UTILIZATION OF PRODUCTS OBTAINED FROM PYROLYSIS OF PADDY STRAW

ANUSHA, B. S.

PALB 9246

DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE

2021

UTILIZATION OF PRODUCTS OBTAINED FROM PYROLYSIS OF PADDY STRAW

ANUSHA, B. S.

PALB 9246

Thesis submitted to the

UNIVERSITY OF AGRICULTURAL SCIENCES, BANGALORE

In partial fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE (Agriculture)

in

ENVIRONMENTAL SCIENCE

BENGALURU **OCTOBER, 2021**

Affectionately Dedicated to

My Beloved Family

and

Beloved Guide

DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE
UNIVERSITY OF AGRICULTURAL SCIENCES BANGALORE

CERTIFICATE

This is to certify that the thesis entitled "**UTILIZATION OF PRODUCTS OBTAINED FROM PYROLYSIS OF PADDY STRAW**" submitted by **Ms. ANUSHA, B. S.,** ID. No. **PALB 9246** for the degree of **MASTER OF SCIENCE (Agriculture)** in **ENVIRONMENTAL SCIENCE** of the University of Agricultural Sciences, Bangalore is a *bona-fide*record of research work carried out by her during the period of her study in this University under my guidance and supervision and no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

Bengaluru
October, 2021

Rinku Verma
(RINKU VERMA)
Major Advisor

APPROVED BY:

Chairperson: Rinku Verma
(RINKU VERMA)

Members:

1. ____________________
(K. T. PRASANNA)

2. ____________________
(M. MAHADEVAMURTHY)

3. ____________________
(VIRESH KUMAR GOUDA)

4. ____________________
(G. GANGADHAR ESHWAR RAO)

ACKNOWLEDGMENT

This endeavor is the result of two years of hard work whereby I am highly indebted to many people who directly and indirectly helped me for its successful completion. The task of acknowledging all the people who made this thesis possible with a few words. However, I will try to do my best to extend my great appreciation to everyone who helped me throughout this study.

I am overwhelmed with heartfelt feelings of gratitude and profound indebtedness to my mentor Dr. Rinku Verma, Assistant Professor, Department of Forestry and Environmental science, University of Agricultural Sciences, Bengaluru and Chairman of my advisory committee. I am grateful and would like to express my deep sense of gratitude and heartful thanks to her for her abysmal guidance, constant encouragement, impeccable advice and support in successful completion of M.Sc programme. Above all her affectionate way of dealing with the things throughout the course of my investigation, helped me to consummate the research work.

I am extremely thankful to Dr. K. T. Prasanna, Professor, Dept. of Forestry and Environmental science, UAS, GKVK, Bengaluru, Dr. M. Mahadevamurthy, Professor Dept. of Forestry and Environmental science, UAS, GKVK, Bengaluru, Dr. Gangadhar Eshwar Rao, Professor, Research Institute on Organic Farming, UAS, GKVK, Bengaluru and Dr. Viresh Kumar Gouda Asst. Professor College of Agricultural Engineering, UAS, GKVK, Bangaluru for their constant guidance and help on all aspects while in carrying out this research work and also for having served as members of my advisory committee.

I gratefully acknowledge my teachers in the Department of Forestry and Environmental Science, UAS, GKVK, Bangalore, Dr. C. Nagarajaiah, Dr. A. S. Devakumar, Dr. Krishna Murthy and Rajesh sir for their valuable suggestions and useful guidance.

My sincere thanks to Mr. Harish, Mr. Mahesh and all the staff of biofuel center, GKVK, Bangalore and non- teaching staff Rudrappa uncle, Devaraj uncle, Sumathi aunty, Shashikala and Anand sir Dept. of Forestry and Environmental Science, GKVK, Bangalore for their valuable help.

Gratitude cannot be seen or expressed; it can only be felt and it is beyond description. Although thanks are poor expression of depth of gratitude one feels, yet there is no better way to express it I acknowledge my parents Sri M. K. Shivakumar and Smt. Yashoda, my sister Ms. B.S. Akshatha and all my family members for their sacrifice, faith, unconditional love, financial support and everything that made me come this far.

I sincerely express my heartfelt thanks to my friends Munny, Shalini for their mental support and encouragement throughout my M.Sc. Degree. without their timely help my research work was incomplete.

It is my pleasure to acknowledge I want to express my fervent thanks to my Department mates Bharath, Bhudesh, Chethan, Karan, Harshi, Praveen, Sumanth and Vipul for their timely help, motivation and encouragement.

I also thankful to my seniors Kokila, Deepika, Ashwini, Lohith, Pinky, Theerthana, Pooja, Chaitra and juniors Hema, Akhila, Ravi, Jujin, Dhanush, Chandrika for their timely help, motivation and encouragement which helped me in the successful completion of my research work.

My sincere and profund thanks to Biofuel unit funded by Govt. of Karnataka and Research Institue on Organic Farming for providing all the facilities for conduction and completion of research work.

Finally, I express my sincere gratitude to University of Agricultural Sciences, GKVK, Bangalore, for providing an opportunity for completing my master's degree programme.

Any omission in this brief acknowledgement doesn‘t mean lack of gratitude.

Bengaluru

October, 2021 **(ANUSHA, B. S.)**

UTILIZATION OF PRODUCTS OBTAINED FROM PYROLYSIS OF PADDY STRAW

ANUSHA, B. S.

ABSTRACT

A poly bag study was undertaken during December 2020 at RIOF, UAS, GKVK Bangalore 65. Pyrolysis of paddy straw was done at 500°C without using catalyst, 2.29 kg of biochar containing 0.41% Nitrogen, 0.04% Phosphorus, 3.83% Potassium, 12 ml Bio oil which is rich in phenol (27.23%) and 101.48 L of syngas was obtained. Further the biochar was used in packet experiment to evaluate the influence of biochar on performance of Field bean using Completely Randomized Design with twenty-four treatments replicated twice. The results revealed that application of 25 tons of biochar + FYM + Vermicompost + Ganajeevamrutha recorded higher growth parameters *viz.*, plant height (66 cm), number of leaves (80), number of branches (14) and yield attributes like number of pods/plant (16) and pod weight/plant (21g). Application of biochar recorded significant improvement in water holding capacity (42%) of the soil. The soil pH (9.5), electrical conductivity (0.19 dSm^{-1}) and organic carbon (6.42 g kg^{-1}) significantly increased, however decrease in bulk density (1.34 Mg m^{-3}) of soil was noticed in the same treatment. There was significant increase in Nitrogen (297 kg ha^{-1}), Phosphorus (63.25 kg ha^{-1}) and Potassium (173.95 kg ha^{-1}) in post-harvest soil. The Iron and Manganese concentration decreased and increase in Zinc and Copper concentration in post-harvest soil was observed.

October, 2021

Department of Forestry and Environmental science
UAS, GKVK, Bengaluru

RINKU VERMA
Major Advisor

ಭತ್ತದ ಹುಲ್ಲಿನ ಪೈರಾಲಿಸಿಸ್ ನಿಂದ ನಿರ್ಬಂಧಿತವಾದ ಉತ್ಪನ್ನಗಳ ಬಳಕೆ

ಅನುಷಾ, ಬಿ.ಎಸ್.

