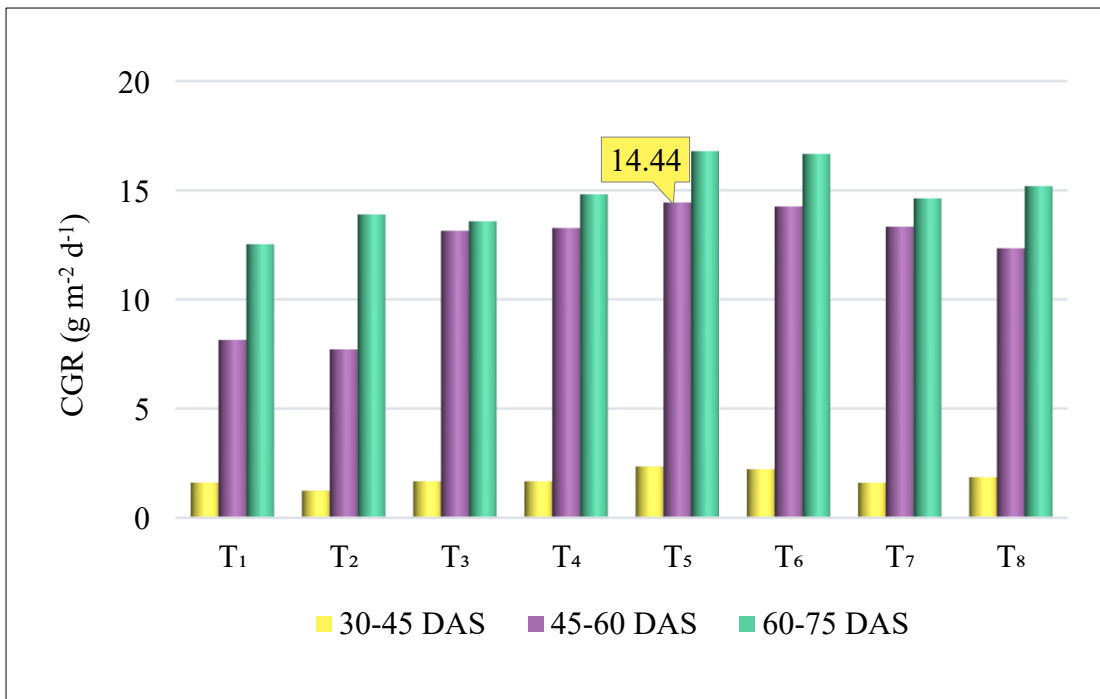


Fig. 7 Effect of seed bacterization and biochar amendment on crop growth rate

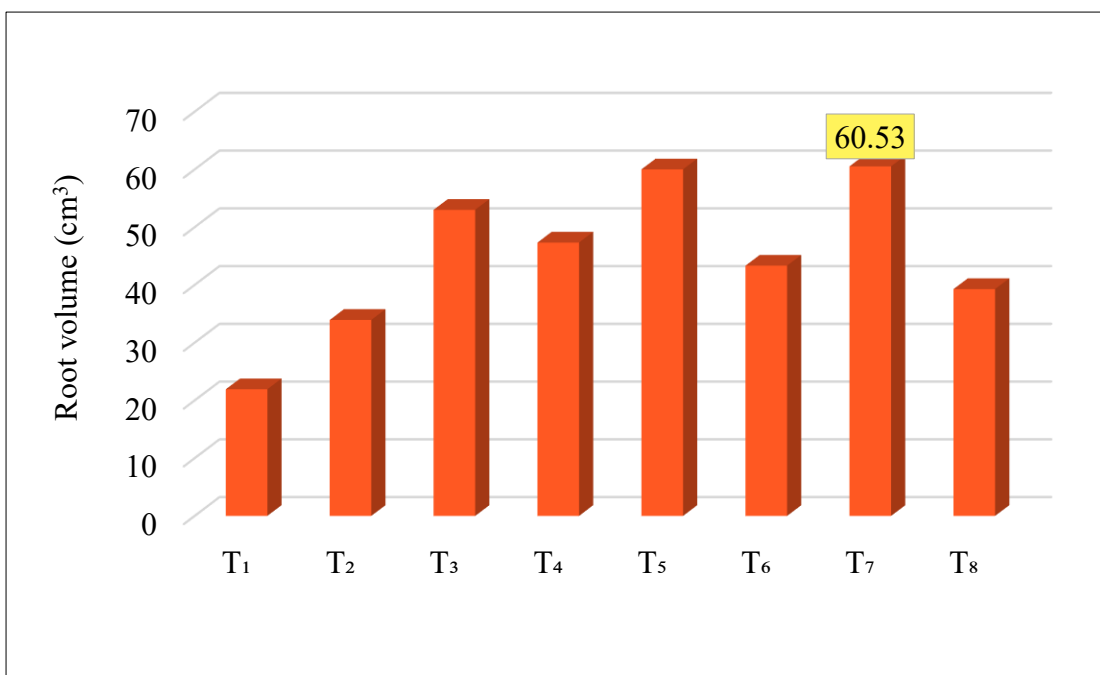


Fig. 8 Effect of seed bacterization and biochar amendment on root volume

biochar application has been reported to increase soil pH, enhance CEC, and promote the availability of essential nutrients for plant uptake (Vikram *et al.*, 2025), which might be the reason for the production of higher CGR in T<sub>6</sub>, T<sub>7</sub> and T<sub>8</sub> treatments.

The effects of different treatments on root depth and root volume were recorded at harvest. While the treatments had no significant effect on root depth, root volume was found to be significantly influenced by the treatments (Fig. 8). In general, seed treatment, irrespective of the bacterial strain applied, was found to improve the root volume in okra (treatments T<sub>3</sub> to T<sub>8</sub>). Among the treatments, T<sub>7</sub> recorded significantly higher root volume (60.53 cm<sup>3</sup>) and was observed to be on a par with the treatments T<sub>5</sub> (60.00 cm<sup>3</sup>) and T<sub>3</sub> (53.00 cm<sup>3</sup>). There was an over 176 per cent increase in root volume in T<sub>7</sub> compared to control (T<sub>1</sub>), which might be due to the synergistic effects of seed treatment with *Bacillus amyloliquefaciens* VLY 24 and soil application of biochar. *Bacillus amyloliquefaciens* possesses the ability to synthesise indole-3-acetic acid (IAA), a key phytohormone that is classified under natural auxins. Chebotar *et al.* (2022) have reported that auxin helps in stimulating root cell division, cell elongation and cell differentiation, contributing to the increased root volume. Luan *et al.* (2023) had reported that *Bacillus amyloliquefaciens* also secretes siderophores, which improve iron availability in the rhizosphere, thereby promoting more vigorous root development. All these factors might have contributed to the higher root volume in T<sub>7</sub> treatment. Earlier, Jamal *et al.* (2018) had reported significantly enhanced root biomass for pepper when *B. amyloliquefaciens* was applied in combination with chemical fertilisers. Yang *et al.* (2025) found that inoculation with *B. amyloliquefaciens* had promoted cluster root formation in white lupin (under P deficient conditions) by stimulating the biosynthesis and transport of auxin. Soil application of biochar was confined to the upper layer of soil, which might have concentrated the nutrients and moisture within the top 20 cm of soil. This stratification of resources might have created favourable conditions for lateral root expansion while limiting vertical root penetration. Due to the porous nature of biochar, there is a decrease in the bulk density of soil and enhanced expansion of okra roots for T<sub>7</sub> treatment. Jaborova *et al.* (2021) and Liu *et al.* (2021) had also reported increased root volume of okra by 28 per cent and 57.2 per cent, respectively, due to the

application of biochar. Similar findings of increased root volume in okra due to the application of tender coconut husk biochar were also reported by Vikram *et al.* (2024b).

### 5.1.2 Yield Attributes of Okra

The number of days to 50 per cent flowering was not found to be significantly different among the treatments, with plants across all treatments generally reaching 50 per cent flowering between 41 and 45 days after sowing.

The number of fruits per plant was significantly increased by the treatments (Fig. 9). In general, the plants that were conditioned with biochar (T<sub>2</sub>, T<sub>6</sub>, T<sub>7</sub> and T<sub>8</sub>) appeared to produce a higher number of fruits per plant. Notably, the treatment effects were statistically significant only for T<sub>8</sub> (30.00), which was comparable with the treatment T<sub>7</sub> (29.00). Dainy (2015) had observed a 30.77 per cent increase in the number of pods per plant for yard long bean with the application of tender coconut husk biochar. Corroborative results of an increased number of pods per plant in okra were also reported by Sikdar *et al.* (2023) in sandy soil supplemented with biochar. The plants in treatments T<sub>8</sub> and T<sub>7</sub> were seed treated with *Bacillus velezensis* PCSE 10 and *Bacillus amyloliquefaciens* VLY 24, respectively. The bacteria might have improved the mobility of nutrients from the soil, which might have increased the fruit production in okra. Balderas-Ruíz *et al.* (2021) also recorded an increased number of fruits per plant in tomato, which were treated with *Bacillus velezensis*.

Significantly higher fruit yield per plant (608.00 g) was recorded for the treatment T<sub>7</sub>, and was found to be statistically comparable with the treatment T<sub>8</sub> (607.33 g) (Fig. 10). Kim *et al.* (2017) reported that *Bacillus amyloliquefaciens* produces certain phytohormones, including gibberellins, which play a vital role in fruit development. This might be the reason for the increased fruit yield per plant in T<sub>7</sub>. The application of biochar might have also contributed to the significantly higher fruit yield per plant in T<sub>7</sub> and T<sub>8</sub>. Gairhe *et al.* (2024) reported that the cumulative benefits of biochar application, such as enhanced water holding capacity, increased organic matter content, improved nutrient uptake, and elevated photosynthetic activity, can collectively contribute to improved fruit development in plants. This might be another reason for the higher fruit yield per plant from T<sub>7</sub> and T<sub>8</sub> treatments. Similar reports of increased

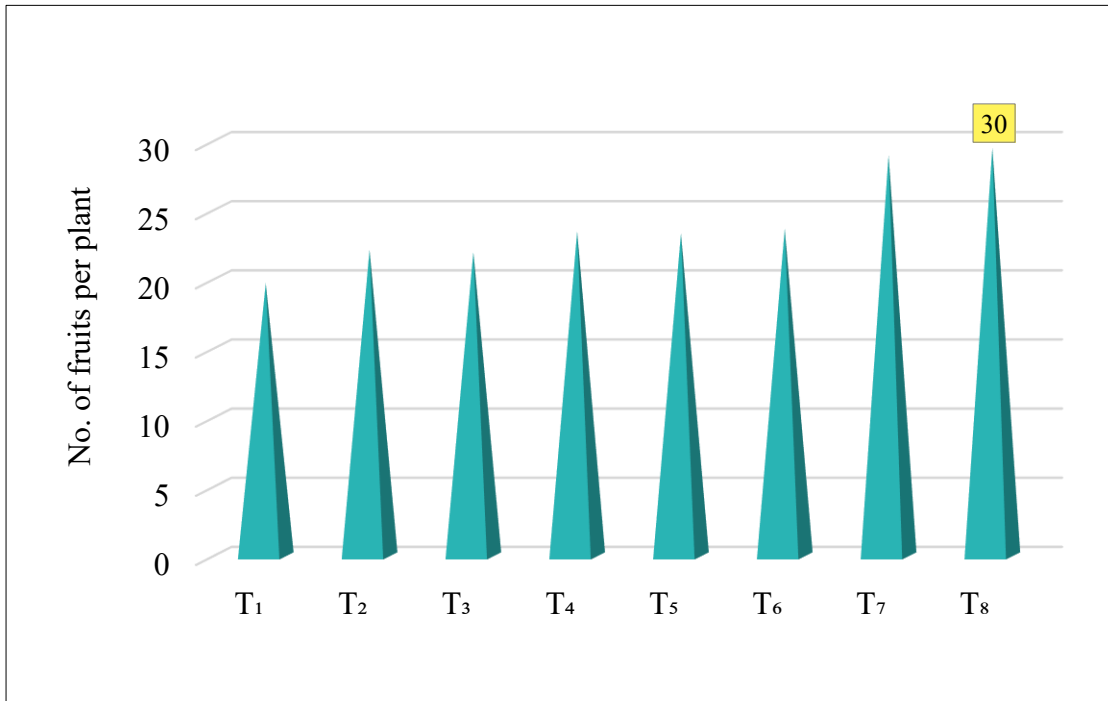


Fig. 9 Effect of seed bacterization and biochar amendment on number of fruits per plant

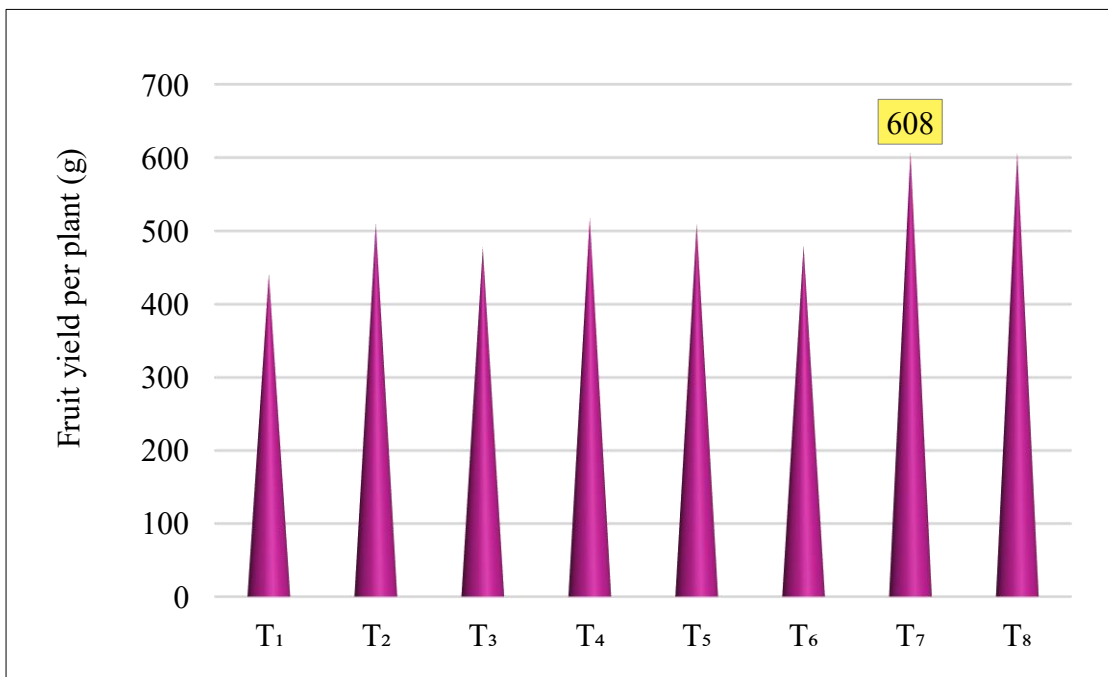


Fig. 10 Effect of seed bacterization and biochar amendment on fruit yield per plant

fruit yield per plant in okra were also reported by Sikdar *et al.* (2023) and Vikram *et al.* (2025) when the plants were conditioned with biochar. The okra plants in T<sub>7</sub> and T<sub>8</sub> were also observed to take up a higher quantity of N (Table 8) from the soil. Nitrogen is known to promote vegetative growth in plants, and hence, a higher N uptake by the plants in T<sub>7</sub> and T<sub>8</sub> could have enhanced the vegetative growth and photosynthetic capacity of the plant and led to the production of increased assimilates. The enhanced availability of assimilates might have ultimately contributed to the significantly higher fruit yield per plant.

Similar to fruit yield per plant, significantly higher yield per hectare was also recorded for the treatment T<sub>7</sub> (14.09 t ha<sup>-1</sup>) and was found comparable to the treatment T<sub>8</sub> (14.07 t ha<sup>-1</sup>) (Fig. 11). This significantly higher yield per hectare in okra for T<sub>7</sub> and T<sub>8</sub> is attributed to the significantly higher yield components such as number of fruits per plant and fruit yield per plant. Similar reports of increased fruit yield in okra (Alexis *et al.*, 2021; Acharya *et al.*, 2022 and Vikram *et al.*, 2025), radishes, lettuces, and sweet peppers (González-Pernas *et al.*, 2022) due to application of biochar have been widely reported.

Even though the fruit yield per plant and fruit yield per hectare were significantly higher for the treatments T<sub>7</sub> and T<sub>8</sub> (Fig. 12), the harvest index was found to be significantly higher for T<sub>2</sub> (0.72). The values were found to be comparable with T<sub>8</sub> (0.71), T<sub>7</sub> (0.70) and T<sub>1</sub> (0.69). Biochar incorporation in the treatments T<sub>2</sub>, T<sub>7</sub> and T<sub>8</sub> might have likely enhanced the nutrient availability, uptake and assimilation. This, in turn, might have contributed to an increased vegetative growth and economic yield in okra, thereby leading to a higher harvest index for T<sub>2</sub>, T<sub>7</sub> and T<sub>8</sub> treatments. For the treatment T<sub>1</sub>, a significant increase in HI might be due to the lower biological yield and economic yield. Dainy (2015) had also reported that the application of biochar resulted in significantly higher harvest index in yard long bean. Vikram *et al.* (2025) also observed an improved harvest index in okra when biochar was applied in combination with FYM and NPK fertilisers.

### 5.1.3 Quality Attributes of Okra

Significantly higher crude fibre content was recorded for the treatment T<sub>7</sub> (16.03%) and was found to be on a par with the treatments T<sub>5</sub> (15.01%) and T<sub>4</sub> (14.81%) (Fig. 13). In general, all the plants which received biochar produced significantly higher crude fibre content compared to the control. The significantly higher crude fibre content in T<sub>7</sub> could be attributed to the improved uptake of essential macronutrients (*viz.*, N and K- Table 8), which play a critical role in cell wall development and cellulose biosynthesis. Crude fibre is the indigestible portion of plant material, primarily comprising structural cell wall components such as cellulose, lignin, and hemicellulose. The enhanced availability and assimilation of these nutrients in T<sub>7</sub> might have promoted the synthesis and accumulation of these fibrous compounds in plant tissues. Similar reports of increased stem hemicellulose, lignin and cellulose in rice due to application of biochar were reported by Miao *et al.* (2023). Increased crude fibre content was also observed due to the application of biochar in tomato (Usman *et al.*, 2023) and okra (Vikram, 2024). *B. amyloliquefaciens* was also shown to stimulate lignin biosynthesis (Irizarry and White, 2018), which might have contributed to the increased fibre content. The application of PGPR was found to increase crude fibre in tomato (Katsenios *et al.*, 2021), sweet corn (Katsenios *et al.*, 2022), cellulose and lignin in wheat (Kolomiiets *et al.*, 2020) and lignin deposition in common bean (Lastochkina *et al.*, 2021).

### 5.1.4 Nutrient Uptake by Okra

The treatment T<sub>7</sub> (82.31 kg ha<sup>-1</sup>) had significantly enhanced the N uptake in okra and was found to be comparable with the treatment T<sub>8</sub> (79.75 kg ha<sup>-1</sup>) (Fig. 14). Hui *et al.* (2018) observed that *Bacillus amyloliquefaciens* increased the available N in soil by increasing the soil NO<sub>3</sub><sup>-</sup> and mineral N concentrations. This might have contributed to the significantly higher available N in soil (Table 10) and likely contributed to a significantly higher N uptake by okra in T<sub>7</sub>. Wang *et al.* (2022) also observed that *B. amyloliquefaciens* improved the N uptake and overall plant growth by enhancing root and shoot growth and nutrient assimilation. *Bacillus velezensis* was observed to enhance the process of soil mineralisation and nitrification (Huang *et al.*, 2024), which might be the reason for the higher available N in soil and higher uptake by okra in T<sub>8</sub>. The application of biochar might have reduced the leaching loss of fertilisers applied and

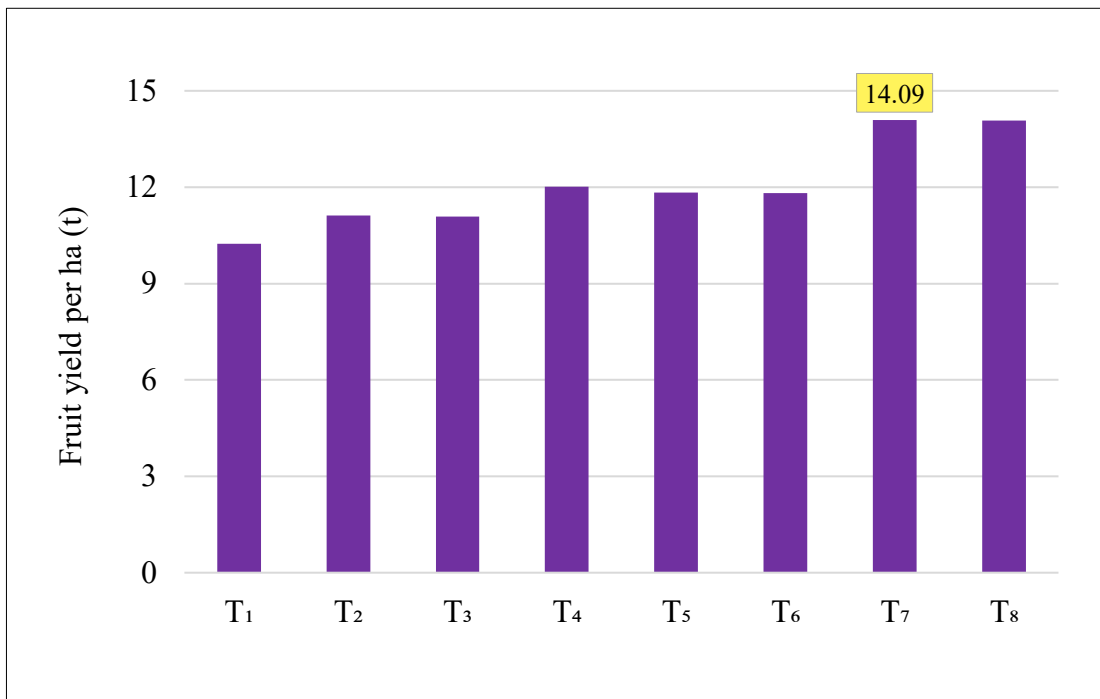


Fig. 11 Effect of seed bacterization and biochar amendment on fruit yield per ha

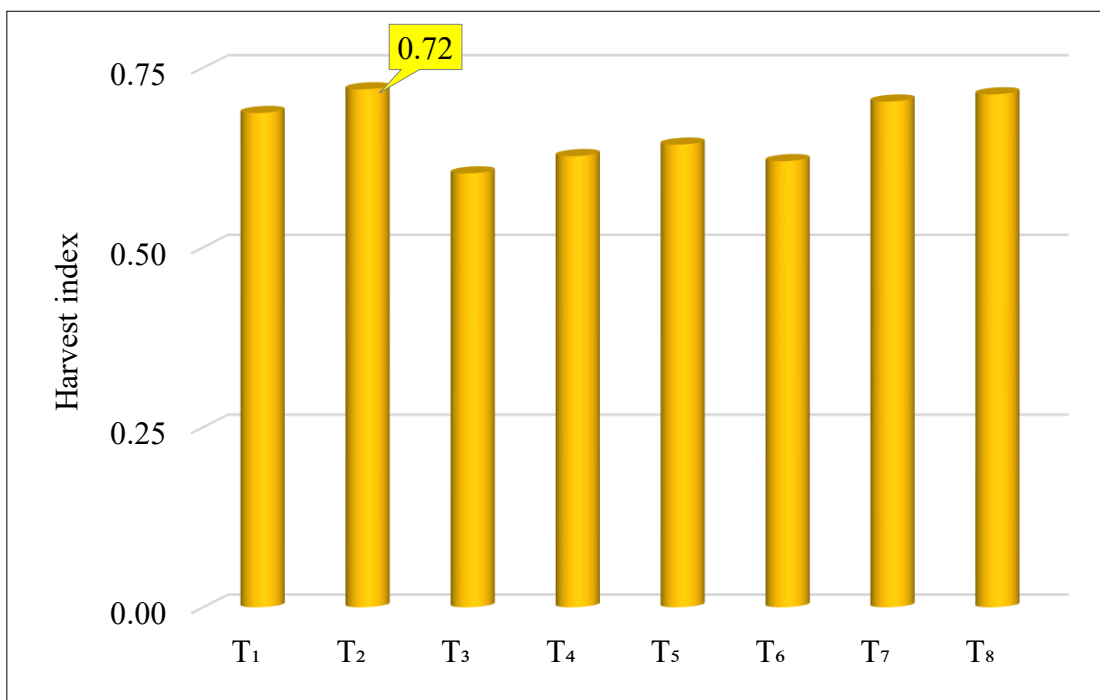


Fig. 12 Effect of seed bacterization and biochar amendment on harvest index

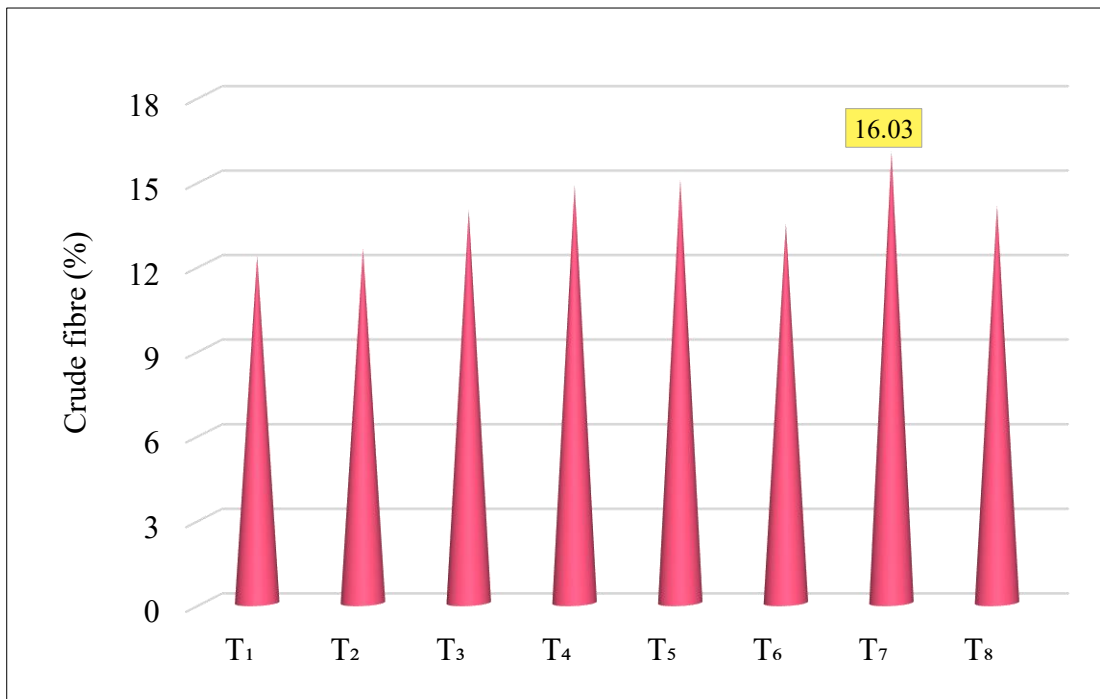


Fig. 13 Effect of seed bacterization and biochar amendment on crude fibre of okra fruits

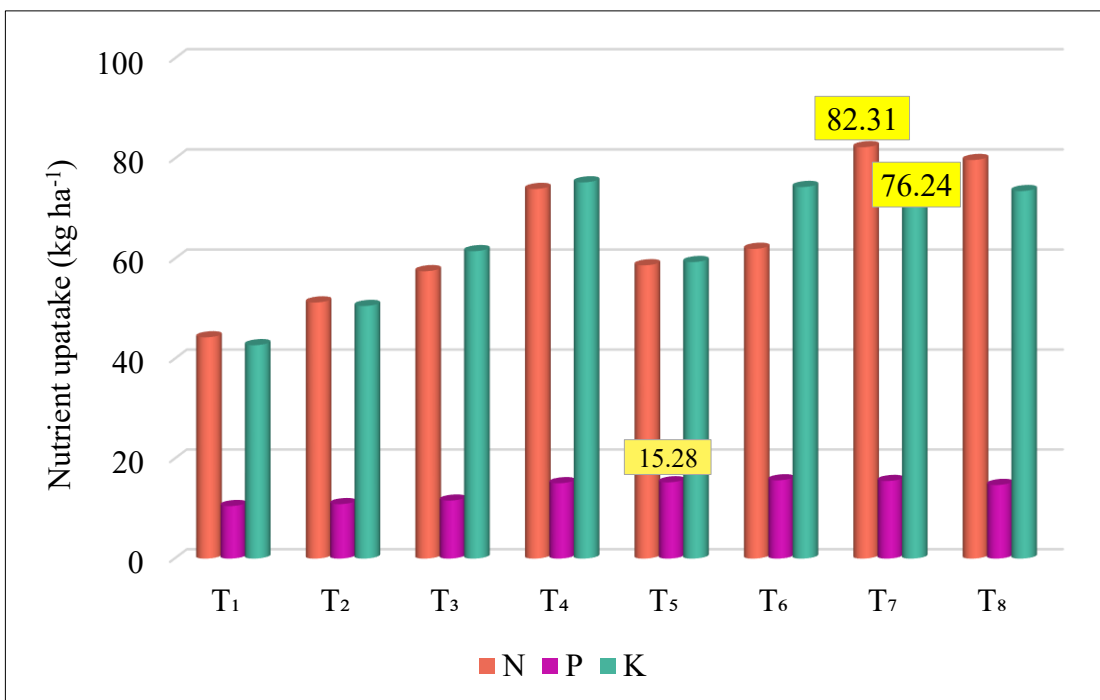


Fig. 14 Effect of seed bacterization and biochar amendment on uptake of N, P, and K by okra

likely helped in the retention of soil N in both T<sub>7</sub> and T<sub>8</sub> treatments. Similar results of enhanced N uptake due to the application of biochar were reported in maize (Peng *et al.*, 2021) and okra (Oluleye *et al.*, 2023).

Significantly higher P uptake was recorded for the treatment T<sub>6</sub> (15.68 kg ha<sup>-1</sup>) and was found to be on a par with the treatments T<sub>7</sub> (15.54 kg ha<sup>-1</sup>), T<sub>5</sub> (15.28 kg ha<sup>-1</sup>), T<sub>4</sub> (15.09 kg ha<sup>-1</sup>) and T<sub>8</sub> (14.74 kg ha<sup>-1</sup>) (Fig. 14). Patani *et al.* (2023) reported that *Bacillus pumilus* could solubilize phosphorus in soil and could produce siderophores. This might be the reason for the effective absorption of P from the soil. Colonisation of roots by *B. pumilus* was found to facilitate greater absorption of P in rice (Liu *et al.*, 2020). The application of biochar as a soil conditioner along with fertiliser was also found to increase the uptake of P in okra. This increased P uptake might be due to the ability of biochar to adsorb nutrients from the applied fertilisers, thereby causing a slow release of nutrients to the soil environment (Apori *et al.*, 2021). Dainy (2015) had observed the enhanced uptake of P in yard long bean with the application of tender coconut husk biochar at 20 t ha<sup>-1</sup> along with PGPR (2%) and NPK fertiliser. Phares *et al.* (2022) had also observed significantly increased P uptake in maize due to co-application of corn cob biochar, inorganic NPK fertiliser, and a mixed culture of *Bacillus* and *Pseudomonas*.

Significantly higher K uptake was recorded for the treatment T<sub>7</sub> (76.24 kg ha<sup>-1</sup>) and was found to be on a par with the treatments T<sub>4</sub> (75.29 kg ha<sup>-1</sup>), T<sub>6</sub> (74.36 kg ha<sup>-1</sup>), T<sub>8</sub> (73.55 kg ha<sup>-1</sup>), and T<sub>3</sub> (61.55 kg ha<sup>-1</sup>) (Fig. 14). The significant increase in uptake of K by okra might be due to the significantly higher K content in soil. Zafar-ul-Hye *et al.* (2019) observed that *Bacillus amyloliquefaciens* significantly enhanced the K concentrations in both grain and shoot of wheat, even in plants that were not conditioned with biochar. Shahzad *et al.* (2021) had also reported that the presence of *Bacillus* species in soil could enhance the availability of macro and micro nutrients from soil. This might be the reason for the higher uptake of K in okra by T<sub>7</sub>, T<sub>6</sub> and T<sub>8</sub>. Xiu *et al.* (2025) had reported that the application of biochar increased the available K pools in soil, enhancing the forms of K that were accessible to plant roots. A similar improvement in K availability due to the application of biochar might have subsequently facilitated a significant uptake of K in okra in T<sub>6</sub>, T<sub>7</sub> and T<sub>8</sub> treatments.

Enhanced uptake of K was observed in yard long bean (Dainy, 2015) and okra (Vikram *et al.*, 2024) due to the application of tender coconut husk biochar.