ಪ್ರಬಂಧ ಸಾರಾಂಶ

ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಜಿಕೆವಿಕೆ ಬೆಂಗಳೂರು 65 ರಲ್ಲಿ ಪ್ಯಾಕೆಟ್ ಅಧ್ಯಯನವನ್ನು ಡಿಸೆಂಬರ್ 2020 ರಲ್ಲಿ ಕೈಗೊಳ್ಳಲಾಯಿತು. ವೇಗವರ್ಧಕವನ್ನು ಬಳಸದೆ 500º ಸೆಲ್ಸಿಯಸ್‌ಯಲ್ಲಿ ಭತ್ತದ ಒಣಹುಲ್ಲಿನ ಪೈರೋಲಿಸಿಸ್‌ನಿಂದ, 0.41 ಶೇಕಡಾ ಸಾರಾಜನಕ, 0.04 ಶೇಕಡಾ ರಂಜಕ, 3.83 ಶೇಕಡಾ ಪೊಟ್ಯಾಸಿಯಮ್ ಹೊಂದಿರುವ 2.29 ಕೆಜಿ ಜೈವಿಕ ಇದ್ದಲು, 12 ಮಿಲಿ ಫಿನಾಲ್ (27.23 ಶೇಕಡಾ) ಸಮೃದ್ಧವಾದ ಜೈವಿಕ ತೈಲ ಮತ್ತು 101.48 ಲೀಟರ್ ಸಿಂಗ್ಯಾಸ್ ಪಡೆಯಲಾಗಿದೆ. ಮತ್ತಷ್ಟು ಜೈವಿಕ ಇದ್ದಲುನ್ನು ಪ್ಯಾಕೆಟ್ ಪ್ರಯೋಗದಲ್ಲಿ ಬಳಸಲಾಗಿದ್ದು, ಅವರೆ ಬೆಳೆಯ ಕಾರ್ಯಕ್ಷಮತೆಯ ಮೇಲೆ ಜೈವಿಕ ಇದ್ದಲಿನ ಪ್ರಭಾವವನ್ನು ಮೌಲ್ಯಮಾಪನ ಮಾಡಲು ಸಂಪೂರ್ಣ ಯಾದೃಚ್ಛಿಕ ವಿನ್ಯಾಸವನ್ನು ಬಳಸಿ ಇಪ್ಪತ್ನಾಲ್ಕು ಉಪಚಾರಗಳನ್ನು ಎರಡು ಬಾರಿ ಪುನರಾವರ್ತಿಸಲಾಗಿದೆ. ಫಲಿತಾಂಶಗಳು 25 ಟನ್ ಜೈವಿಕ ಇದ್ದಲು + ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ + ಎರೆಹುಳು ಗೊಬ್ಬರ + ಘನಜೀವಾಮೃತದ ಅನ್ವಯವು ಸಸ್ಯದ ಎತ್ತರ (66 ಸೆಂಮೀ), ಎಲೆಗಳ ಸಂಖ್ಯೆ (80), ಕೊಂಬೆಗಳ ಸಂಖ್ಯೆ ಪ್ರತಿ ಗಿಡಕ್ಕೆ (14) ಮತ್ತು ಇಳುವರಿ ಗುಣಲಕ್ಷಣಗಳು ಬೀಜಗಳ ಸಂಖ್ಯೆ ಪ್ರತಿ ಗಿಡಕ್ಕೆ (16) ಮತ್ತು ಬೀಜಗಳ ತೂಕ ಪ್ರತಿ ಗಿಡಕ್ಕೆ (21 ಗ್ರಾಂ) ಹೆಚ್ಚಿನ ಬೆಳವಣಿಗೆಯ ನಿಯತಾಂಕಗಳನ್ನು ದಾಖಲಿಸಿದೆ ಎಂದು ತಿಳಿದುಬಂದಿದೆ. ಜೈವಿಕ ಇದ್ದಲನ್ನು ಅನ್ವಯಿಸುವುದರಿಂದ ಮಣ್ಣಿನ ನೀರಿನ ಹಿಡಿದಿಡುವ ಸಾಮರ್ಥ್ಯದಲ್ಲಿ (42 ಶೇಕಡಾ) ಗಮನಾರ್ಹ ಸುಧಾರಣೆ ದಾಖಲಾಗಿದೆ. ಮಣ್ಣಿನ ರಸಸಾರ (9.5), ವಿದ್ಯುತ್ ವಾಹಕತೆ (0.19 ಡೆಸಿ ಸೀಮೆನ್ಸ್ ಪ್ರತಿ ಮೀಟರ್‌ಗೆ) ಮತ್ತು ಸಾವಯವ ಇಂಗಾಲ (6.42 ಗ್ರಾಂ ಪ್ರತಿ ಕೆಜಿಗೆ) ಗಣನೀಯವಾಗಿ ಹೆಚ್ಚಾಗಿದೆ. ಕೊಯ್ಲಿನ ನಂತರದ ಮಣ್ಣಿನಲ್ಲಿ ಸಾರಜನಕ (297 ಕೆಜಿ ಪ್ರತಿ ಹೆಕ್ಟೇರ್‌ಗೆ), ರಂಜಕ (63.25 ಕೆಜಿ ಪ್ರತಿ ಹೆಕ್ಟೇರ್‌ಗೆ) ಮತ್ತು ಪೊಟ್ಯಾಸಿಯಮ್ (173.95 ಕೆಜಿ ಪ್ರತಿ ಹೆಕ್ಟೇರ್‌ಗೆ) ಗಮನಾರ್ಹ ಹೆಚ್ಚಳ ಕಂಡುಬಂದಿದೆ. ಕಬ್ಬಿಣ ಮತ್ತು ಮ್ಯಾಂಗನೀಸ್ ಸಾಂದ್ರತೆಯು ಕಡಿಮೆಯಾಗಿದೆ ಮತ್ತು ಕೊಯ್ಲಿನ ನಂತರದ ಮಣ್ಣಿನಲ್ಲಿ ಸತುವು ಮತ್ತು ತಾಮ್ರದ ಸಾಂದ್ರತೆಯು ಹೆಚ್ಚಾಗಿದೆ.

ಅಕ್ಟೋಬರ್, 2021

ಅರಣ್ಯ ಮತ್ತು ಪರಿಸರ ವಿಜ್ಞಾನ ವಿಭಾಗ
ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಬೆಂಗಳೂರು

ರಿಂಕು ವರ್ಮಾ
ಪ್ರಧಾನ ಸಲಹೆಗಾರರು

Effect of paddy straw biochar on growth and yield parameters of field bean and soil properties

ANUSHA B S., PALB 9246

Department of Forestry and Environmental Science, College of Agriculture, GKVK, Bengaluru

Introduction

❖Agricultural crop residues form a major source of biomass in India and annually about 69.7 million tonnes of crop residues are produced from the six major crops. Hence, the conversion of crop waste into biochar helps to offset CO_2 emission and increase the carbon sequestration in the soil under changing climate.

❖Biochar is a carbon rich substance obtained from thermal decomposition of plant biomass through the process of pyrolysis. The special characteristics of the biochar are its effectiveness in retaining most of the nutrients and making them available to plants rather than other organic substances such as natural leaf litter, compost or manures. Biochar typically has a powerful aromatic structure and is therefore biochemically more recalcitrant than any other type of organic matter in soils and may last in the soil for thousands of years. Therefore it's feasible to use biochar as part of a change to organic farming methods to transform agriculture from a net carbon emitter to a method to restore carbon stocks in the soil.