### 5.1.5 Soil Parameters After the Harvest of Okra

In general, all the plants conditioned with biochar had recorded a significantly higher water holding capacity (WHC) in soil (Fig. 15). The treatment T<sub>8</sub> recorded a significantly higher WHC of 38.61 per cent and was found to be on a par with the treatments T<sub>2</sub> (38.44%), T<sub>7</sub> (38.06%), T<sub>6</sub> (37.63%), T<sub>3</sub> (34.36%) and T<sub>5</sub> (34.27%). Biochar, due to its porous structure, has the ability to absorb and retain water within the soil matrix. Munir *et al.* (2025) observed that the application of biochar increased both mesoporosity and microporosity in soil, thereby enhancing its WHC. This structural improvement might be the reason for the significantly higher WHC observed in soils amended with biochar. Vikram *et al.* (2024) also observed that the application of tender coconut husk biochar along with FYM and RDF in okra increased the water holding capacity of soil.

The treatments significantly increased the available N in soil after the harvest of okra (Fig. 16). Among the treatments, T<sub>8</sub> recorded significantly higher available N (276.14 kg ha<sup>-1</sup>) and was found to be on a par with T<sub>6</sub> (260.21 kg ha<sup>-1</sup>), T<sub>7</sub> (254.89 kg ha<sup>-1</sup>) and T<sub>4</sub> (244.27 kg ha<sup>-1</sup>). The porous structure of biochar created favourable microsites for microbial colonisation, which in turn enhanced critical soil biological processes such as nitrogen mineralisation, nitrification, and the solubilisation of other essential nutrients (Acharya *et al.*, 2022). This might be the reason for the significantly higher available N content in soil for T<sub>8</sub>, T<sub>7</sub> and T<sub>6</sub> treatments. *Bacillus velezensis* plays an important role in the transformation of nitrogen in soil. The soil N in T<sub>8</sub> might have been transformed to a more available form by *Bacillus velezensis*. In a study by Shi *et al.* (2022), the inoculation of peach trees with *Bacillus velezensis* was found to significantly influence the soil N availability. Ninety days post-inoculation, the available nitrogen content in the soil increased by 22.42 per cent. Biochar has been shown to reduce nitrate-nitrogen leaching, enhance the nitrate retention capacity of soil, and decrease soil nitrate reductase activity, denitrification intensity, and nitrogen oxide emissions. Collectively, these effects contribute to a reduction in nitrogen losses through both leaching and volatilisation (Cong *et al.*, 2023). This finding aligns with the results

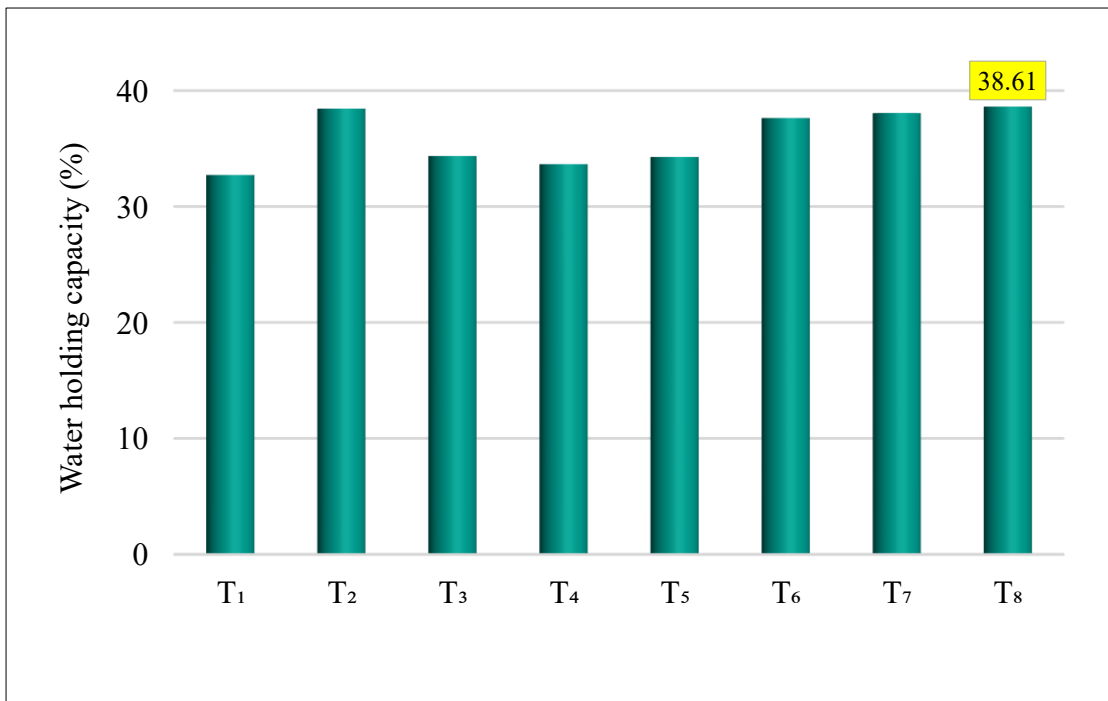


Fig. 15 Effect of seed bacterization and biochar amendment on WHC of soil after the harvest of okra

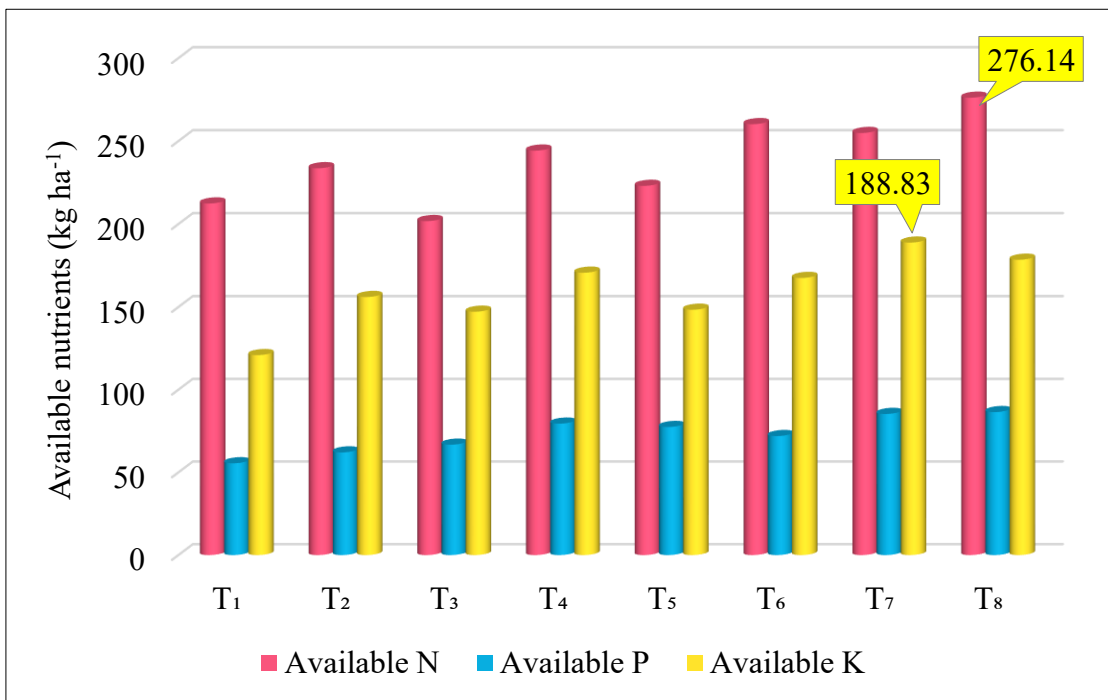


Fig. 16 Effect of seed bacterization and biochar amendment on available N, P, and K of soil after the harvest of okra

reported by Oluleye *et al.* (2023), who observed that the combined application of NPK fertiliser and biochar at 5 t ha<sup>-1</sup> in okra led to a 75 per cent increase in available nitrogen in the soil. Gairhe *et al.* (2024) also reported that the application of biochar at 18 t ha<sup>-1</sup> in okra increased the soil nitrogen content compared to the control.

There was no significant difference among treatments with respect to available phosphorus content in soil after the harvest of okra.

The treatment T<sub>7</sub> recorded a significantly higher available K (188.83 kg ha<sup>-1</sup>) and was found to be on a par with T<sub>8</sub> (178.49 kg ha<sup>-1</sup>), T<sub>4</sub> (170.69 kg ha<sup>-1</sup>) and T<sub>6</sub> (167.52 kg ha<sup>-1</sup>) (Fig. 16). *Bacillus amyloliquefaciens* has the ability to solubilise K (Verma *et al.*, 2015) in soils. The significantly higher content of available K in soil for the treatments T<sub>7</sub> and T<sub>4</sub> might be due to the increased K solubilising ability of *B. amyloliquefaciens*. Qin *et al.* (2017) observed that cucumber seedlings grown in substrates inoculated with *B. amyloliquefaciens* exhibited significantly higher levels of available K during the growth period. Gao *et al.* (2025) had also reported that the combination of *Bacillus amyloliquefaciens* and biochar in rice significantly enhanced soil available K by 45.9 per cent. In the treatments T<sub>7</sub>, T<sub>8</sub> and T<sub>6</sub>, biochar is used as a soil conditioner. Biochar contains a considerable amount of water-soluble potassium, which is present in the form of ionic salts. Vikram *et al.* (2024a) had also reported that biochar produced from tender coconut husk had a significantly higher percentage of potassium. Therefore, when applied to soil, a strong K fertiliser effect is formed. When the exchangeable and water-soluble K content in soil increases, they are naturally transformed into slow-release K, which is stored in the interlayers (Xiu *et al.*, 2025). This might have contributed to the significantly higher available K in T<sub>7</sub>, T<sub>8</sub> and T<sub>6</sub> treatments. Acharya *et al.* (2022) also reported that the application of biochar in combination with goat manure in okra significantly improved available potassium.

#### 5.1.6 Microbial Population After the Harvest of Okra

The fungal population in soil after the harvest of okra was found to be significantly influenced by the treatments (Fig. 17). Significantly higher fungal population was observed in the treatment T<sub>1</sub> (4.58 log CFU g<sup>-1</sup> soil), and it was on a par with T<sub>2</sub> (4.53 log CFU g<sup>-1</sup> soil). The acidic nature of the soil in the treatment T<sub>1</sub> (5.95

log CFU g<sup>-1</sup> soil) and T<sub>2</sub> (6.01 log CFU g<sup>-1</sup> soil) might have contributed to the observed fungal population. In general, the fungal population in soil was found to be significantly lower for seed treated plants. Some rhizobacteria tend to show anti-fungal properties, which might be the reason for significantly reduced soil population of fungi in the soil where the bacterized plants were grown (Bhattacharyya *et al.*, 2020).

Actinomycetes were observed to be significantly higher in T<sub>7</sub> (5.98 log CFU g<sup>-1</sup> soil) and was on a par with T<sub>2</sub> (5.91 log CFU g<sup>-1</sup> soil), T<sub>8</sub> (5.87 log CFU g<sup>-1</sup> soil), T<sub>1</sub> (5.84 log CFU g<sup>-1</sup> soil), T<sub>6</sub> (5.83 log CFU g<sup>-1</sup> soil) and T<sub>4</sub> (5.72 log CFU g<sup>-1</sup> soil) (Fig. 17). The microhabitat offered by application of biochar in T<sub>7</sub>, T<sub>2</sub>, T<sub>8</sub> and T<sub>6</sub> might have served as protection to the actinomycetes and acted as a rich source of carbon. This is in line with the findings of Gul *et al.* (2015), who explained that the internal surface area of biochar helped to adsorb more organic and inorganic compounds, thereby enhancing the mineral nutrients supply and energy to the soil microbial population. Actinomycetes are known to decompose the more resistant and indecomposable organic substances (Bhatti *et al.*, 2017). Hence, the actinomycetes inside biochar might have contributed to the significantly higher values of available N, P, and K in soil (Table 14).

## 5.2 ASSESSING THE RESIDUAL EFFECT OF SEED BACTERIZATION AND BIOCHAR AMENDMENT ON GROWTH AND YIELD OF AMARANTHUS

### 5.2.1 Residual Effect of Seed Bacterization and Biochar Amendment on the Yield of Sequential Crop of Amaranthus

The effect of treatments on the yield of amaranthus was not significant. The amaranthus variety used was KAU Vaika, which is a multi-cut variety. At harvest (40 DAS), there was heavy rainfall (224.80 mm - Fig.1) and the experimental field was flooded as Onattukara region has a higher water table. Hence, a single harvest could only be taken, which might be the reason for the non-significant difference in yield.

### 5.2.2 Residual Effect of Seed Bacterization and Biochar Amendment on the Nutrient Uptake of Amaranthus

The treatment T<sub>7</sub> (22.59 kg ha<sup>-1</sup>) recorded significantly higher N uptake by amaranthus and was on a par with T<sub>8</sub> (22.26 kg ha<sup>-1</sup>), T<sub>2</sub> (22.07 kg ha<sup>-1</sup>), T<sub>4</sub> (21.21 kg ha<sup>-1</sup>) and T<sub>6</sub> (21.10 kg ha<sup>-1</sup>) (Fig. 18). This could be attributed to the relatively higher

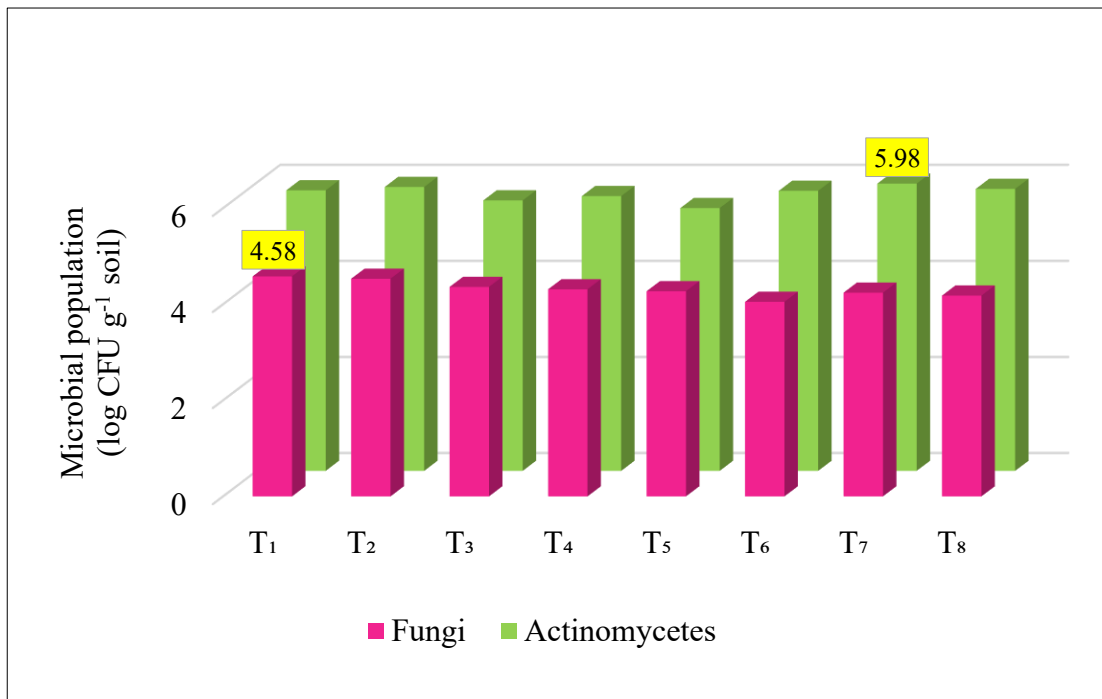


Fig. 17 Effect of seed bacterization and biochar amendment on microbial population of soil after the harvest of okra

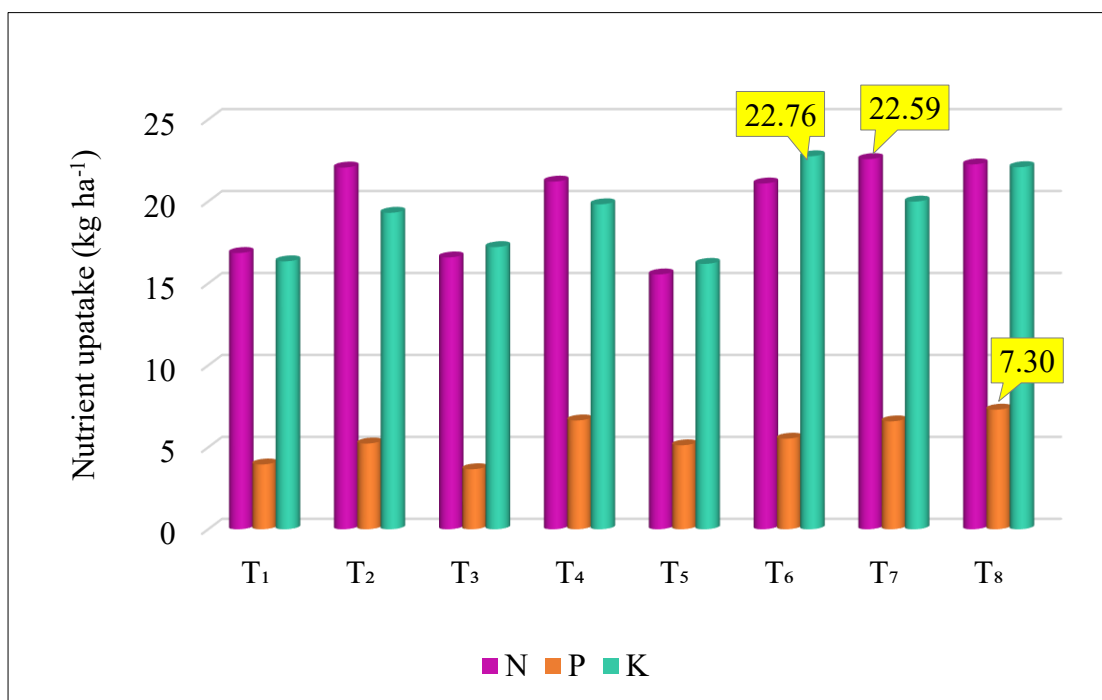


Fig. 18 Residual effect of seed bacterization and biochar amendment on uptake of N, P, and K by amaranthus

available nitrogen in the soil after the harvest of okra. In treatments T<sub>7</sub> and T<sub>4</sub>, *Bacillus amyloliquefaciens* VLY 24 was used for seed treatment in okra. The colonisation of the bacteria in soil might have improved the N uptake by solubilising ammonia. Xue *et al.* (2021) had also recorded an increased nitrogen recovery rate by 19 per cent and decreased ammonia volatilisation loss rate by 43 per cent in Chinese cabbage with the application of *B. amyloliquefaciens*. Kuzyakov *et al.* (2014) reported that, due to the long-term stability of biochar in soil, a single application may exert prolonged effects. This persistent presence of biochar in the soil could be a contributing factor to the higher nitrogen uptake observed in treatments T<sub>7</sub>, T<sub>8</sub>, T<sub>2</sub>, and T<sub>6</sub>. This is also in confirmation with the findings of Cong *et al.* (2023), who observed that one-time application of biochar seven years before had significantly increased the N uptake in maize.

Significantly higher P uptake was observed for the treatment T<sub>8</sub> (7.30 kg ha<sup>-1</sup>) and was found to be on a par with the treatments T<sub>4</sub> (6.64 kg ha<sup>-1</sup>) and T<sub>7</sub> (6.58 kg ha<sup>-1</sup>) (Fig. 18). Mosela *et al.* (2022) reported that *Bacillus velezensis* has several phosphatase genes that govern the solubilisation of phosphorus. These mechanisms of P solubilisation and mineralisation might have favoured an increase in P uptake in treatment T<sub>8</sub>. Similar reports of increased P content in the grains of soybean following application of *Bacillus velezensis* were also reported by Vitorino *et al.* (2024). Cong *et al.* (2023) also reported that a one-time application of biochar had significantly increased the P uptake in maize even after seven years. This might be the reason for the higher P uptake observed in treatments T<sub>7</sub> and T<sub>8</sub>.

Significantly higher K uptake (22.76 kg ha<sup>-1</sup>) was recorded for the treatment T<sub>6</sub> and was found to be on a par with the treatments T<sub>8</sub> (22.09 kg ha<sup>-1</sup>), T<sub>7</sub> (19.99 kg ha<sup>-1</sup>), T<sub>4</sub> (19.83 kg ha<sup>-1</sup>) and T<sub>2</sub> (19.31 kg ha<sup>-1</sup>) (Fig. 18). Win *et al.* (2019) reported that the production of plant growth regulators at the root interface due to the inoculation of plant growth promoting bacteria had improved the nutrient uptake in plants. This might be the reason for the significantly higher K uptake in amaranthus for T<sub>6</sub>, T<sub>8</sub>, T<sub>7</sub> and T<sub>4</sub> treatments. Nawaz *et al.* (2020) also observed an increased K uptake by wheat upon inoculation with *B. pumilus*. The application of biochar (in T<sub>6</sub>, T<sub>7</sub>, T<sub>8</sub> and T<sub>2</sub>) might have conditioned the soil in retaining higher concentrations of available K (after the harvest of okra), which might be the reason for the higher K uptake in amaranthus. This is in

confirmation with the findings of Kuo *et al.* (2020), who had also reported that application of biochar could reduce leaching and increase the availability of K to plants.

### 5.2.3 Residual Effect of Seed Bacterization and Biochar Amendment on the Soil Parameters After the Harvest of Amaranthus

Soil parameters such as WHC, pH, EC, CEC, OC and microbial population were found not significant after the harvest of amaranthus. The higher rainfall of 224.80 mm (Fig. 1), along with the flooded condition at Onattukara during the harvest of amaranthus, might have caused non-significant residual effect of treatments on these soil parameters.

Among the different treatments, the treatment T<sub>8</sub> recorded significantly higher available N (196.48 kg ha<sup>-1</sup>) which was found to be on a par with the treatments T<sub>6</sub> (180.55 kg ha<sup>-1</sup>) and T<sub>7</sub> (175.24 kg ha<sup>-1</sup>) (Fig. 19). The application of biochar might have retained the available N in soil which might be the reason for the significantly higher available N in T<sub>8</sub>, T<sub>6</sub> and T<sub>7</sub> treatments. Similar reports of increased absorption of total soluble N and increased nutrient retention capacity of soil were reported by Adekiya *et al.* (2020) due to the application of biochar. Wijitkosum *et al.* (2025) also reported that a one-time application of biochar in maize had increased the soil N up to the second crop cycle.

The treatment T<sub>7</sub> recorded significantly higher available P of 62.38 kg ha<sup>-1</sup> (Fig. 19). The treatment T<sub>7</sub> was found to be on a par with the treatments T<sub>4</sub> (61.42 kg ha<sup>-1</sup>), T<sub>8</sub> (61.23 kg ha<sup>-1</sup>) and T<sub>5</sub> (57.35 kg ha<sup>-1</sup>). The significant increase in soil available P for the treatments T<sub>7</sub> and T<sub>8</sub> might be due to the ability of biochar to adsorb plant nutrients on its surface and gradually release them. Frimpong *et al.* (2021) also observed that a single application of biochar in a maize, okra and cassava cropping sequence resulted in increased available phosphorus.

The treatment T<sub>7</sub> recorded significantly higher available K (128.66 kg ha<sup>-1</sup>) and was found to be on a par with T<sub>8</sub> (125.72 kg ha<sup>-1</sup>), T<sub>4</sub> (122.07 kg ha<sup>-1</sup>) and T<sub>6</sub> (116.98 kg ha<sup>-1</sup>) (Fig. 19). The presence of cation exchange sites on the surface of biochar increases the retention of available K in soil (Adekiya *et al.*, 2020). Moreover, the higher porosity and larger specific surface area of biochar, as applied in treatments T<sub>7</sub>, T<sub>8</sub> and

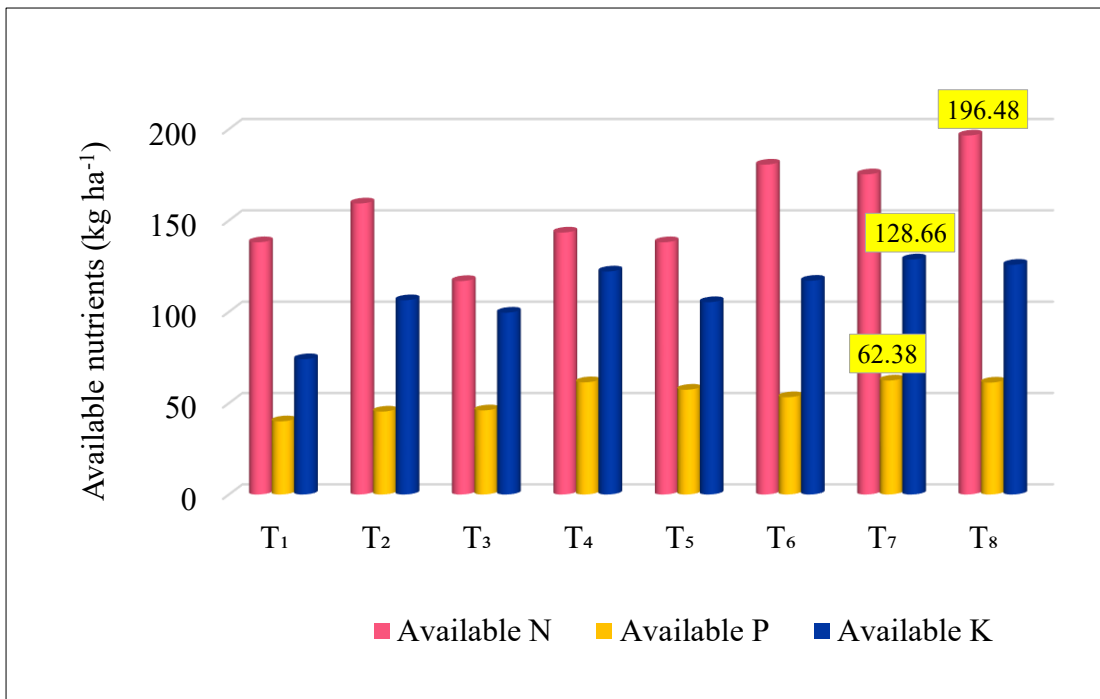


Fig. 19 Residual effect of seed bacterization and biochar amendment on available N, P, and K in soil after the harvest of amaranthus

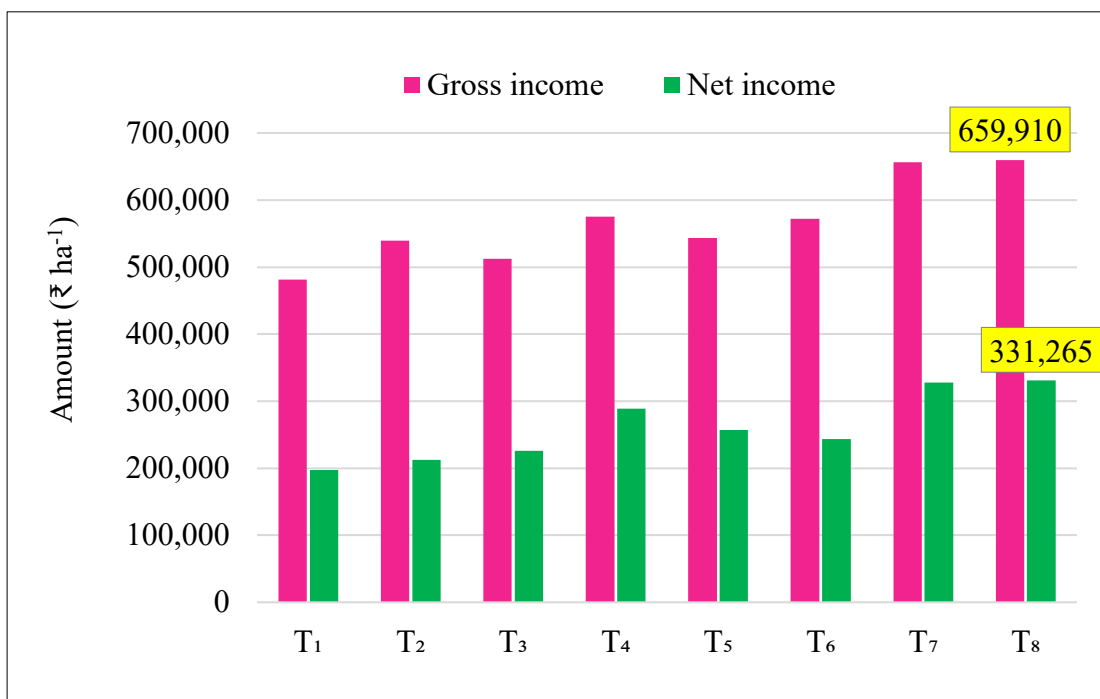


Fig. 20 Effect of seed bacterization and biochar amendment on economics of cultivation

T<sub>6</sub>, confer excellent adsorption capacity. This characteristic likely reduced the leaching of available K and might have accounted for the significantly increased K availability. Zhang *et al.* (2022) also reported that application of biochar had significantly enhanced the K availability in soil, even after four years of application. Bao *et al.* (2024) also observed that one time application of biochar along with NPK fertilisers resulted in higher water-soluble K in soil even after nine years.

### 5.3 OKRA EQUIVALENT YIELD

The higher okra equivalent yield was obtained with T<sub>8</sub> (18.85 t ha<sup>-1</sup>) and was followed by T<sub>7</sub> (18.75 t ha<sup>-1</sup>) and T<sub>4</sub> (16.43 t ha<sup>-1</sup>).

### 5.4 ECONOMICS OF CULTIVATION

The results on economics of cultivation are presented in Fig. 20. The highest gross income (₹ 6,59,910 ha<sup>-1</sup>) was recorded for the treatment T<sub>8</sub> (T<sub>2</sub> + Seed treatment with *Bacillus velezensis* PCSE 10), followed by T<sub>7</sub> (₹ 6,56,170 ha<sup>-1</sup>). Net income also followed the same trend. Higher net income was obtained from T<sub>8</sub> (₹ 3,31,265 ha<sup>-1</sup>) followed by T<sub>7</sub> (₹ 3,27,525 ha<sup>-1</sup>). The BC ratio was found to be higher for T<sub>8</sub> (2.01) and T<sub>4</sub> (2.01), followed by T<sub>7</sub> (2.00).

The present study revealed that the growth and yield of okra, followed by a sequential bulk crop of amaranthus, could be significantly influenced by seed treatment with beneficial bacteria, combined with the application of biochar (5 t ha<sup>-1</sup>), FYM (5 t ha<sup>-1</sup>) and the full recommended dose of nutrients under the sandy loam soil conditions of Onattukara.

# *Summary*

---

## 6. SUMMARY

The investigation entitled ‘Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains’ was conducted at the Department of Agronomy, College of Agriculture, Vellayani, during 2023-2025. The objectives were to assess the effect of seed bacterization and biochar amendment on the growth and yield of okra and to analyse the residual effect of treatments on the sequential crop of amaranthus in Onattukara.

The experiment was conducted at the Instructional Farm attached to Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam, from January to May 2025. Okra var. Varsha Uphar was used as the first crop, followed by the bulk crop of amaranthus, var. KAU Vaika. The experiment was done in two parts, where in the first part, the experiment was laid out in a randomised block design with eight treatments, which were replicated thrice. The treatments were T<sub>1</sub> (FYM 20 t ha<sup>-1</sup> + 100% RDN (KAU POP)), T<sub>2</sub> (5 t ha<sup>-1</sup> biochar + 5 t ha<sup>-1</sup> FYM+100% RDN), T<sub>3</sub> (T<sub>1</sub> + Seed treatment with *Bacillus pumilus* VLY 17), T<sub>4</sub> (T<sub>1</sub> + Seed treatment with *Bacillus amyloliquefaciens* VLY 24), T<sub>5</sub> (T<sub>1</sub> + Seed treatment with *Bacillus velezensis* PCSE 10), T<sub>6</sub> (T<sub>2</sub> + Seed treatment with *Bacillus pumilus* VLY 17), T<sub>7</sub> (T<sub>2</sub> + Seed treatment with *Bacillus amyloliquefaciens* VLY 24), and T<sub>8</sub> (T<sub>2</sub> + Seed treatment with *Bacillus velezensis* PCSE 10). In the treatments T<sub>3</sub> to T<sub>8</sub>, seeds of okra were treated with isolates of *Bacillus pumilus* VLY 17, *Bacillus amyloliquefaciens* VLY 24, and *Bacillus velezensis* PCSE 10, which were obtained from the Department of Agricultural Microbiology. The treated okra seeds were sown at a spacing of 60 cm x 30 cm. Biochar prepared from tender coconut husk was applied during land preparation as per treatments. All the cultural practices for the crop were done as per the package of practices recommendations of Kerala Agricultural University. For the sequentially cropped amaranthus, seeds were broadcasted in the same plots and were raised as a bulk crop without manuring. The observations on growth, yield, quality parameters, nutrient uptake and soil properties were statistically analysed, and salient findings of the study are briefed below.