❖ Objective:

✓ To evaluate the effect of paddy straw biochar on field bean and post harvest soil properties.

Material and Methods

❖ The paddy straw biochar was produced by the process of pyrolysis at 500°C and was ground to pass through 0.2 mm sieve for further application.

Experiment details:

Materials used: FYM, Vermicompost, Ganajeevamrutha,
Paddy straw biochar
Location: Organic farming, GKVK, Bangalore.
Season: Rabi
Crop, Variety: Field bean, Hebbal Avarae
Design: CRD
No. of treatments: 24
No. of replications: 2
Initial soil properties:
pH – 7.2, EC – 0.22 dSm^{-1}, OC- 5.2 g kg^{-1}, N – 263.54 kg ha^{-1}, P_2O_5 - 46.37 kg ha^{-1}, K_2O - 196 kg ha^{-1}

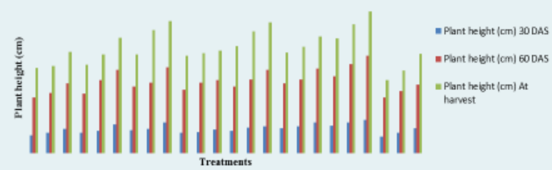
Treatment details:

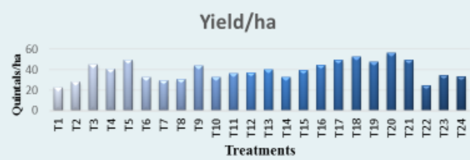
T_1: 15 tons of BC + FYM
T_2: 15 tons of BC + VC
T_3: 15 tons of BC + GJ
T_4: 20 tons of BC + FYM
T_5: 20 tons of BC + VC
T_6: 20 tons of BC + GJ
T_7: 25 tons of BC + FYM
T_8: 25 tons of BC + VC
T_9: 25 tons of BC + GJ
T_{10}: 15 tons of BC + FYM+ VC
T_{11}: 15 tons of BC + FYM+ GJ
T_{12}: 15 tons of BC + VC + GJ
T_{13}: 20 tons of BC + FYM +VC
T_{14}: 20 tons of BC + FYM + GJ
T_{15}: 20 tons of BC + VC + GJ
T_{16}: 25 tons of BC + FYM +VC
T_{17}: 25 tons of BC + FYM + GJ
T_{18}: 25 tons of BC + VC+ GJ
T_{19}:15 tons of BC + FYM + VC + GJ
T_{20}: 20 tons of BC + FYM +VC + GJ
T_{21}: 25 tons of BC + FYM +VC + GJ
T_{22}: 15 tons of BC
T_{23}: 20 tons of BC
T_{24}:25 tons of BC

VC-Vermicompost, BC-Biochar, GJ-Ganajeevamrutha.

Experimental Results

Fig 1: Effect of paddy straw biochar on Field bean





Paddy straw biochar

Field bean crop at 30 DAS

Table 1: Influence of biochar on soil properties after harvest of Field bean

Treatment details	pH	EC (dSm^{-1})	OC (g kg^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
T_1	7.20	0.10	5.48	265.50	53.00	159.00
T_2	7.97	0.11	5.46	269.00	55.50	159.00
T_3	8.02	0.11	5.40	270.50	56.75	160.70
T_4	7.52	0.12	5.60	271.00	56.11	159.00
T_5	7.33	0.12	5.66	273.00	58.60	163.50
T_6	7.85	0.13	5.72	273.00	60.13	166.00
T_7	7.24	0.14	5.86	274.00	59.11	165.80
T_8	7.44	0.16	5.98	277.50	60.91	167.90
T_9	8.20	0.17	6.11	278.50	61.60	167.70
T_{10}	7.47	0.12	5.63	266.00	55.00	169.10
T_{11}	7.77	0.11	5.46	265.00	56.25	167.50
T_{12}	7.92	0.11	5.45	268.50	54.25	169.00
T_{13}	7.53	0.14	5.87	272.00	58.50	168.10
T_{14}	7.30	0.14	5.83	272.50	59.35	169.50
T_{15}	7.26	0.16	6.15	271.50	59.95	170.50
T_{16}	7.52	0.16	6.12	274.50	59.00	168.30
T_{17}	7.41	0.15	5.88	277.00	60.25	170.10
T_{18}	7.36	0.16	6.18	279.50	61.60	169.50
T_{19}	7.60	0.16	6.13	286.00	60.10	169.80
T_{20}	8.98	0.18	6.20	291.50	63.10	172.90
T_{21}	9.50	0.19	6.42	297.00	63.25	173.90
T_{22}	6.76	0.10	5.47	255.50	48.85	158.00
T_{23}	7.65	0.12	5.72	258.00	52.45	159.20
T_{24}	8.03	0.16	6.11	261.50	53.15	158.50
S.Em±	**0.01**	**0.066**	**0.03**	**2.36**	**0.94**	**1.24**
C.D @ 5%	**0.02**	**0.193**	**0.09**	**6.89**	**2.75**	**3.64**

Summary

✓ Application of biochar along with other organic inputs helps in improving nutrient availability in soil hence improves crop growth.

✓ Compared to all the treatments T_{21} which received 25 tons of biochar + FYM + Vermicompost + Ganajeevamrutha showed best result followed by T_{20} which recieved 20 tons of biochar + FYM + Vermicompost + Ganajeevamrutha.

Discussion

➢ Increase in plant available N, P, K, total Organic carbon and soil pH is a function of biochar addition and in turn helps in increasing the crop yield. Similar results were observed by Pandit *et al.*, (2018).

➢ Increase in the dosage of biochar showed positive impact on growth and yield parameters of field bean and in turn it helps in improving the physical and chemical properties of soil, Similar observation were recorded by Karer *et al.*, (2013).

Advisory committee:

Chairperson:
Dr. Rinku Verma

Members:
Dr. K. T. Prasanna
Dr. M. Mahadevamurthy
Dr. Viresh Kumar Gouda
Dr. G. Gangadhar Eshwar Rao

References

• PANDIT, N.R., MULDER, J., HALE, S.E., ZIMMERMAN, A.R., PANDIT, B.H. AND CORNELISSEN, G., 2018. Multi-year double cropping biochar field trials in Nepal: finding the optimal biochar dose through agronomic trials and cost-benefit analysis. *Sci. Total Environ.*, **637**, 1333-1341.