The growth attributes, viz., height of the okra plants, number of leaves per plant, LAI, RGR, CGR, and root volume, were significantly influenced by the combined application of biochar and beneficial bacteria. At 60 DAS, the treatment T<sub>7</sub> resulted in

significantly taller plants (94.20 cm), higher number of leaves per plant (23.73) and higher LAI (3.21). The treatment T<sub>7</sub> also resulted in significantly higher RGR during 30-45 DAS (0.100 g g<sup>-1</sup> d<sup>-1</sup>), 45-60 DAS (0.137 g g<sup>-1</sup> d<sup>-1</sup>), and root volume at harvest (60.53 cm<sup>3</sup>). Significantly higher CGR (14.44 g m<sup>-2</sup> d<sup>-1</sup>) was observed in T<sub>5</sub> during 45-60 DAS, which remained comparable with T<sub>6</sub> (14.26 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>7</sub> (13.33 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>4</sub> (13.27 g m<sup>-2</sup> d<sup>-1</sup>), T<sub>3</sub> (13.15 g m<sup>-2</sup> d<sup>-1</sup>) and T<sub>8</sub> (12.34 g m<sup>-2</sup> d<sup>-1</sup>). This might be due to the combined effect of seed treatment and the application of biochar in soil, where beneficial bacteria might have solubilised phosphate, produced siderophores, and stimulated plant growth, while tender coconut husk biochar might have absorbed and held moisture in sandy loam soils, contributing to the increased growth attributes.

In general, the yield and yield attributes were found to be higher in plants that were conditioned with biochar (T<sub>2</sub>, T<sub>6</sub>, T<sub>7</sub> and T<sub>8</sub>). Significantly higher number of fruits per plant was obtained from T<sub>8</sub> (30.00), and was comparable with the treatment T<sub>7</sub> (29.00). Fruit yield per plant (608.00 g) and yield per hectare (14.09 t ha<sup>-1</sup>) were found to be significantly higher in T<sub>7</sub> and were comparable with T<sub>8</sub> treatment. The bacteria might have produced phytohormones, improved the nutrient mobility in soil, and biochar might have concentrated the nutrients near the root zone of okra, which could be the reason for increased fruit production. Harvest index was found to be significantly higher for T<sub>2</sub> (0.72) could be due to increased biological and economic yield.

All the plants which received biochar produced significantly higher crude fibre content compared to the control. Higher crude fibre content was observed for the treatment T<sub>7</sub> (16.03%). The treatments had no significant effect on vitamin C content.

The plants that were conditioned with biochar and treated with bacteria had significantly improved the uptake of N, P and K in okra. The treatment T<sub>7</sub> significantly increased the N uptake (82.31 kg ha<sup>-1</sup>) and K uptake (76.24 kg ha<sup>-1</sup>) in okra, but significantly higher P uptake was observed for the treatment T<sub>6</sub> (15.68 kg ha<sup>-1</sup>). This was found to be on a par with the treatments T<sub>7</sub>, T<sub>5</sub>, T<sub>4</sub>, and T<sub>8</sub>. Increased nutrient uptake and plant growth might be due to enhanced root growth and nutrient assimilation in plants.

Among the soil parameters, treatments supplemented with biochar produced significantly higher WHC. The treatment T<sub>8</sub> (38.61%) produced significantly higher water holding capacity and was comparable with the treatments T<sub>2</sub>, T<sub>7</sub>, T<sub>6</sub>, T<sub>3</sub>, and T<sub>5</sub>. The porous structure of biochar might have adsorbed and retained moisture, increasing the WHC. The treatment T<sub>8</sub> recorded significantly higher available N (276.14 kg ha<sup>-1</sup>), while T<sub>7</sub> recorded significantly increased available K (188.83 kg ha<sup>-1</sup>). The ability of bacteria to transform N and solubilise K, along with the ability of biochar to retain nutrients and produce a K fertiliser effect, could be the reason for increased availability of N and K in soil.

Among the microbial populations in soil after the harvest of okra, the fungal population was significantly higher in the treatment T<sub>1</sub> (4.58 log CFU g<sup>-1</sup> soil) and was on a par with T<sub>2</sub>, while actinomycetes were observed to be significantly higher in T<sub>7</sub> (5.98).

For sequentially cropped amaranthus, the treatments could not produce any significant effects on yield. The uptake of N, P and K by amaranthus was significantly influenced by the treatments. Treatment T<sub>7</sub> recorded significantly higher N uptake (22.59 kg ha<sup>-1</sup>) and was comparable with the treatments T<sub>8</sub>, T<sub>2</sub>, T<sub>4</sub>, and T<sub>6</sub>. Significantly higher P uptake (7.30 kg ha<sup>-1</sup>) was recorded for the treatment T<sub>8</sub> and was found to be on a par with the treatments T<sub>4</sub> and T<sub>7</sub>, while K uptake (22.76 kg ha<sup>-1</sup>) was significantly higher in T<sub>6</sub> and was comparable with T<sub>8</sub>, T<sub>7</sub>, T<sub>4</sub>, and T<sub>2</sub>.

Among the soil parameters, after the harvest of amaranthus, the treatment T<sub>8</sub> recorded significantly higher available N (196.48 kg ha<sup>-1</sup>), while the treatment T<sub>7</sub> recorded significantly higher available P (62.38 kg ha<sup>-1</sup>) and higher available K (128.66 kg ha<sup>-1</sup>).

The results of the economic analysis revealed that higher gross income (₹ 6,59,910 ha<sup>-1</sup>) and net income (₹ 3,31,265 ha<sup>-1</sup>) were recorded for the treatment T<sub>8</sub> followed by T<sub>7</sub>. The BC ratio was found to be higher for T<sub>8</sub> (2.01) and T<sub>4</sub> (2.01), followed by T<sub>7</sub> (2.00).

The findings of the study revealed that seed treatment with beneficial bacteria, combined with the application of biochar (5 t ha<sup>-1</sup>), farm yard manure (5 t ha<sup>-1</sup>), and the full RDN (110:35:70 kg N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O ha<sup>-1</sup>), could significantly enhance the growth and yield of okra and the sequential bulk crop of amaranthus under sandy loam soil conditions of Onattukara.

#### FUTURE LINES OF WORK

- Experiment can be planned with different levels of RDN.
- Bacterial treatments can be explored with other application methods such as foliar spraying, soil drenching, or root dipping.
- The synergistic effects of biochar and bacterial inoculants can be explored to understand their role in soil health management.
- The bacterial strains applied as treatments can be re-isolated to study the bacterial population after the crop period.

# *References*

---

## 7. REFERENCES

- Abdallah, D. B., Frikha-Gargouri, O., and Tounsi, S. 2018. Rhizospheric competence, plant growth promotion and biocontrol efficacy of *Bacillus amyloliquefaciens* subsp. *plantarum* strain 32a. *Biol. Control* 124: 61-67.
- Acharya, N., Vista, S. P., Shrestha, S., Neupane, N., and Pandit, N. R. 2022. Potential of biochar-based organic fertilizers on increasing soil fertility, available nutrients, and okra productivity in slightly acidic sandy loam soil. *Nitrogen* 4(1): 1-15.
- Adekiya, A. O., Agbede, T. M., Olayanju, A., Ejue, W. S., Adekanye, T. A., Adenusi, T. T., and Ayeni, J. F. 2020. Effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam alfisol. *Sci. World J.* 2020(1): 9391630.
- Alexis, Z. P., Martial, T. T., and Pierre-François, D. 2021. Influence of the beneficial microorganisms bioformulations on the soil physicochemical parameters and the nutritional profile of *Abelmoschus esculentus* cultivated in Cameroon. *J. Agric. Ecol. Res. Int.* 22(5): 1-18.
- Ali, A. B., Elshaikh, N. A., Hussien, G., Abdallah, F. E., and Hassan, S. 2020. Biochar addition for enhanced cucumber fruit quality under deficit irrigation. *Biosci. J.* 36(6): 1930-1937.
- Ali, I., Yuan, P., Ullah, S., Iqbal, A., Zhao, Q., Liang, H., Khan, A., Imran, Zhang, H., Wu, X., Wei, S., Gu, M., and Jiang, L. 2022. Biochar amendment and nitrogen fertilizer contribute to the changes in soil properties and microbial communities in a paddy field. *Front. Microbiol.* 13: 834751.
- Anith, K.N., Radhakrishnan, N. V., and Manomohandas, T. P. 2003. Screening of antagonistic bacteria for biological control of nursery wilt of black pepper (*Piper nigrum*). *Microbiol. Res.* 158(2): 91-97.
- Anwar, H., Wang, X., Hussain, A., Rafay, M., Ahmad, M., Latif, M., Jamshaid, M. U., Khalid, I., Dar, A., and Mustafa, A. 2021. Comparative effects of bio-wastes in combination with plant growth-promoting bacteria on growth and productivity of okra. *Agronomy* 11(10): 2065.

- Apori, S. O., Byalebeka, J., Murongo, M., Ssekandi, J., and Noel, G. L. 2021. Effect of co-applied corncob biochar with farmyard manure and NPK fertilizer on tropical soil. *Res. Environ. Sustain.* 5: 100034.
- Athira, P. V., Radhakrishnan, N. V., and Anith, K. N. 2021. Seed biopriming and spraying at fruit set with microbial agents suppress anthracnose disease and improve growth and yield in chilli. *J. Tropic. Agric.* 59(2).
- Atlas, R. M. and Parks, L. C. 1993. *Microbiological media*. Boca Raton. FL: CRC Press. 1079p.
- Balderas-Ruíz, K. A., Gómez-Guerrero, C. I., Trujillo-Roldán, M. A., Valdez-Cruz, N. A., Aranda-Ocampo, S., Juárez, A. M., Leyva, E., Galindo, E., and Serrano-Carreón, L. 2021. *Bacillus velezensis* 83 increases productivity and quality of tomato (*Solanum lycopersicum* L.): Pre and postharvest assessment. *Curr. Res. Microb. Sci.* 2: 100076.
- Bao, Z., Dai, W., Su, X., Liu, Z., An, Z., Sun, Q., Jing, H., Lin, L., Chen, Y., and Meng, J. 2024. Long-term biochar application promoted soil aggregate-associated potassium availability and maize potassium uptake. *GCB Bioenergy* 16: e13134.
- Bhattacharyya, C., Banerjee, S., Acharya, U., Mitra, A., Mallick, I., Haldar, A., Haldar, S., Ghosh, A., and Ghosh, A. 2020. Evaluation of plant growth promotion properties and induction of antioxidative defense mechanism by tea rhizobacteria of Darjeeling, India. *Sci. Rep.* 10: 15536.
- Bhatti, A. A., Haq, S., and Bhat, R. A. 2017. Actinomycetes benefaction role in soil and plant health. *Microb. Pathog.* 111: 458-467.
- Bouyoucos, G. J., 1962. Hydrometer method improved for making particle size analyses of soils 1. *Agron. J.* 54(5): 464-465.
- Calzavara, A. K., Hertel, M. F., Debiasi, T. V., Tiepo, A. N., Oliveira, A. L. M. D., Oliveira, H. C., Stolf-Moreira, R., and Pimenta, J. A. 2021. Does inoculation with associative bacteria improve tolerance to nitrogen deficiency in seedlings of neotropical tree species? *Environ. Exp. Bot.* 189: 104529.

- Cappuccino, J. G. and Sherman, N. 1996. *Microbiology-A Laboratory Manual* (4<sup>th</sup> Ed.). The Benjamin/ Cummings Publishing Company Inc., California, 213p.
- Chebotar, V. K., Chizhevskaya, E. P., Vorobyov, N. I., Bobkova, V. V., Pomyaksheva, L. V., Khomyakov, Y. V., and Konovalov, S. N. 2022. The quality and productivity of strawberry (*Fragaria* × *ananassa* Duch.) improved by the inoculation of PGPR *Bacillus velezensis* BS89 in field experiments. *Agronomy* 12(11): 2600.
- Chen, L., Shi, H., Heng, J., Wang, D., and Bian, K. 2019. Antimicrobial, plant growth promoting and genomic properties of the peanut endophyte *Bacillus velezensis* LDO2. *Microbiol. Res.* 218: 41-48.
- Chen, T. Y., Tzean, Y., Chang, T. D., Wang, X. R., Yang, C. M., and Lin, Y. H. 2024. Characterization of biofertilization and biocontrol potential of *Bacillus velezensis* KHH13 from organic soils. *Agronomy* 14: 1135.
- Chen, X. H., Scholz, R., Borris, M., Junge, H., Mogel, G., Kunz, S., and Borris, R. 2009. Difficidin and bacilysin produced by plant-associated *Bacillus amyloliquefaciens* are efficient in controlling fire blight disease. *J. Biotechnol.* 140(1-2): 38-44.
- Chen, X., Yang, F., Bai, C., Shi, Q., Hu, S., Tang, X., Peng, L., and Ding, H. 2022. *Bacillus velezensis* strain GUMT319 reshapes soil microbiome biodiversity and increases grape yields. *Biology* 11: 1486.
- Cheng, Y., Jiang, X., He, X., Wu, Z., Lv, Q., Zhao, S., Zhang, X., Wang, S., He, H., and Liu, J. 2025. *Bacillus velezensis* 20507 promotes symbiosis between *Bradyrhizobium japonicum* USDA110 and soybean by secreting flavonoids. *Front. Microbiol.* 16:1572568.
- Choub, V., Ajuna, H. B., Won, S. J., Moon, J. H., Choi, S. I., Maung, C. E. H., Kim, C. W., and Ahn, Y. S. 2021. Antifungal activity of *Bacillus velezensis* CE 100 against anthracnose disease (*Colletotrichum gloeosporioides*) and growth promotion of walnut (*Juglans regia* L.) trees. *Int. J. Mol. Sci.* 22: 10438.

- Cisternas-Jamet, J., Salvatierra-Martínez, R., Vega-Gálvez, A., Stoll, A., Uribe, E., and Goñi, M. G. 2020. Biochemical composition as a function of fruit maturity stage of bell pepper (*Capsicum annum*) inoculated with *Bacillus amyloliquefaciens*. *Sci. Hortic.* 263: 109107.
- Cong, M., Hu, Y., Sun, X., Yan, H., Yu, G., Tang, G., Chen, S., Xu, W., and Jia, H. 2023. Long-term effects of biochar application on the growth and physiological characteristics of maize. *Front. Plant Sci.* 14: 1172425.
- Dainy, M. M. S. 2015. Investigations on the efficacy of biochar from tender coconut husk for enhanced crop production. Ph.D. (Ag.) thesis, Kerala Agricultural University, Thrissur, 208p.
- Dhouib, H., Zouari, I., Abdallah, D. B., Belbahri, L., Taktak, W., Triki, M. A., and Tounsi, S. 2019. Potential of a novel endophytic *Bacillus velezensis* in tomato growth promotion and protection against Verticillium wilt disease. *Biol. Control* 139: 104092.
- Dipta, B., Kirti, S., Bhardwaj, S., Gupta, S., and Kaushal, R. 2017. Phosphate solubilizing potential of *Bacillus pumilus* for the enhancement of Cauliflower (*Brassica oleracea* var. *botrytis* L.). *Ecol. Environ. Conserv.* 23(3): 1541-1548.
- Dobrzynski, J., Jakubowska, Z., and Dybek, B. 2022. Potential of *Bacillus pumilus* to directly promote plant growth. *Front. Microbiol.* 13:1069053.
- Donald, C. M. and Hamblin, J. 1976. Biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Adv. Agron.* 28: 361-405.
- Evans, G. C. 1972. *The quantitative analysis of plant growth*. Oxford: Blackwell Scientific Publications, 295p.
- Frimpong, K. A., Phares, C. A., Boateng, I., Abban-Baidoo, E., and Apuri, L. 2021. One-time application of biochar influenced crop yield across three cropping cycles on tropical sandy loam soil in Ghana. *Heliyon* 7: e06267.

- Gairhe, J. J., Bhattarai, P., Gyanwali, P., Khanal, R., Mainali, R., Poudel, S., Pokhrel, M., and Sharma, P. K. 2024. Effect of various biochar on selected soil properties and agronomical parameters of okra (*Abelmoschus esculentus* L.) at Rupandehi, Nepal. *Arch. Agric. Environ. Sci.* 9(1): 134-142.
- Gao, G., Li, X., Ma, J., Cui, Y., Ying, M., Huang, L., and Li, M., 2025. *Bacillus amyloliquefaciens* SQ-2 and biochar: A promising combination for enhancing rice growth in Pb/Al-contaminated acidic soils. *Microorganisms* 13: 1556.
- Gao, W., Gao, K., Guo, Z., Liu, Y., Jiang, L., Liu, C., Liu, X., and Wang, G. 2021. Different responses of soil bacterial and fungal communities to 3 years of biochar amendment in an alkaline soybean soil. *Front. Microbiol.* 12: 630418.
- González-Pernas, F. M., Grajera-Antolín, C., García-Cámara, O., González-Lucas, M., Martín, M. T., González-Egido, S., and Aguirre, J. L. 2022. Effects of biochar on biointensive horticultural crops and its economic viability in the Mediterranean climate. *Energies* 15(9): 3407.
- Gopinath, P. P., Parsad, R., Joseph, B., and Adarsh, V. S. 2020. GRAPES: General R shiny based analysis platform empowered by statistics. Available: <https://www.kaugrapes.com/>
- Gul, A., Kidoglu, F., Tüzel, Y., and Tüzel, I. H., 2008. Effects of nutrition and *Bacillus amyloliquefaciens* on tomato (*Solanum lycopersicum* L.) growing in perlite. *Span. J. Agric. Res.* 6(3): 422-429.
- Gul, S., Whalen, J. K., Thomas, B. W., Sachdeva, V., and Deng, H. 2015. Physico-chemical properties and microbial responses in biochar-amended soils: Mechanisms and future directions. *Agric. Ecosyst. Environ.* 206: 46-59.
- Hasan, N., Khan, I. U., Farzand, A., Heng, Z., Moosa, A., Saleem, M., and Canning, T. 2022. *Bacillus altitudinis* HNH7 and *Bacillus velezensis* HNH9 promote plant growth through upregulation of growth-promoting genes in upland cotton. *J. Appl. Microbiol.* 132: 3812-3824.

- Hong, S., Kim, T. Y., Won, S. J., Moon, J. H., Ajuna, H. B., Kim, K. Y., and Ahn, Y. S. 2022. Control of fungal diseases and fruit yield improvement of strawberry using *Bacillus velezensis* CE 100. *Microorganisms* 10: 365.
- Huang, M., Zhang, Y., Yu, Q., Qian, S., Shi, Y., Zhang, N., Michelsen, A., Zhang, J., Müller, C., Li, S., Zhang, R., Shen, Q., and Zou, J. 2024. *Bacillus velezensis* SQR9-induced ammonia-oxidizing bacteria stimulate gross nitrification rates in acidic soils. *Appl. Soil Ecol.* 201: 105503.
- Hui, C., Sun, P., Guo, X., Jiang, H., Zhao, Y., and Xu, L. 2018. Shifts in microbial community structure and soil nitrogen mineralization following short-term soil amendment with the ammonifier *Bacillus amyloliquefaciens* DT. *Int. Biodeterior. Biodegrad.* 132: 40-48.
- Ilmiah, H. H., Sulistyaningsih, E., and Joko, T. 2021. Fruit morphology, antioxidant activity, total phenolic and flavonoid contents of *Salacca zalacca* (Gaertner) Voss by applications of goat manures and *Bacillus velezensis* B-27. *J. Sustain. Agric.* 36(2): 270-282
- Irizarry, I. and White, J. F. 2018. *Bacillus amyloliquefaciens* alters gene expression, ROS production and lignin synthesis in cotton seedling roots. *J. Appl. Microbiol.* 124: 1589-1603.
- Jaborova, D., Annapurna, K., Al-Sadi, A. M., Alharbi, S. A., Datta, R., and Zuan, A. T. K. 2021. Biochar and Arbuscular mycorrhizal fungi mediated enhanced drought tolerance in okra (*Abelmoschus esculentus*) plant growth, root morphological traits and physiological properties. *Saudi J. Biol. Sci.* 28(10): 5490-5499.
- Jabin, N. P. P. 2022. Biochar for carbon sequestration, soil health and crop productivity. Ph.D. (Ag.) thesis, Kerala Agricultural University, Thrissur, 311p.
- Jabin, N. P. P. and Rani, B., 2020. Biochar effects on CO<sub>2</sub> emission and nitrogen mineralization in sandy and laterite soils. *Int. J. Chem. Stud.* 8(4): 2913-2916.
- Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi, 489p.

- Jamal, Q., Lee, Y. S., Jeon, H. D., and Kim, K. Y. 2018. Effect of plant growth-promoting bacteria *Bacillus amyloliquefaciens* Y1 on soil properties, pepper seedling growth, rhizosphere bacterial flora and soil enzymes. *Plant Protect. Sci.* 54(3): 129–137.
- Joo, G. J., Kim, Y. M., Kim, J. T., Rhee, I. K., Kim, J. H., and Lee, I. J. 2005. Gibberellins producing rhizobacteria increase endogenous gibberellins content and promote growth of red peppers. *J. Microbiol.* 43(6): 510-515.
- Joseph, S., Cowie, A. L., Zwieten, L. W., Bolan, N., Budai, A., Buss, W., Cayuela, M. L., Graber, E. R., Ippolito, J. A., Kuzyakov, Y., Luo, Y., Ok, Y. S., Palansooriya, K. N., Shepherd, J., Stephens, S., Weng, Z., and Lehmann, J. 2021. How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. *GCB Bioenergy* 13(11): 1731-1764.
- Kamalraj, R., Nandhivarman, M., Poyyamoli, G., Gowthamraj, G., and Priyadharshini, S. 2017. Effect of inorganic and organic amendments on the proximate composition of okra [*Abelmoschus esculentus* (L) Moench]. *J. Adv. Food Sci. Technol.* 4(2): 67-72.
- Katsenios, N., Andreou, V., Sparangis, P., Djordjevic, N., Giannoglou, M., Chanioti, S., Stergiou, P., Xanthou, M., Kakabouki, I., Vlachakis, D., Djordjevic, S., Katsaros, G., and Efthimiadou, A. 2021. Evaluation of plant growth promoting bacteria strains on growth, yield and quality of industrial tomato. *Microorganisms* 9(10): 2099.
- Katsenios, N., Andreou, V., Sparangis, P., Djordjevic, N., Giannoglou, M., Chanioti, S., Kasimatis, C., Kakabouki, I., Leonidakis, D., Danalatos, N., Katsaros, G., and Efthimiadou, A. 2022. Assessment of plant growth promoting bacteria strains on growth, yield and quality of sweet corn. *Sci. Rep.* 12: 11598.
- KAU [Kerala Agricultural University] 2024. *Package of Practices Recommendations: Crops* (16<sup>th</sup> Ed.). Kerala Agricultural University, Thrissur, 434p.

- Kaushal, M., Mandyal, P., and Kaushal, R. 2019. Field based assessment of *Capsicum annuum* performance with inoculation of rhizobacterial consortia. *Microorganisms* 7(3): 89.
- Khan, I., Iqbal, B., Khan, A. A., Inamullah, Rehman, A., Fayyaz, A., Shakoor, A., Farooq, T. H., and Wang, L. X. 2022. The interactive impact of straw mulch and biochar application positively enhanced the growth indexes of maize (*Zea mays* L.) crop. *Agronomy* 12(10): 2584.
- Khan, Z., Rahman, M. H. U., Haider, G., Amir, R., Ikram, R. M., Ahmad, S., Schofield, H. K., Riaz, B., Iqbal, R., Fahad, S., Datta, R., Baazeem, A., Sabagh, A. E., and Danish, S. 2021. Chemical and biological enhancement effects of biochar on wheat growth and yield under arid field conditions. *Sustainability* 13(11): 5890.
- Kim, M. J., Radhakrishnan, R., Kang, S. M., You, Y. H., Jeong, E. J., Kim, J. G., and Lee, I. J. 2017. Plant growth promoting effect of *Bacillus amyloliquefaciens* H-2-5 on crop plants and influence on physiological changes in soybean under soil salinity. *Physiol. Mol. Biol. Plants* 23(3): 571-580.
- Kolomiets, Y. V., Grigoryuk, I. P., Likhanov, A. F., Butsenko, L. M., Pasichnyk, L. A., and Blume, Y. B. 2020. Induction of wheat resistance against the causative agent of basal bacteriosis with growth-promoting bacteria. *Cytol. Genet.* 54(6): 514-21.
- Kumar, A., Singh, S., Mukherjee, A., Rastogi, R. P., and Verma, J. P. 2021. Salt-tolerant plant growth-promoting *Bacillus pumilus* strain JPVS11 to enhance plant growth attributes of rice and improve soil health under salinity stress. *Microbiol. Res.* 242: 126616.
- Kuo, Y. L., Lee, C. H., and Jien, S. H. 2020. Reduction of nutrient leaching potential in coarse-textured soil by using biochar. *Water* 12: 2012.
- Kuzyakov, Y., Bogomolova, I., and Glaser, B. 2014. Biochar stability in soil: Decomposition during eight years and transformation as assessed by compound-specific <sup>14</sup>C analysis. *Soil Biol. Biochem.* 70: 229-236.

- Lastochkina, O., Aliniaiefard, S., Garshina, D., Garipova, S., Pusenkova, L., Allagulova, C., Fedorova, K., Baymiev, A., Koryakov, I., and Sobhani, M. 2021. Seed priming with endophytic *Bacillus subtilis* strain-specifically improves growth of *Phaseolus vulgaris* plants under normal and salinity conditions and exerts anti-stress effect through induced lignin deposition in roots and decreased oxidative and osmotic damages. *J. Plant Physiol.* 263: 153462.
- Le, T. H., Vu, D. N., Nguyen, T. H. P., Le, M. H., Nguyen, C. T., Do, T. T., Le, V. T., Pham, M. P., and Vu, D. D., 2025. Amending coral soil using exopolysaccharide from salt-tolerant *Bacillus velezensis* TSD5 bacteria from an atoll in Vietnam. *J. Appl. Biol. Biotechnol.* 13(5): 151-162
- Li, W., Sun, L., Wu, H., Gu, W., Lu, Y., Liu, C., Zhang, J., Li, W., Zhou, C., Geng, H., Li, Y., Peng, H., Shi, C., Wang, D., and Peng, G. 2024b. *Bacillus velezensis* YXDHD1-7 prevents early blight disease by promoting growth and enhancing defense enzyme activities in tomato plants. *Microorganisms* 12: 921.
- Li, Z., Hao, Y., Li, H., Fu, T., Li, J., Peng, Y., Chang, J., Chen, L., Xie, D., Chen, X., Gu, W., Song, Z., and Zhang, B. 2024a. Biochar improves wax gourd (*Benincasa hispida* (Thunb.) Cogn.) yield and quality by regulating the chemical properties of acidic soil and promoting nutrient uptake. *Agronomy* 14: 1750.
- Liu, H., Wang, Z., Xu, W., Zeng, J., Li, L., Li, S., and Gao, Z. 2020. *Bacillus pumilus* LZP02 promotes rice root growth by improving carbohydrate metabolism and phenylpropanoid biosynthesis. *Mol. Plant Microbe Interact.* 33(10): 1222-1231.
- Liu, Q., Meki, K., and Ma, X. 2021. Enhanced growth of okra (*Abelmoschus esculentus*) in soil amended with biochar and fulvic acid. In: *E3S Web of Conferences*, 251: 02067.
- Liu, Y., Wang, L., Peng, J., Wang, C., and Wang, M. 2025. Effect of *Bacillus velezensis* GHt-q6 on Cucumber Root Soil Microecology and Root-Knot Nematodes. *Agronomy* 15: 1000.

- Lu, K., Jin, Q., Lin, Y., Lu, W., Li, S., Zhou, C., Jin, J., Jiang, Q., Ling, L., and Xiao, M. 2020. Cell-free fermentation broth of *Bacillus velezensis* strain S3-1 improves pak choi nutritional quality and changes the bacterial community structure of the rhizosphere soil. *Front. Microbiol.* 11:2043.
- Luan, P., Yi, Y., Huang, Y., Cui, L., Hou, Z., Zhu, L., Ren, X., Jia, S., and Liu, Y. 2023. Biocontrol potential and action mechanism of *Bacillus amyloliquefaciens* DB2 on *Bipolaris sorokiniana*. *Front. Microbiol.* 14: 1149363.
- Luo, L., Zhao, C., Wang, E., Raza, A., and Yin, C. 2022. *Bacillus amyloliquefaciens* as an excellent agent for biofertilizer and biocontrol in agriculture: An overview for its mechanisms. *Microbiol. Res.* 259: 127016.
- Lv, D., Zhang, L., Guo, Y., Zhao, F., Cao, Z., Jha, S. K., Kpalari, D. F., and Wang, X. 2025. Effect of *Bacillus velezensis* on the structure of the rhizosphere microbial community and yield of soybean. *BMC Plant Biol.* 25: 1052.
- Ma, T., Yang, C., Cai, F., Cui, L., and Wang, Y. 2022. Optimizing fermentation of *Bacillus amyloliquefaciens* 3–5 and determining disease suppression and growth in cucumber (*Cucumis sativus*). *Biol. Control* 176: 105070.
- Ma, Y., Zuohereguli, K., Zhang, L., Kang, Y., Shi, L., Xu, H., Ruan, Y., Wen, T., Mei, X., Dong, C., Xu, Y., and Shen, Q. 2025. Soil microbial mechanisms to improve pear seedling growth by applying *Bacillus* and *Trichoderma*-amended biofertilizers. *Plant Cell Environ.* 48(6): 3968-3980.
- Madaki, A. B., Aliyu, H. D., Ari, J. L., Kazzayo, A. M., Iliyasu, H. N., Moses, D., and Saleh, A. A., 2025. Effect of biochar on the growth and yield of okra (*Abelmoschus esculentus*). *J. Res. Agric. Food Sci.* 2(2): 73-79.
- Mahdi, I., Allaoui, A., Fahsi, N., and Biskri, L. 2022. *Bacillus velezensis* QA2 potentially induced salt stress tolerance and enhanced phosphate uptake in quinoa plants. *Microorganisms* 10: 1836.

- Malik, L., Sanaullah, M., Mahmood, F., Hussain, S., Siddique, M. H., Anwar, F., and Shahzad, T. 2022. Unlocking the potential of co-applied biochar and plant growth-promoting rhizobacteria (PGPR) for sustainable agriculture under stress conditions. *Chem. Biol. Technol. Agric.* 9(1): 58.
- Martin, J. P. 1950. Use of acid, rose bengal, and streptomycin in the plate method for estimating soil fungi. *Soil Sci.* 69(3): 215-232.
- Masood, S., Zhao, X. Q., and Shen, R. F. 2019. *Bacillus pumilus* increases boron uptake and inhibits rapeseed growth under boron supply irrespective of phosphorus fertilization. *AoB Plants* 11(4): 1-10.
- Masood, S., Zhao, X. Q., and Shen, R. F. 2020. *Bacillus pumilus* promotes the growth and nitrogen uptake of tomato plants under nitrogen fertilization. *Sci. Hortic.* 272: 109581.
- Masto, R. E., Ansari, M. A., George, J., Selvi, V. A., and Ram, L. C., 2013. Co-application of biochar and lignite fly ash on soil nutrients and biological parameters at different crop growth stages of *Zea mays*. *Ecol. Eng.* 58: 314-322.
- Masulili, A., Suryani, R., and Kurniadi, E. 2025. The use of biochar and fertilizer to maximize the growth and yield of ginger on degraded alluvial soil. *J. Degrad. Min. Lands Manag.* 12(3): 7523-7532.
- Medeiros, C. A. A. and Bettiol, W. 2021. Multifaceted intervention of *Bacillus* spp. against salinity stress and Fusarium wilt in tomato. *J. Appl. Microbiol.* 131(5): 2387-2401.
- Meng, Q., Jiang, H., and Hao, J. J. 2016. Effects of *Bacillus velezensis* strain BAC03 in promoting plant growth. *Biol. Control.* 98: 18-26.
- Miao, W., Li, F., Lu, J., Wang, D., Chen, M., Tang, L., Xu, Z., and Chen, W. 2023. Biochar application enhanced rice biomass production and lodging resistance via promoting co-deposition of silica with hemicellulose and lignin. *Sci. Total Environ.* 855: 158818.

- Mini, V. and Mathew, U., 2015. Soil based nutrient management plan for Onattukara sandy tract of Kerala. *Asian J. Soil Sci.* 10(1): 99-103.
- Mosela, M., Andrade, G., Massucato, L. R., Almeida, S. R. D. A., Nogueira, A. F., Filho, R. B. D. L., Zeffa, D. M., Mian, S., Higashi, A. Y., Shimizu, G. D., Teixeira, G. M., Branco, K. S., Faria, M. V., Giacomini, R. M., Scapim, C. A., and Gonçalves, L. S. A. 2022. *Bacillus velezensis* strain Ag75 as a new multifunctional agent for biocontrol, phosphate solubilization and growth promotion in maize and soybean crops. *Sci. Rep.* 12: 15284.
- Munir, M., Nazir, A., Khan, A., Saleem, S., and Ali, H. E. 2025. Effect of cattails (*Typha angustifolia* L.) biochar on soil fertility and okra productivity as an effective eco-friendly soil amendment. *Sustainability* 17(4): 1675.
- Musa, U. T. and Usman, T. H., 2016. Leaf area determination for maize (*Zea mays* L.), okra (*Abelmoschus esculentus* L.) and cowpea (*Vigna unguiculata* L.) crops using linear measurements. *J. Biol. Agric. Healthc.* 6(4): 104-111.
- Musick, G. J., Fairchi, M. L., Ferguson, V. L., and Zuber, M. S. 1965. A method of measuring root volume in corn (*Zea mays* L.). *Crop Sci.* 5: 601-602.
- Nagula, S. 2017. Technology refinement for biochar production and evaluation of its effect on soil health and crop productivity. Ph.D. (Ag.) thesis, Kerala Agricultural University, Thrissur, 158p.
- Nan, J., Jiehua, Q., Dagang, T., Huanbin, S., Zhiquan, L., Hui, W., Shuwei, X., Huizhe, C., Meng, W., and Yanjun, K. 2025. Mixture of *Bacillus amyloliquefaciens* and *Bacillus pumilus* modulates community structures of rice rhizosphere soil to suppress rice seedling blight. *Rice Sci.* 32(1): 118-130.
- Nawaz, A., Shahbaz, M., Asadullah, Imran, A., Marghoob, M. U., Imtiaz, M., and Mubeen, F. 2020. Potential of salt tolerant PGPR in growth and yield augmentation of wheat (*Triticum aestivum* L.) under saline conditions. *Front. Microbiol.* 11:2019.