• KARER, J., WIMMER, B., ZEHETNER, F., KLOSS, S. AND SOJA, G., 2013. Biochar application to temperate soils: effects on nutrient uptake and crop yield under field conditions. *Agric. Food Sci.*, **22**(4), 390-403.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

Abbreviation	Full form	Abbreviation	Full form
%	Per cent	KCl	Potassium chloride
@	At the rate of	DAS	Days after sowing
ºC	Degrees Celsius	$KMnO_4$	Potassium permanganate
ha	hectare (s)	Mg	Magnesium
BD	Bulk Density	kg	Kilogram
$CaCl_2$	Calcium chloride	$Mg\ m^{-3}$	Mega gram per cubic meter
$CaCO_3$	Calcium carbonate	Ml	Millilitre
CD	Critical difference	Mm	Millimetre
cm	Centimetre	Mn	Manganese
$C\ mol\ (p+)\ kg^{-1}$	Centimole per kilogram	NaOH	Sodium hydroxide
Cu	Copper	$ZnSO_4$	Zinc sulphate
$dS\ m^{-1}$	Decisiemen per meter	NPK	Nitrogen, phosphorus and potassium
$kg\ ha^{-1}$	Kilogram per hectare	NS	Non-significant
DTPA	Diethylenetriamine Penta acetic acid	OC	Organic carbon
HCl	Hydrochloric acid	RCBD	Randomized complete blockdesign
EBT	Erichrome black – T	P_2O_5	Phosphorus pentoxide
et al.,	and other people	PD	Particle density
EC	Electrical conductivity	Ppm	parts per million
etc.,	and so on	SOC	Soil organic carbon
Fig.	Figure	FYM	Farm yard manure
g	Gram	$K_2Cr_2O_7$	Potassium dichromate
H_2SO_4	Sulphuric acid	K_2O	Potassium oxide

I INTRODUCTION

Every year approximately 92 metric tons of crop waste is burned in India, causing excessive particulate matter emission and air pollution. Burning of Crop residue is a major environmental problem responsible health issues and leads to Global warming. Harvesting of crops generates large volume of residue both on and off farm. Crop residues is not a waste but rather a useful natural resource. Frequent residue burning of paddy straw leads to complete loss of microbial population and causes environmental pollution. Smoke from this burning leads to a cloud of particulates and produce toxic cloud resulting in severe air pollution. Including emission of greenhouse gases that contribute to global warming increase levels of particulate matter (PM) and smog cause health hazard, loss of biodiversity of agricultural lands and deterioration of soil fertility. During October month this problem with smog and air pollution are witnessed in Delhi due to straw burning in northern parts of India especially in Punjab and Haryana.

Crop residues are India's major source of biomass, with approximately 69.7 million tonnes of residue produced annually by 6 major crops in India (NPMCR 2014); So, the conversion of crop waste into biochar under changing climate helps to offset CO_2 emission and increase the carbon sequestration in the soil. One way to reduce this is by pyrolysis / thermal depolymerisation which is the decomposition or cracking of materials in absence of oxygen. There are two types of pyrolysis, one is slow pyrolysis and the other fast pyrolysis. Pyrolysis yields Biochar, Biooil and Syngas. The present work will look into the potential utility of the above via slow pyrolysis.

Biochar is a carbon rich substance obtained from thermal decomposition of plant biomass through the process of pyrolysis. The special characteristics of the biochar are its effectiveness in retaining most of the nutrients and maintaining them available to plants rather than other organic substances such as natural leaf litter, compost or manures. Biochar typically has a powerful aromatic structure and is therefore biochemically more recalcitrant than any other type of organic matter in soils and may last in the soil for thousands of years. Therefore, it’s feasible to use biochar as a part of change to organic farming methods to transform agriculture from a net carbon emitter to a method to restore carbon stocks in the soil. Further, it also helps in improving the productivity of soil resulting in higher yields. This technology is also a measure for controlling Greenhouse Gas emission and ways to effectively enhance natural rates of carbon sequestration in the soil.

Biochar, which is produced by the thermo-chemical decomposition of organic material (crop residues and wood waste) under partial or full exclusion of oxygen (pyrolysis) at a relatively higher temperature range of 450°C to 600°C and it has been the subject of researchers for many years. Converting inexpensive, available crop straws into biochar and adding them to soils can have substantial agricultural and environmental benefits (Wang *et al*., 2013). There is sufficient evidence that due to its particular structure and composition, biochar land use may theoretically increase carbon sequestration, boosts soil health and crop productivity by contributing to sustainable management of organic residues (Lehmann and Joseph, 2009).

Application of biochar improved the soil health, increase the carbon capture and storage, reduce the greenhouse gas emission and enhance the crop yield with sustained soil health, which enables to meet the food grain needs of the ever growing population (Kannan *et al.,* 2013). Recently, biochar applications have gained momentum with features such as: carbon sequestration, enhancing nutrient uptake from the soil, reducing soil compaction, improves soil physical condition, and helps to reduce nitrous oxide emission (Lehmann and Rondon, 2005; Lehmann, 2007).

Biochar is extremely porous, typically alkaline, and has a wide specific surface area (Glaser *et al*., 2002; Downie *et al*., 2009). Because of these intrinsic chemical and physical properties, biochar can theoretically affect a variety of soil characteristics, including soil pH, porosity, bulk density and ability to retain water (Glaser *et al*., 2002; Chan *et al*., 2007). In addition, biochar absorbs ions from soil solution by a mixture of electrostatic, complexing and capillary pressures on their surfaces and in pores (Major *et al*., 2010). This biochar properties can significantly decrease soil nutrient leaching (Lehmann *et al*., 2003) as well as the accessibility of ions to soil microorganisms. Thus preliminary research by scientists and environmentalists in various parts of the world shows the beneficial impact of biochar in agriculture to increase the production of different crops.

The use of biochar in agricultural systems is a viable option that can improve the natural rate of carbon sequestration in the soil, reduce agricultural waste and improve soil quality. Initial results of the application of biochar suggest that it improves soil health and crop yields. Biochar has a lasting impact on soil physical properties, availability of nutrients, soil microbial activity, carbon sequestration capacity, crop yield/production and mitigation of Greenhouse gas. It is one of the abundant sources for the production of paddy straw biochar from farm waste that can be used locally, and its application to the soil has a great impact on the physical, chemical and biological properties of the soil. Rice straw biochar produced at 500 ^{o}C can be used locally at the same price as Farmyard Manure (FYM), and their role in plant growth, yield, and maintaining soil health are immeasurable compared to FYM. Thus keeping this in view, to evaluate the performance of Field bean which is grown throughout India for its green pods as vegetable and dry seeds as pulse as influenced by paddy straw biochar and soil properties, the present research entitled **"Utilization of products obtained from pyrolysis of paddy straw."** was conducted with following objectives.

Objectives of research work

1) To study the characterization of paddy biochar.

2) To evaluate the performance of paddy biochar application on Field bean.

3) To study the characterization of paddy bio oil.

II REVIEW OF LITERATURE

The present literatures are gone through as a basic structure for the further studies on Utilization of products obtained from pyrolysis of paddy straw. The review related to the present investigation is given in the following headings:

2.1 To study the characterization of paddy biochar.

2.2 To evaluate the performance of paddy biochar application on Field bean.

2.3 To study the characterization of paddy bio oil.

2.1 To study the characterization of paddy biochar.

Schmidt and Noack (2000), researched biochar as a carbonaceous substance that includes a number of certain specific classes of polycyclic aromatic hydrocarbons.

Antal *et al.* (2003) reported that low temperatures of pyrolysis that produce torrified-like biochars containing semi-degraded cellulose and hemicellulose compounds because 300 to 400 ºC is the critical temperature range for their structural breakdown. Compared to 500 ºC, biochars that were formed at 250 ºC potentially include more stable classes of carboxylic acid.

It was found that specific biochar materials can decompose to differing degrees, based on the physical and chemical properties of a given biochar as reported by Hamer *et al*. (2004). Researchers also observed that two biochars formed at different temperatures released 0.3 and 0.8 per cent of initial C as CO_2.