- Ngo, N. P., Yamada, T., Higuma, S., Ueno, N., Saito, K., Kojima, K., Maeda, M., Yamaya-Ito, H., Ohkama-Ohtsu, N., Kanekatsu, M., and Yokoyama, T. 2019. Spore inoculation of *Bacillus pumilus* TUAT1 strain, a biofertilizer microorganism, enhances seedling growth by promoting root system development in rice. *Soil Sci. Plant Nutr.* 65(6): 598-604.
- Niazi, A., Manzoor, S., Asari, S., Bejai, S., Meijer, J., and Bongcam-Rudloff, E. 2014. Genome analysis of *Bacillus amyloliquefaciens* subsp. *plantarum* UCMB5113: A rhizobacterium that improves plant growth and stress management. *PLoS One* 9(8): e104651.
- Nicholson, W. L., Munakata, N., Horneck, G., Melosh, H. J., and Setlow, P. 2000. Resistance of *Bacillus* endospores to extreme terrestrial and extraterrestrial environments. *Microbiol. Mol. Biol. Rev.* 64(3): 548-572.
- Nimbalkar, S. D., Patil, D. S., and Rajwade, P. R., 2023. Effect of microbial enriched biochar with fertilizer doses on soil properties and yield under soybean (*Glycine max*)–wheat (*Triticum aestivum*) cropping sequence. *Int. J. Plant Soil Sci.* 35(7): 146-156.
- Obadi, A., Alharbi, A., Alomran, A., Alghamdi, A. G., Louki, I., Alkhasha, A., and Alqardaei, T. 2024. Enhancement in tomato yield and quality using biochar amendments in greenhouse under salinity and drought stress. *Plants* 13(12): 1634.
- Oluleye, A. K., Ogunlade, M. O., and Adewoyin, O. B. 2023. Response of okra, *Abelmoschus esculentus* (L.) Moench, to biochar derived from cocoa pod husk and NPK fertiliser. *Trop. Agric.* 100(1): 11-19.
- Pandey, C., Bajpai, V. K., Negi, Y. K., Rather, I. A., and Maheshwari, D. K. 2018. Effect of plant growth promoting *Bacillus* spp. on nutritional properties of *Amaranthus hypochondriacus* grains. *Saudi J. Biol. Sci.* 25: 1066-1071.
- Patani, A., Prajapati, D., Ali, D., Kalasariya, H., Yadav, V. K., Tank, J., Bagatharia, S., Joshi, M., and Patel, A. 2023. Evaluation of the growth-inducing efficacy of various *Bacillus* species on the salt-stressed tomato (*Lycopersicon esculentum* Mill.). *Front. Plant Sci.* 14: 1168155.

- Peng, J., Han, X., Li, N., Chen, K., Yang, J., Zhan, X., Luo, P., and Liu, N. 2021. Combined application of biochar with fertilizer promotes nitrogen uptake in maize by increasing nitrogen retention in soil. *Biochar* 3: 367-379.
- Phares, C. A., Amoakwah, E., Danquah, A., Afrifa, A., Beyaw, L. R., and Frimpong, K. A. 2022. Biochar and NPK fertilizer co-applied with plant growth promoting bacteria (PGPB) enhanced maize grain yield and nutrient use efficiency of inorganic fertilizer. *J. Agric. Food Res.* 10: 100434.
- Piper, C. S. 1966. *Soil and Plant Analysis*. Hans Publishers, Bombay, 368p.
- Punnoose, A. and Anitha, S. 2017. Biochar on the growth and yield performance of amaranth (*Amaranthus tricolor* L.). *Trends Biosci.* 10(16): 2908-2912.
- Qin, Y., Shang, Q., Zhang, Y., Li, P., and Chai, Y. 2017. *Bacillus amyloliquefaciens* L-S60 reforms the rhizosphere bacterial community and improves growth conditions in cucumber plug seedling. *Front. Microbiol.* 8: 2620.
- Qu, H., Zhao, L., Zhao, F., Liu, Y., and Yang, Z. 2016. Biocontrol of gray mold decay in pear by *Bacillus amyloliquefaciens* strain BA3 and its effect on postharvest quality parameters. *Pol. J. Microbiol.* 65(2): 171-176.
- Rahman, M., Sabir, A. A., Mukta, J. A., Khan, M. M. A., Mohi-Ud-Din, M., Miah, M. G., Rahman, M., and Islam, M. T. 2018. Plant probiotic bacteria *Bacillus* and *Paraburkholderia* improve growth, yield and content of antioxidants in strawberry fruit. *Sci. Rep.* 8: 2504.
- Reddy, T. Y. and Reddy, G. H. S. 2016. *Principles of Agronomy* (5<sup>th</sup> ed.). Kalyani Publishers, New Delhi, 653p.
- Sabate, D. C. and Brandán, C. P. 2022. *Bacillus amyloliquefaciens* strain enhances rhizospheric microbial growth and reduces root and stem rot in a degraded agricultural system. *Rhizosphere* 22: 100544.
- Sadasivam, S. and Manickam, A. 1996. *Biochemical Methods for Agricultural Sciences*. Wiley Eastern Ltd., New Delhi, India, 246p.

- Samaras, A., Efthimiou, K., Roumeliotis, E., and Karaoglanidis, G. S. 2018, June. Biocontrol potential and plant-growth-promoting effects of *Bacillus amyloliquefaciens* MBI 600 against *Fusarium oxysporum* f. sp. *radicis-lycopersici* on tomato. In: Moriones, E. Fernández-Muñoz, R., and Beuzón, C. R. (eds), *Proc. V Int. Symp. on Tomato Diseases: Perspectives and Future Directions in Tomato Protection (Acta Horticulturae, 1207)*, International Society for Horticultural Science, pp. 139-146.
- Sánchez, E., Zabaleta, R., Navas, A. L., Maldonado, V. N. F., Fabani, M. P., Mazza, G., and Rodriguez, R. 2025. Influence of walnut shell biochar and fertilizer on lettuce production in hydroponic and conventional systems. *Agronomy* 15(3): 658.
- Saxena, J., Rana, G., and Pandey, M. 2013. Impact of addition of biochar along with *Bacillus* sp. on growth and yield of French beans. *Sci. Hortic.* 162: 351-356.
- Shahzad, A., Qin, M., Elahie, M., Naeem, M., Bashir, T., Yasmin, H., Younas, M., Areeb, A., Irfan, M., Billah, M., Shakoor, A., and Zulfiqar, S. 2021. *Bacillus pumilus* induced tolerance of maize (*Zea mays* L.) against cadmium (Cd) stress. *Sci. Rep.* 11: 17196.
- Shao, J., Xu, Z., Zhang, N., Shen, Q., and Zhang, R. 2014. Contribution of indole-3-acetic acid in the plant growth promotion by the rhizospheric strain *Bacillus amyloliquefaciens* SQR9. *Biol. Fertil. Soils* 51: 321–330.
- Sheteiwy, M. S., Elgawad, H. A., Xiong, Y. C., Macovei, A., Brestic, M., Skalicky, M., Shaghaleh, H., Hamoud, Y. A., and El-Sawah, A. M. 2021. Inoculation with *Bacillus amyloliquefaciens* and mycorrhiza confers tolerance to drought stress and improve seed yield and quality of soybean plant. *Physiol. Plant.* 172(4): 2153-2169.
- Shi, H., Lu, L., Ye, J., and Shi, L. 2022. Effects of two *Bacillus velezensis* microbial inoculants on the growth and rhizosphere soil environment of *Prunus davidiana*. *Int. J. Mol. Sci.* 23(21): 13639.

- Siddiqui, Z. A., Baghel, G., and Akhtar, M.S. 2007. Biocontrol of *Meloidogyne javanica* by *Rhizobium* and plant growth-promoting rhizobacteria on lentil. *World J. Microbiol. Biotechnol.* 23: 435-441.
- Sikdar, A., Zaman, N., Deb, S., Chakma, N., and Sharif, M. O. 2023. Effect of co-application of different biochars and inorganic fertilizers on the growth and yield of okra (*Abelmoschus esculentus* L.) in sandy soil. *J. Agrofor. Environ.* 16(2): 20-27.
- Stefan, M., Dunca, S., Olteanu, Z., Oprica, L., Ungureanu, E., Hritcu, L., Mihasan, M., and Cojocaru, D. 2010. Soybean (*Glycine max* [L] Merr.) inoculation with *Bacillus pumilus* RS3 promotes plant growth and increases seed protein yield: Relevance for environmentally-friendly agricultural applications. *Carpath. J. Earth Environ. Sci.* 5(1): 131-138.
- Subbiah, D. V. and Asija, G. L. 1956. Rapid procedure for estimation of available nitrogen in soil. *Curr. Sci.* 25: 259-260.
- Sun, D., Meng, J., and Chen, W. 2013. Effects of abiotic components induced by biochar on microbial communities. *Acta Agric. Scand. Sect. B-Soil Plant Sci.* 63(7): 633-641.
- Suthar, R. G., Wang, C., Nunes, M. C. N., Chen, J., Sargent, S. A., Bucklin, R. A., and Gao, B. 2018. Bamboo biochar pyrolyzed at low temperature improves tomato plant growth and fruit quality. *Agriculture* 8: 153.
- Syuhada, A. B., Shamshuddin, J., Fauziah, C. I., Rosenani, A. B., and Arifin, A. 2016. Biochar as soil amendment: Impact on chemical properties and corn nutrient uptake in a Podzol. *Can. J. Soil Sci.* 96(4): 400-412.
- Tian, L., Zhang, W., Zhou, G. D., Li, S., Wang, Y., Yang, B., Bai, T., Fan, H., He, P., and Zheng, S. J., 2023. A biological product of *Bacillus amyloliquefaciens* QST713 strain for promoting banana plant growth and modifying rhizosphere soil microbial diversity and community composition. *Front. Microbiol.* 14: 1216018.

- Timilsina, S., Khanal, A., Vista, S. P., and Poon, T. B. 2020. Effect of biochar application in combination with different nutrient sources on cauliflower production at Kaski Nepal. *J. Agric. Environ.* 21: 82-89.
- Trabelsi, D., Ammar, H. B., Mengoni, A., and Mhamdi, R. 2012. Appraisal of the crop-rotation effect of rhizobial inoculation on potato cropping systems in relation to soil bacterial communities. *Soil Biol. Biochem.* 54: 1-6.
- Tu, M., Zhu, Z., Zhao, X., Cai, H., Zhang, Y., Yan, Y., Yin, K., Sha, Z., Zhou, Y., Chen, G., and Zou, L. 2025. The versatile plant probiotic bacterium *Bacillus velezensis* SF305 reduces red root rot disease severity in the rubber tree by degrading the mycelia of *Ganoderma pseudoferreum*. *J. Integr. Agric.* 24(8): 3112-3126.
- Umamaheswari, R., Rao, M. S., Chaya, M. K., Sowmyavani, M., Navyashree, R. K., and Kavya, B. M., 2022. Effect of *Bacillus pumilus* IIHR Bp-2 1% AS and *Pseudomonas putida* IIHR Pp-2 1% AS on *Meloidogyne incognita* infecting okra (*Abelmoschus esculentus* (L.) Moench). *Pest Manag. Hortic. Ecosyst.* 28(1): 126-132.
- Usman, M., Ahmad, N., Raza, W., Zhao, Z., Abubakar, M., Rehman, S. U., Ikram, S., and Tariq, H. 2023. Impact of biochar on the yield and nutritional quality of tomatoes (*Solanum lycopersicum*) under drought stress. *J. Sci. Food Agric.* 103: 3479-3488.
- Verma, P. Yadav, A. N., Khannam, K. S., Kumar, S., Saxena, A. K., and Suman, A. 2015. Alleviation of cold stress in wheat seedlings by *Bacillus amyloliquefaciens* IARI-HHS2-30, an endophytic psychrotolerant K-solubilizing bacterium from NW Indian Himalayas. *Natl. J. Life Sci.* 12(2): 105-110.
- Vikram, K. 2024. Characterization and standardization of biochar as a soil conditioner for okra [*Abelmoschus esculentus* (L.) Moench] in Onattukara Sandy Plain. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 81p.
- Vikram, K. Jayapal, A., Pillai, S., Isaac, S. R., and Mini, V. 2025. Biochar for enhancing yield, nutrient uptake, and soil fertility in okra. *J. Sustain. Tech. Agric.* 1(1): 1-16.

- Vikram, K., Jayapal, A., Pillai, P. S., Isaac, S. R., and Mini, V. 2024a. Characterization of biochar produced from different agro-wastes. *J. Crop Weed* 20(1): 12-20.
- Vikram, K., Jayapal, A., Pillai, P. S., Isaac, S. R., and Mini, V. 2024b. Tender coconut husk biochar augments the growth and yield of okra in Onattukara sandy plains. *J. Krishi Vigyan* 12(1): 164-168.
- Vinci, G., Cozzolino, V., Mazzei, P., Monda, H., Savy, D., Drosos, M., and Piccolo, A. 2018. Effects of *Bacillus amyloliquefaciens* and different phosphorus sources on Maize plants as revealed by NMR and GC-MS based metabolomics. *Plant Soil* 429: 437-450.
- Vitorino, L. C., da Silva, E. J., Oliveira, M. S., Silva, I. D. O., Santos, L. D. S., Mendonça, M. A. C., Oliveira, T. C. S., and Bessa, L. A. 2024. Effect of a *Bacillus velezensis* and *Lysinibacillus fusiformis*-based biofertilizer on phosphorus acquisition and grain yield of soybean. *Front. Plant Sci.* 15: 1433828.
- Wang, J., Qu, F., Liang, J., Yang, M., and Hu, X. 2022a. *Bacillus velezensis* SX13 promoted cucumber growth and production by accelerating the absorption of nutrients and increasing plant photosynthetic metabolism. *Sci. Hortic.* 301: 111151.
- Wang, Q., Ou, E. L., Wang, P. C., Chen, Y., Wang, Z. Y., Wang, Z. W., Fang, X. W., and Zhang, J. L. 2022b. *Bacillus amyloliquefaciens* GB03 augmented tall fescue growth by regulating phytohormone and nutrient homeostasis under nitrogen deficiency. *Front. Plant Sci.* 13: 979883.
- Watson, D. J. 1947. Comparative physiological studies in the growth of field crops. I: Variation in assimilation rate and leaf area between species and varieties within and between years. *Ann. Bot.* 11: 41-76.
- Watson, D. J., 1958. The dependence of net assimilation rate on leaf-area index. *Ann. Bot.* 22(85): 37-54.
- Wijitkosum, S., Sriburi, T., and Toonsiri, P. 2025. Effect of one-time application of biochar and compost on soil and maize during 5-time consecutive periods of crop cultivation. *Emerg. Sci. J.* 9(1): 114-130.