Brown *et al*. (2006) recorded that at lowest (300 ºC) and maximum (> 1000 ºC) pyrolysis temperature, lower surface area (~10 $m^2\ g^{-1}$) of biochars was formed. Although higher surface are (~400 $m^2\ g^{-1}$) was reported at 650 to 850 ºC as intermediate pyrolysis temperature (Lua and Yang, 2004).

Gaskin *et al.* (2008) observed that the overall feedstock nutrients extractable and Mehlich I is concentrated after pyrolysis in biochar. Some biochar may act as a fertilizer as well as a carbon sequester depending on the feedstock.

Biochar and charcoal have a low volume density of about 300 kg m^{-3} compared to a normal density of 1300 kg m^{-3} in soil. Particles may be of rather small quality, and structures may be hydrophobic in comparison Deluca and Aplet (2008). A biochar's porosity and surface area have a greater effect of surface binding on the nutrient retention ability.

Novak e*t al*. (2009) reported that higher pyrolytic temperature (>400°C) was observed to produce biochars with alkaline pH.

Downie *et al.* (2009) observed that the biochar porosity, which defines its surface region, has an extremely variable pore size range that includes nano-(< 0.9 nm), micro-(< 2 nm) to macro-pores (> 50 nm) and biochar has lower bulk density than mineral soil with organic soil values.

Lei *et al*. (2009) these biochar properties are influenced by pyrolytic parameters and feedstock type.

Study on physical and chemical properties of different forms of biochar from peanut hulls, peacan shells, poultry litter, and switch grass were carried out. Novak *et al.* (2009) found higher pyrolysis temperatures resulted in lower biochar mass recovery, greater surface areas, elevated pH and higher ash contents.

Rodriguez *et al.* (2009) noted that, in a maize trial in Colombia, the biochar produced from sugarcane bagasse increased soil pH from 4.0–4.5 to 6.0–6.5. Biochar is found predominantly in soil organic matter (SOM) fractions that reside in small clusters of soil particles, or soil aggregates, rather than as free organic matter.

Steinbeiss *et al.* (2009) stated that biochars with low temperatures were found to have a less compact C structure and are predicted to have greater reactivity in soil than biochars with higher temperatures and to contribute more to soil fertility.

Singh *et al.* (2010) proposed that wood biochars had higher total C, lower ash output, lower total N, P, K, S, Ca, Mg, Al, Na and Cu components, and lower possible cation exchange capacity (CEC) and exchangeable cations than manure-based biochars, and that leaf biochars were usually intermediate. Higher pyrolysis temperature raised the basicity of the biochar, pH of the substrate and lowered acidity.

The fined biochars are melted easily and rapidly than pelleted. These changes will affect the ability of biochar mixing into soils, also some significant physical parameters such as specific surface area, surface charge, particle size distribution, porosity, bulk density and specific gravity, water-holding capacity, and hydraulic conductivity as reported by Zimmerman (2010).

As investigated by Wu *et al*. (2012) pyrolysis temperature had a greater influence than residence time on the chemical composition and structure of rice straw-derived biochar produced at low heating rate. The rice straw-derived biochar especially produced at 400 ^{O}C had high alkalinity and cation exchange capacity, and high levels of available phosphorus and extractable cations.

Ippolito *et al.* (2012) Biochar is characterized with its lower specific surface area, higher water-holding capacity, lower pH, more carboxyl and phenol groups, and higher cation exchange capacity (CEC), when pyrolysis happens at low temperature.

Wang *et al.* (2013) observed that rising biochar pyrolysis temperature from 500 to 700 ºC enhanced ash volume, surface area, pH, total P and Ca content and decreased biochar output, CEC, total acid and nitrogen content. Excessive residence period from 4 to 8 or 16 hours, increased the BET surface area and biochar ash amount but decreased biochar yield. Study of Fourier-transform infrared spectroscopy (FTIR) found that, at a higher temperature, more recalcitrant and aromatic compounds were developed in the biochar.

Analysis carried out by Jindo *et al.* (2014) revealed the chemical and physical properties, which are strongly related to the form of the initial substance used and the conditions of pyrolysis, and the results showed that the biochar obtained at 600 °C has a high recalcitrant character while that obtained at 400 °C maintains flexible and easily labile compounds. Owing to the inclusion of silica elements into its chemical structure, the biochar derived from rice materials (rice husk and rice straw) exhibited high yield and special chemical properties. The biochar obtained from wood products was lower in carbon content and high in absorption.

Wan *et al*. (2014) showed that pH, carbonate content, base cation, and biochar alkalinity increased with temperature rise in pyrolysis. Biochar's elevated pH was due to hydrolysis of the Ca, Mg, and K salts.

In a study estimated the bulk density values of biochars produced from different feedstock and it ranged from 0.25 to 0.6 g cm^{-3} Brewer *et al*. (2014). Low-temperature pyrolysis produced high biochar yields; in contrast, high-temperature pyrolysis led to biochar with a high C content, large surface area, and high adsorption characteristics as reported by Jindo *et al*. (2014).

Batool *et al*. (2015) showed that in stressed plants, stomatal conductance and transpiration decreased and nearly reached zero. On the other side, comparison with untreated plants, water use efficiency (WUE) has increased in stressed plants that produce biochar and gypsum. Biochar alone is a better strategy for fostering plant growth and WUE in particular.

Rumi *et al*. (2015) reported that biochar is a carbon rich material contains 50 per cent of its original carbon, which is highly recalcitrant nature, which are produced during pyrolysis process. Along with the biochar some amount of bio-oil and gases are also produced.

Figueredo *et al*. (2017) discovered that the biochar, a material of organic waste pyrolysis, can be used as a soil conditioner and also as a solid waste management option. The results showed the existence of C, H, N, O, ashes, macro and micronutrients, mineral process characterization, and functional groups. Relationships between O/C and H/C decreased with rising pyrolysis temperature, which determines greater biochar C stability.

2.2 To evaluate the performance of paddy Biochar application on crops.

Lehmann and Randon (2005) showed that depending on the amount of biochar added, significant improvements in plant productivity were achieved ranging from 20 to 220 per cent. Increase the yields of maize and peanut due to changes in P availability through increased root colonization of arbuscular mycorrhizal fungi was recorded by Yamato *et al*. (2006).

Cumulative yield increase of rice and sorghum on a Brazilian Oxisol after three repeated biochar applications at the rate 7 t ha^{-1} for two years were reported by Steiner *et al*. (2007). The progressive increase in beneficial effects of biochar overtime was due to increased NPK availability in soil.

Asai *et al*. (2009) conducted a study to know the effect of rate of biochar application on rice with varied level of N and P at ten different sites with two cultivars. Biochar application resulted in higher grain yields at the sites where P availability was low. Whereas in the absence of N fertilizer and at the highest rate of biochar application, there was reduction in leaf chlorophyll content indicating biochar application is highly dependent on soil fertility and fertilizer management.

Van Zwiteten *et al*. (2010) reported that plant biomass increased significantly with increasing biochar addition when applied in combination with lower N application rates. Application of biochar at the highest rate resulted in significantly more NO_3-N in the soil. Application of biochar also increased microbial activity and available P in the soil.

Feng *et al.* (2014) reviewed a 2009 long-term field trial to assess the impact of biochar on crop yield of beans and soil properties in an alkaline environment. Five treatments were incorporation of straw, incorporation of straw with inorganic fertilizer and incorporation of straw with inorganic fertilizer, and biochar 30, 60, and 90 t ha^{-1}, respectively. The study showed significantly increase in average yield over the first four growing seasons. The findings indicated that biochar could be used without yield degradation or major impacts on resource supply in alkaline soils.

A field experiment conducted by Coumaravel *et al*. (2015) with hybrid maize, the result revealed that application of biochar at 10 t ha^{-1} along with the recommended dose of fertilizer + FYM 12 t ha^{-1} and Azospirillum at 2 kg ha^{-1} significantly increased yield and nutrient uptake.

Alie Kamara *et al*. (2015) observed that the use of biochar increased the supply of phosphorus, exchangeable cations and CEC when opposed to soil management without biochar. Plant height, number of tillers, and dry biomass weight of rice varieties grown in rice straw biochar adjusted soils were substantially higher than those of untreated soils. Biomass yield and tiller figures represented the most significant improvement in plant growth characteristics as a part of biochar introduction to soil.

Haider *et al.* (2016) reported that aged biochar was more effective than fresh biochar for nutrient capture and delivery, a property which may lead to increased crop yield over time.

The six biochars differed in pH, ash quality, equivalent Calcium carbonate ($CaCO_3$), total base cations, CEC, and other properties (pore scale, functional surface groups). Desmodium's gross dry weights is raised 2 to 4-fold over the control or lime treatment after biochar applications. Ultimately, Arnoldus and Nguyen (2016), concluded that comparable $CaCO_3$ and complete simple cations were among the biochar's most significant properties responsible for improving the productivity of acid soils and plant productivity.

Kalyani *et al.* (2016) reported increased plant height, number of leaves and yield of the bean, fenugreek and mint with biochar in the combination of organic manure than biochar alone or compost alone.

A field trial at Alasulige village Sakleshpur taluk, district of Hassan, Karnataka conducted by Mamatha *et al.* (2018) to use the simple slag as a soil modification and nutrient source in acid soil relative to lime. Results of the experiment showed that significantly higher yields of paddy grain (50.32 q ha^{-1}) and straw (65.93 q ha^{-1}) were observed in treatment T_9 (100% RDF + simple slag at 2 t ha^{-1}) followed by T_{10} (100% RDF + lime at 2 t ha^{-1}).

2.3 To study the characterization of Paddy Bio oil

Mokhlisse, and Chanaa. (1999) experimental results show that the bio-oil yield of steam pyrolysis is significantly higher than that of normal and nitrogen pyrolysis. Bio-oil yield increases with increasing steam velocity. This result is consistent with the theory that for higher velocities secondary reactions such as char formation are prevented.

Ozbay *et al*. (2001) reported the kinetics of pyrolysis reactions shows that the primary pyrolysis reactions takes place in the temperature range of 200–400°C which results in formation of solid product, char. Temperatures above 400°C, solid residue slowly undergoes further chemical and physical transformations which leads to the formation of liquid and gas products. Pyrolysis temperatures up to 600°C maximizes the production of bio-oils and temperatures above 700°C maximizes gaseous products while minimizing char formation.

Pütün *et al*. (2004) experimented that Bio-oil yield was 33.41% when steam velocity was 1.3 cm/s and this value increased to 35.86% with the velocity of 2.7 cm/s. The opposite was observed for the solid product; char yield decreased from 17.05% to 14.82% when steam velocity was decreased.

Tsai *et al.* (2007) reported that temperatures above 550°C are favorable in the successive aromatization reactions, such as the cracking of the light organics, oligomerization, cyclization, hydrogen or hydride transfer, and aromatization, and Bio-oil produced by fast pyrolysis of cellulosic biomass is an emulsion of water (~20% w/w) and a wide range of oxygenated organic compounds including organic acids, aldehydes, alcohols, phenols, carbohydrates, and lignin-derived oligomers.

Goyal *et al.* (2008) stated that product yields from slow pyrolysis are approximately 35% biochar, 30% bio-oil, and 35% syngas by mass.

Fahmi *et al.* (2008) observed that Cellulosic feedstocks, bio-oil yield decreases with increasing ash content and the average molecular weight of the bio-oil fraction increases with lignin content of the feedstock.

Laird *et al*. (2009) observed that Pyrolysis of biomass, acids are partitioned into the bio-oil fraction while bases – primarily K_2O, CaO, and MgO – are partitioned into the biochar fraction and lighter aromatic molecules, including most single ring and smaller polycyclic aromatic hydrocarbons (PAHs) are distilled into the bio-oil fraction during pyrolysis.

Zhang *et al*. (2011) reported that four distinct conditions required for the pyrolysis processes: Medium temperatures, High heating rates, Short vapor residence times and fast condensation. CC bonds of the biomass functional groups broken to create bio-oil, and biochar, and residual non-condensable compounds with C-O bonds.

Report by Huang *et al*. (2012) found that biomass rich in cellulose or hemicellulose contains higher olefins yield in the bio-oil produced than the feedstocks with higher lignin content.

Choi *et al*. (2012) stated that in association with catalyst loading, pyrolysis variant conditions also influence the yield and composition of the pyrolysate. The conditions (operating parameters) are tempered to direct the pyrolysis reaction to the desired quality and quantity of bio-oil. The typical operating parameters for fixed, fluidized bed, batch and auger pyrolyzers can include; Biomass loading, Biomass particle size, Nitrogen flow rate, Pyrolysis temperature and Time.

Shi *et al.* (2012) evaluated the influence of the acid washed straw forms slightly more bio-oil compared to gaseous products than untreated straw, over a temperature range of 300–700°C. Similarly, in a temperature range of 500–700°C, the untreated straw yields more char than water for the acid treated straw. The visible differences in the products distribution between the treated and untreated straw indicates the influence the alkali and alkali earth metals had on the rice straw pyrolysis.

Shun *et al*. (2013) observed the catalysts upgrades the quality of the pyrolysis oil through cracking, deoxygenation, oligomerization, cyclization, aromatization, alkylation, isomerization and polymerization. The catalytic upgrade mainly increases the heating value (energy density) of the bio-oil. Catalysts tailor thermally driven fast pyrolysis reactions to yield high quality and more stable bio-oil.

Jacobson *et al*. (2013) observed that the bio-oil contains complex heterogeneous mixtures of aromatics and aliphatic oxygenated compounds as Phenolics, Carbohydrates, Alcohol, Aldehydes, Ketones and Carboxylic acids.

Jacobson *et al.* (2013) explained the pretreated biomass has higher lignin content than the virgin biomass, more phenolic compounds are produced upon catalytic pyrolysis over the less acidic silicate catalysts. Remarkably, pore blockade by bio-oil macromolecules and active site deactivation are avoided by the use of aluminosilicate during bio-oil upgrading process.

The catalysts significantly alter the composition of the non-catalytic pyrolysis oil by eliminating acids and reducing phenol as reported by Zhang *et al.* (2014). Also, reduction of linear aldehydes and anhydro sugars (mainly laevoglucose) and the formation of cycloalkanes, aromatics and other light hydrocarbon compounds substantially change the bio-oil chemical composition. The capabilities of the catalysts confirm to upgrade the fuel properties of bio-oil and enhance the formation of some valuable chemicals.