- Win, K. T., Okazaki, K., Ohkama-Ohtsu, N., Yokoyama, T., and Ohwaki, Y. 2020. Short-term effects of biochar and *Bacillus pumilus* TUAT-1 on the growth of forage rice and its associated soil microbial community and soil properties. *Biol. Fertil. Soils* 56(4): 481-497.
- Win, K. T., Okazaki, K., Ookawa, T., Yokoyama, T., and Ohwaki, Y. 2019. Influence of rice-husk biochar and *Bacillus pumilus* strain TUAT-1 on yield, biomass production, and nutrient uptake in two forage rice genotypes. *PLoS One* 14(7): e0220236.
- Win, K. T., Oo, A. Z., Ohkama-Ohtsu, N., and Yokoyama, T. 2018. *Bacillus pumilus* strain TUAT-1 and nitrogen application in nursery phase promote growth of rice plants under field condition. *Agronomy* 8(10): 216.
- Xiu, L., Sun, Y., and Han, X. 2025. Effects of biochar amendment on potassium supply capacity and potassium accumulation in soybean across diverse soils. *Plants* 14(13): 1959.
- Xue, L., Sun, B., Yang, Y., Jin, B., Zhuang, G., Bai, Z., and Zhuang, X. 2021. Efficiency and mechanism of reducing ammonia volatilization in alkaline farmland soil using *Bacillus amyloliquefaciens* biofertilizer. *Environ. Res.* 202: 111672.
- Yang, J., Li, S., Zhou, X., Du, C., Fang, J., Li, X., Zhao, J., Ding, F., Wang, Y., Zhang, Q. and Wang, Z., Liu, J., Dong, G., Zhang, J., Xu, F., and Xu, W. 2025. *Bacillus amyloliquefaciens* promotes cluster root formation of white lupin under low phosphorus by mediating auxin levels. *Plant Physiol.* 197(2): 676.
- Zafar-ul-Hye, M., Danish, S., Abbas, M., Ahmad, M., and Munir, T. M. 2019. ACC deaminase producing PGPR *Bacillus amyloliquefaciens* and *Agrobacterium fabrum* along with biochar improve wheat productivity under drought stress. *Agronomy* 9(7): 343.
- Zhang, M., Liu, Y., Wei, Q., Gou, J., Liu, L., Gu, X., and Wang, M. 2023. The co-application of PGPR and biochar enhances the production capacity of continuous cropping peppers in the Karst Yellow Soil Region of Southwest China. *Horticulturae* 9(10): 1104.

- Zhang, M., Riaz, M., Xia, H., Li, Y., Wang, X., and Jiang, C. 2022. Four-year biochar study: Positive response of acidic soil microenvironment and citrus growth to biochar under potassium deficiency conditions. *Sci. Total Environ.* 813: 152515.
- Zhong, X., Jin, Y., Ren, H., Hong, T., Zheng, J., Fan, W., Hong, J., Chen, Z., Wang, A., Lu, H., Zhong, K., and Huang, G. 2024. Research progress of *Bacillus velezensis* in plant disease resistance and growth promotion. *Front. Ind. Microbiol.* 2:1442980.

**SEED BACTERIZATION AND BIOCHAR AMENDMENT FOR  
OKRA-AMARANTHUS CROPPING SEQUENCE IN  
ONATTUKARA SANDY PLAINS**

**By  
HARSHITHA S.  
(2023-11-039)**

**ABSTRACT**

**of the thesis submitted in partial fulfilment of the  
requirements for the degree of**

**MASTER OF SCIENCE IN AGRICULTURE**

**Faculty of Agriculture  
Kerala Agricultural University**



**DEPARTMENT OF AGRONOMY  
COLLEGE OF AGRICULTURE  
VELLAYANI, THIRUVANANTHAPURAM – 695 522  
KERALA, INDIA**

**2026**

## ABSTRACT

The study entitled ‘Seed bacterization and biochar amendment for okra-amaranthus cropping sequence in Onattukara Sandy Plains’ was conducted at the Department of Agronomy, College of Agriculture, Vellayani, during 2023-2025. The objectives were to assess the effect of seed bacterization and biochar amendment on the growth and yield of okra and to analyse the residual effect of treatments on the sequential crop of amaranthus in Onattukara. The experiment was conducted at the Instructional Farm attached to Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam.

The field experiment was laid out in randomised block design with eight treatments replicated thrice. Okra var. Varsha Uphar was raised as the first crop, followed by a bulk crop of amaranthus (var. KAU Vaika). The treatments were, T<sub>1</sub>: FYM 20 t ha<sup>-1</sup> + 100% RDN (KAU POP), T<sub>2</sub>: 5 t ha<sup>-1</sup> biochar + 5 t ha<sup>-1</sup> FYM + 100% RDN, T<sub>3</sub>: T<sub>1</sub> + Seed treatment with *Bacillus pumilus* VLY 17, T<sub>4</sub>: T<sub>1</sub> + Seed treatment with *Bacillus amyloliquefaciens* VLY 24, T<sub>5</sub>: T<sub>1</sub> + Seed treatment with *Bacillus velezensis* PCSE 10, T<sub>6</sub>: T<sub>2</sub> + Seed treatment with *Bacillus pumilus* VLY 17, T<sub>7</sub>: T<sub>2</sub> + Seed treatment with *Bacillus amyloliquefaciens* VLY 24, and T<sub>8</sub>: T<sub>2</sub> + Seed treatment with *Bacillus velezensis* PCSE 10. The bacterial isolates used for seed treatment were obtained from the Department of Agricultural Microbiology. Biochar was prepared from tender coconut husk and was applied as basal during land preparation for okra.

The combined effect of biochar and seed treatment had significantly improved the growth, yield, quality, nutrient uptake and soil parameters of okra. At 60 DAS, the treatment T<sub>7</sub> resulted in significantly taller plants (94.20 cm), higher number of leaves per plant (23.73) and higher LAI (3.21). The treatment T<sub>7</sub> also resulted in significantly higher RGR during 30-45 DAS (0.100 g g<sup>-1</sup> d<sup>-1</sup>), 45-60 DAS (0.137 g g<sup>-1</sup> d<sup>-1</sup>), and root volume at harvest (60.53 cm<sup>3</sup>). Significantly higher CGR (14.44 g m<sup>-2</sup> d<sup>-1</sup>) was observed in T<sub>5</sub> during 45-60 DAS.

The treatment T<sub>8</sub> resulted in significantly more number of fruits per plant (30) and was on a par with T<sub>7</sub> (29). The treatment T<sub>7</sub> resulted in significantly higher fruit yield per plant (608.00 g) and yield per hectare (14.09 t), which remained comparable with

T<sub>8</sub> (607.33 g and 14.07 t respectively). Harvest index (0.72) was found to be significantly higher for T<sub>2</sub> treatment.

Significantly higher crude fibre content was recorded for the treatment T<sub>7</sub> (16.03%). The treatment T<sub>7</sub> exhibited significantly higher N uptake (82.31 kg ha<sup>-1</sup>) and K uptake (76.24 kg ha<sup>-1</sup>), while the treatment T<sub>6</sub> resulted in significantly higher P uptake (15.68 kg ha<sup>-1</sup>).

The treatment T<sub>8</sub> significantly improved the water holding capacity (38.61%) and available N status (276.14 kg ha<sup>-1</sup>) of soil. The treatment T<sub>7</sub> was observed to significantly improve the available K (188.83 kg ha<sup>-1</sup>). Actinomycetes count (5.98 log CFU g<sup>-1</sup> soil) was observed to improve significantly in T<sub>7</sub> treatment. The fungal population was significantly higher in T<sub>1</sub> (4.58 log CFU g<sup>-1</sup> soil) and was on a par with T<sub>2</sub> (4.53 log CFU g<sup>-1</sup> soil).

The residual effect of treatments could not produce any significant effect on the yield of amaranthus. However, significantly higher N, P and K uptake was observed in amaranthus with the treatments T<sub>7</sub> (22.59 N kg ha<sup>-1</sup>), T<sub>8</sub> (7.30 P kg ha<sup>-1</sup>) and T<sub>6</sub> (22.76 K kg ha<sup>-1</sup>), respectively.

The treatment T<sub>8</sub> resulted in significantly higher available N (196.48 kg ha<sup>-1</sup>) after the harvest of amaranthus. The treatment T<sub>7</sub> resulted in significantly higher available P (62.38 kg ha<sup>-1</sup>) and available K (128.66 kg ha<sup>-1</sup>). The equivalent yield of the system was found to be higher in T<sub>8</sub> (18.85 t ha<sup>-1</sup>).

The results on economics of cultivation revealed that T<sub>8</sub> recorded a higher gross income (₹ 6,59,910 ha<sup>-1</sup>) and net income (₹ 3,31,265 ha<sup>-1</sup>), followed by T<sub>7</sub> (₹ 6,56,170 ha<sup>-1</sup> and ₹ 3,27,525 ha<sup>-1</sup>), with higher BCR observed for treatments T<sub>8</sub> (2.01) and T<sub>4</sub> (2.01), followed by T<sub>7</sub> (2.00).

The results of the present study revealed that the growth and yield of okra, followed by a sequential bulk crop of amaranthus, could be significantly enhanced by seed treatment with beneficial bacteria in combination with biochar (5 t ha<sup>-1</sup>), farm yard manure (5 t ha<sup>-1</sup>), and the full recommended dose of nutrients (110:35:70 kg N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O ha<sup>-1</sup>) under the sandy loam soil conditions of Onattukara.

## സംഗ്രഹം

ഓണാട്ടുകരയിലെ മണൽ കലർന്ന പശിമരാശി മണ്ണിൽ വെണ്ട കൃഷിയും തുടർന്നുള്ള ചീര കൃഷിയും ചെയ്യുവാൻ വേണ്ടി വെണ്ട വിത്തിൽ ബാക്ടീരിയ സംയോജിപ്പിച്ചും മണ്ണിലേക്കു ബയോച്ചാർ നൽകുന്നതും അടിസ്ഥാനമാക്കി ഒരു ഗവേഷണ പഠനം 2023-2025 കാലഘട്ടത്തിൽ വെള്ളായണി കാർഷിക കോളേജിലെ അഗ്രോണമി വിഭാഗത്തിലും ഓണാട്ടുകര പ്രാദേശിക കാർഷിക ഗവേഷണ കേന്ദ്രത്തിലുമായി നടത്തുകയുണ്ടായി. വെണ്ട വിത്തുകൾ ബാക്ടീരിയ കൊണ്ട് സംയോജിപ്പിക്കുന്നതു കൊണ്ടും മണ്ണിൽ ബയോച്ചാർ നൽകുന്നത് കൊണ്ടും വെണ്ടയുടെ വളർച്ചയിലും വിളവിലുമുണ്ടാകുന്ന മാറ്റങ്ങൾ വിലയിരുത്തുക, തുടർന്നുള്ള ചീര കൃഷിയിൽ ഇവയുടെ പ്രഭാവം ഉണ്ടോ എന്ന് പരിശോധിക്കുക എന്നിവയായിരുന്നു പ്രധാന ഗവേഷണ ലക്ഷ്യങ്ങൾ.

രണ്ട് ഘട്ടങ്ങളിലായാണ് പരീക്ഷണം നടത്തിയത്. ഒന്നാം വിളയായി വെണ്ടയുടെ 'വർഷ ഉപഹാർ' എന്ന ഇനവും, തുടർന്നുള്ള ചീര കൃഷിക്കായി 'വൈക' എന്ന ഇനവുമാണ് കൃഷിക്ക് ഉപയോഗിച്ചത്. ആദ്യ ഘട്ടത്തിലുള്ള വെണ്ട കൃഷിക്ക്, റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന ഗവേഷണ രീതിയാണ് ഉപയോഗിച്ചത്. ഇതിലേക്കായി എട്ട് തരത്തിലുള്ള ട്രീട്മെന്റുകൾ മൂന്ന് തവണ ആവർത്തിച്ചുകൊണ്ടാണ് ഗവേഷണം നടത്തിയത്. ബാസിലസ് പ്യൂമിലസ്, ബാസിലസ് അമൈലോ ലിക്വഫേഷ്യൻസ്, ബാസിലസ് വെലെസെൻസിസ് എന്നിങ്ങനെയുള്ള മൂന്നു തരം ബാക്റ്റീരിയകളെ ഉപയോഗിച്ചുള്ള വിത്ത് സംസ്കരണം (seed treatment) വെണ്ടയിൽ നടത്തുകയും, ഇവ കേരള കാർഷിക സർവകലാശാലയുടെ ശുപാർശ പ്രകാരമുള്ള വളപ്രയോഗത്തോടൊപ്പവും, ബയോച്ചാറും കാലി വളവും ചേർന്നുള്ള സംയോജിത വളപ്രയോഗത്തോടൊപ്പവും നൽകുകയുണ്ടായി. വിത്ത് സംസ്കരണത്തിന് ഉപയോഗിച്ച ബാക്ടീരിയൽ ഐസൊലേറ്റുകൾ ലഭിച്ചത് വെള്ളായണി കാർഷിക കോളേജിലെ അഗ്രികൾച്ചറൽ മൈക്രോബയോളജി വിഭാഗത്തിൽ നിന്നാണ്.

കരിക്കിന്റെ തോണ്ടിൽ നിന്നുണ്ടാക്കിയ ബയോചാർ വെണ്ട കൃഷിക്ക് നിലമൊരുക്കുമ്പോൾ തന്നെ അടിവളമായി നൽകി. വെണ്ട വിത്തിൽ ബാക്ടീരിയ സംയോജിപ്പിക്കുന്നതു കൊണ്ടും, ബയോച്ചാർ മണ്ണിൽ നൽകുന്നത് കൊണ്ടും, വെണ്ടയുടെ വളർച്ച, വിളവ്, ഗുണം എന്നിവ മെച്ചപ്പെടുകയും, മണ്ണിന്റെ ജലസംഭരണശേഷി, മറ്റു സ്വഭാവ സവിശേഷതകൾ, അവയിലെ സൂക്ഷ്മാണുക്കൾ എന്നിവയെ ഗണ്യമായി വർദ്ധിപ്പിക്കുന്നതായും പഠനത്തിൽ നിന്നും മനസിലായി. എന്നാൽ ഈ മെച്ചപ്പെട്ട സാഹചര്യങ്ങൾക്ക് തുടർന്നുള്ള ചീര കൃഷിയുടെ വിളവിൽ ഗണ്യമായ മാറ്റം കൊണ്ട് വരാനായില്ല. എന്നാൽ, ഇതിലൂടെ നല്ല വരുമാനവും ഗുണലാഭ അനുപാതവും (BCR) വർദ്ധിക്കുന്നതായി കണ്ടു.

ഓണാട്ടുകരയിലെ മണൽ കലർന്ന പശിമരാശി മണ്ണിൽ വെണ്ടയും തുടർന്നുള്ള ചീര കൃഷിയുടെയും മെച്ചപ്പെട്ട വളർച്ചക്കും വിളവിനും ഗുണലാഭ അനുപാതവും ലഭിക്കുന്നതിലേക്കായി, വെണ്ട വിത്തിൽ തന്നെ ബാക്ടീരിയ സംയോജിപ്പിച്ചും മണ്ണിലേക്കു ബയോച്ചാറും കാലിവളവും (ഒരു ഹെക്ടറിന് 5 ടൺ വീതം എന്ന തോതിൽ) നൽകുകയും ചെയ്യണം. ഇതോടൊപ്പം കേരള കാർഷിക സർവകലാശാലയുടെ ശുപാർശ പ്രകാരമുള്ള മുഴുവൻ വളവും (ഹെക്ടറിന് 110:35:70 കിലോ ഗ്രാം എന്ന തോതിൽ പാക്യജനകം, ഭാവഹം, ക്ഷാരം എന്നിവ) നൽകുകയും വേണം.

# *Appendices*

---

## Appendix I

Weather parameters during the experimental period (January – May 2025)

Standard week	Mean temperature (°C)		Total rainfall (mm)
	Min.	Max.	
2 (08 Jan – 14 Jan)	22.50	34.50	0.00
3 (15 Jan – 21 Jan)	22.86	34.43	0.00
4 (22 Jan – 28 Jan)	23.29	34.43	0.00
5 (29 Jan – 04 Feb)	23.57	34.86	0.00
6 (05 Feb – 11 Feb)	23.29	34.57	0.00
7 (12 Feb – 18 Feb)	23.57	35.14	0.00
8 (19 Feb – 25 Feb)	23.57	34.57	0.00
9 (26 Feb – 04 Mar)	23.43	34.29	1.00
10 (05 Mar – 11 Mar)	23.29	34.29	0.00
11 (12 Mar – 18 Mar)	23.57	34.43	0.00
12 (19 Mar – 25 Mar)	23.43	34.29	8.50
13 (26 Mar – 01 Apr)	23.43	34.14	8.00
14 (02 Apr – 08 Apr)	23.43	34.43	26.70
15 (09 Apr – 15 Apr)	23.29	34.29	22.00
16 (16 Apr – 22 Apr)	23.29	34.00	0.00
17 (23 Apr – 29 Apr)	23.43	34.71	33.00
18 (30 Apr – 06 May)	23.57	34.14	0.00
19 (07 May – 13 May)	23.57	34.29	20.00
20 (14 May – 20 May)	23.86	33.43	79.20
21 (21 May – 27 May)	24.29	33.71	224.80

## Appendix II

Average cost of inputs and market price of produce

<b>Cost of inputs (₹ kg<sup>-1</sup>)</b>	
Okra seeds	2250
Amaranthus seeds	3000
Lime	11
FYM	4
Biochar	20
Urea	10
Rajphos	15
MOP	35
PP chemical	2500
<b>Labour charge (₹ day<sup>-1</sup>)</b>	
Men	1000
Women	1000
<b>Price of produce (₹ kg<sup>-1</sup>)</b>	
Okra	35
Amaranthus	30