A study by Naqvi *et al.* (2014) on both catalytic and non-catalytic pyrolysis of paddy husk biomass in a drop type fixed bed pyrolizer. They studied the effect of temperature (300 – 600 °C) and catalyst loading on the pyrolysis of the biomass in a drop type fixed bed pyrolizer. Thermal pyrolysis oil yield increased from 350 to 450 °C, and maximum yield was obtained at 450 °C. However, the paddy husk is catalytically pyrolysis at 450 °C and varying catalyst loading ratio from 0.5 to 2. A catalyst loading of 0.5 favors highest de-oxygenation rate and the catalytic pyrolysis oil yield was highest.

Shen *et al.* (2015) explained that individual biomass macromolecules (cellulose, hemicellulose and lignin) pyrolyzed under varying range of temperatures contribute the essential functionalities to the bio-oil. Cellulose decomposes to laevoglucose, and then fragmented to linear compounds as furfural, acetone, alcohols and ketones.

Veses *et al.* (2015) reported that the catalyst loading critically influences bio-oil yield; higher loading ratio discourages bio-oil yield but increases the biochar and gas production. Small catalyst dosage is often recommended because it led to a high yield of bio-oil, rich in phenol derived compounds and less in low molecular weight oxygenates.

III MATERIAL AND METHODS

The research entitled “Utilization of products obtained from pyrolysis of paddy straw” was undertaken during 2020-2021. In this study, a potted experiment was conducted in the GKVK at Bangalore. The details of the material used and methodologies adopted during the investigation are described in this chapter.

3.1 General description of the product

3.1.1 Biochar

Biochar prepared from paddy straw was used. The paddy straw biochar was produced at 500°C was used in the present experiment and burnt material was ground to pass through 0.2 mm sieve.

Characterization of biochar

The biochar used in this present study was characterized for its various physicochemical properties such as bulk density, water holding capacity, pH, EC, and total elemental composition by adopting standard analytical procedures. The analytical procedures employed for analysis of different parameters are given in Table 3.1.

3.1.2 Ganajeevamrutha

10 kg of desi cow dung was mixed with 500 g of pulse flour, 500 ml desi cow urine, 100 g jaggery and a hand full of soil and shade dried for 3 days and then powdered and used for the experiment.

3.2 Weather during crop growth period

During crop growth period, a total rainfall of 358.2 mm was received from September to December. Maximum temperature ranged from 27.2°C to 34.5°C and minimum temperature ranged from 19.0°C to 20.5°C.

Table 3.1: Methods employed for the analysis of biochar

Sl. No.	Parameter	Method	Reference
1.	pH	Potentiometry	Jackson (1973)
2.	EC (dSm^{-1})	Conductometry	Jackson (1973)
3.	MWHC (%)	Keen's cup method	Pipper (1966)
4.	Bulk density (g/cc)	Keen's cup method	Pipper (1966)
5.	Total carbon (%)	Dry combustion method (CHNS, LECO)	Page *et al.* 1982
6.	Nitrogen (%)	Kjeldahl digestion & distillation method	Jackson (1973)
7.	Phosphorus (%)	Diacid digestion & vanadomolybdate method	Jackson (1973)
8.	Potassium (%)	Diacid digestion & vanadomolybdate method	Jackson (1973)
9.	Calcium (%)	Complexometric titration method	Jackson (1973)
10.	Magnesium (%)	Complexometric titration method	Jackson (1973)
11.	Sulphur (ppm)	0.15% CaCl extraction & Turbidity	Black (1965)
12.	Iron (ppm)	Diacid digestion & Atomic Absorption Spectrophotometry	Lindsay and Norwell (1978)
13.	Copper (ppm)		
14.	Manganese (ppm)		
15.	Zinc (ppm)		

3.3 Design and layout of the experiment

The experiment was laid out in a Completely Randomized Design (CRD) having twenty four treatment combinations and replicated twice on a net packet. The plan of layout of the experiment is shown in Fig 1.

3.3.1 Experimental details

Table 3.2: Experimental details

Crop	Field bean
Variety	Hebbal avare
Season	Rabi
Polythene bag size	18 x 18 inches
Date of sowing	18/12/2020
Date of harvest	1/4/2021
Source of nutrients	Paddy straw Biochar, FYM, Vermi compost, Ganajeevamrutha

N

R_1	R_2	R_1	R_2
T_{12}	T_8	T_{16}	T_6
T_{20}	T_1	T_{23}	T_3
T_5	T_{10}	T_6	T_{24}
T_{11}	T_2	T_{10}	T_{16}
T_1	T_5	T_{23}	T_9
T_{13}	T_{19}	T_3	T_2
T_4	T_{17}	T_{15}	T_{14}
T_9	T_{12}	T_{17}	T_4
T_{14}	T_7	T_{21}	T_{18}
T_{22}	T_{20}	T_{24}	T_{21}
T_7	T_{15}	T_8	T_{11}
T_{18}	T_{13}	T_{19}	T_{22}

Fig. 3.1: Arrangement of packets

PADDY STAW BIOCHAR

BIO OIL

Plate 1: Products obtained from pyrolysis

PACKET FILLING

SOWING OF FIELD BEAN

Plate 2: A view of Packet filling and sowing of Field bean

3.3.2 Treatment details

Table 3.3: Treatment details

Treatments	Details
T_1	15 tons of Biochar + FYM
T_2	15 tons of Biochar + VC
T_3	15 tons of Biochar + Ganajeevamrutha
T_4	20 tons of Biochar + FYM
T_5	20 tons of Biochar + VC
T_6	20 tons of Biochar + Ganajeevamrutha
T_7	25 tons of Biochar + FYM
T_8	25 tons of Biochar + VC
T_9	25 tons of Biochar + Ganajeevamrutha
T_{10}	15 tons of Biochar + FYM+ VC
T_{11}	15 tons of Biochar + FYM+ Ganajeevamrutha
T_{12}	15 tons of Biochar + VC + Ganajeevamrutha
T_{13}	20 tons of Biochar + FYM +VC
T_{14}	20 tons of Biochar + FYM + Ganajeevamrutha
T_{15}	20 tons of Biochar + VC + Ganajeevamrutha
T_{16}	25 tons of Biochar + FYM + VC
T_{17}	25 tons of Biochar + FYM + Ganajeevamrutha
T_{18}	25 tons of Biochar + VC+ Ganajeevamrutha
T_{19}	15 tons of Biochar + FYM + VC + Ganajeevamrutha
T_{20}	20 tons of Biochar + FYM + VC + Ganajeevamrutha
T_{21}	25 tons of Biochar + FYM + VC + Ganajeevamrutha
T_{22}	15tons of Biochar
T_{23}	20tons of Biochar
T_{24}	25tons of Biochar

Table 3.3.1: Treatment details

Treatments	Details	Quantity of inputs added per packet (g)			
		Biochar	FYM	VC	Ganajeevamrutha
T_1	15 tons of Biochar + FYM	42.75	34.2	-	-
T_2	15 tons of Biochar + VC	42.75	-	10.26	-
T_3	15 tons of Biochar + Ganajeevamrutha	42.75	-	-	2.85
T_4	20 tons of Biochar + FYM	57	34.2	-	-
T_5	20 tons of Biochar + VC	57	-	10.26	-
T_6	20 tons of Biochar + Ganajeevamrutha	57	-	-	2.85
T_7	25 tons of Biochar + FYM	71.25	34.2	-	-
T_8	25 tons of Biochar + VC	71.25	-	10.26	-
T_9	25 tons of Biochar + Ganajeevamrutha	71.25	-	-	2.85
T_{10}	15 tons of Biochar + FYM+ VC	42.75	34.2	10.26	-
T_{11}	15 tons of Biochar + FYM+ Ganajeevamrutha	42.75	34.2	-	2.85
T_{12}	15 tons of Biochar + VC + Ganajeevamrutha	42.75	-	10.26	2.85
T_{13}	20 tons of Biochar + FYM +VC	57	34.2	10.26	-
T_{14}	20 tons of Biochar + FYM + Ganajeevamrutha	57	34.2	-	2.85
T_{15}	20 tons of Biochar + VC + Ganajeevamrutha	57	-	10.26	2.85
T_{16}	25 tons of Biochar + FYM + VC	71.25	34.2	10.26	-
T_{17}	25 tons of Biochar + FYM + Ganajeevamrutha	71.25	34.2	-	2.85
T_{18}	25 tons of Biochar + VC+ Ganajeevamrutha	71.25	-	10.26	2.85
T_{19}	15 tons of Biochar + FYM + VC + Ganajeevamrutha	42.75	34.2	10.26	2.85
T_{20}	20 tons of Biochar + FYM + VC + Ganajeevamrutha	57	34.2	10.26	2.85
T_{21}	25 tons of Biochar + FYM + VC + Ganajeevamrutha	71.25	34.2	10.26	2.85
T_{22}	15tons of Biochar	42.75	-	-	-
T_{23}	20tons of Biochar	57	-	-	-
T_{24}	25tons of Biochar	71.25	-	-	-

* Each packet consisted of 10kg each consisting of 6kgs of soil added initially and to the remaining 4 kgs of soil, desired quantity of the inputs as per the treatments have been added finally achieving a total of 4kgs (soil + inputs (depending on the treatment the following were added : Biochar /FYM / VC/ Ganajeevamrutha).

30 DAYS AFTER SOWING OF FIELD BEAN

60 DAYS AFTER SOWING OF FIELD BEAN

Plate 3: General view of experimental site at different growth stages of Field bean

Table 3.4: Initial physico-chemical properties of the soil

PARAMETERS	VALUES
Sand	62.73
Silt	20.41
Clay	16.86
Textural class	Sandy loam
Bulk density (g/cc^{-1})	1.41
Maximum water holding capacity (%)	34.1
Soil pH	7.2
Electrical conductivity ($dS\ m^{-1}$)	0.22
Organic carbon (%)	0.72
Available Nitrogen ($kg\ ha^{-1}$)	263.54
Available Phosphorus ($kg\ ha^{-1}$)	46.37
Available Potassium ($kg\ ha^{-1}$)	196
Available Sulphur (ppm)	31.98
Exchangeable Calcium (c mol (p+) kg^{-1})	2.56
Exchangeable Magnesium (c mol (p+) kg^{-1})	1.2
DTPA Zn (ppm)	0.43
DTPA Fe (ppm)	18.9
Cu (ppm)	0.21
Mn (ppm)	9.98
B (ppm)	0.45

Table 3.5: Methods employed for analysis of soil samples

Sl. No	Parameter	Method	Reference
Physical analysis			
1.	Texture	International pipette method	Pipper (1966)
2.	MWHC (%)	Keen's cup method	Pipper (1966)
3.	Bluk density (g/cc)	Keen's cup method	Pipper (1966)
Chemical analysis			
4.	pH	Potentiometry	Jackson (1973)
5.	EC (dSm^{-1})	Conductometry	Jackson (1973)
6.	Organic carbon (%)	Wet oxidation	Walkley & Black (1934)
7.	Available Nitrogen (kg ha^{-1})	Kjeldahl digestion & distillation method	Jackson (1973)
8.	Available Phosphorus (kg ha^{-1})	Diacid digestion & vanadomolybdate method	Jackson (1973)
9.	Available Potassium (kg ha^{-1})	Diacid digestion & vanadomolybdate method	Jackson (1973)
10.	Exchangeable Calcium (c mol (p+) kg^{-1})	Complexometric titration method	Jackson (1973)
11.	Exchangeable Magnesium (c mol (p+) kg^{-1})	Complexometric titration method	Jackson (1973)
12.	Available Sulphur (ppm)	0.15% CaCl extraction & Turbidity	Black (1965)
13.	DTPA Fe (ppm)	Atomic Absorption Spectrophotometry	Lindsay and Norwell (1978)
14.	Cu (ppm)		
15.	Mn (ppm)		
16	Zn (ppm)		

3.4 Effect of different levels of paddy straw biochar on growth and yield parameters of Field bean

3.4.1 Plant height

The plant height was measured at 30, 60 days after sowing and at harvest and the mean plant height was worked out and expressed in centimetre (cm).

3.4.2 Number of branches per plant of Field bean

The number of branches per plant was counted at 30, 60 days after sowing and at harvest stages and the average number of branches per plant was documented.

3.4.3 Number of leaves per plant of Field bean

The number of leaves per plant was counted at 30, 60 days after sowing and at harvest stages and the average number of leaves per plant was documented.

3.4.4 Number of pods per plant of Field bean

Number of pods per plant is counted.

3.4.5 Pod weight per plant of Field bean

Pods per plant were weighed and the data was documented.

3.5 Collection of soil samples

3.5.1 Collection of soil samples

Soil samples at a plough layer depth (0-15 cm depth) were obtained from each of the experimental twenty-four treatment pots after the crop's harvest. The samples obtained were dried in shade, rendered with a pestle and motor to ground, passed through 2 mm sieve, and placed in polythene bags.

3.6 Preparation of plant samples

The plant samples obtained from the crop were dried powdered and examined for macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Fe, Zn, Mn and Cu).

3.6.1 Methods employed for plant sample analysis of Paddy straw

3.6.1.1 Nitrogen (%)

0.5 grams of plant samples were digested with conc. sulphuric acid (H_2SO_4) and digestion mixture (K_2SO_4: $CuSO_4.5H_2O$: selenium in the ratio of 100:20:1) until green residue was collected. The digested content was distilled by the Micro Kjeldhal. The ammonia produced was trapped in boric acid (H_3BO_4) and was then measured by titrating against standardized sulphuric acid (Pipper, 1966).

3.6.1.2 Digestion of plant samples for nutrients estimation

One gram of the dried and ground samples was pre-digested with 10 ml HNO_3 (62%) for 24 hours, then digested in a vacuumed chamber at 85ºC on sand bath with the following steps: the pre-digested samples were treated with 10 ml di-acid mixture reagent (HNO_3 + $HClO_4$ at a ratio of 10:4) and held on sand bath until white precipitate was left in the bottom. After filtration, the digested samples were diluted with distilled water and volume formed to a defined concentrations. Using normal techniques this extract was used to estimate P, K, Ca, Mg and micronutrients (Fe, Cu, Mn, and Zn).

3.6.1.3 Phosphorus (%)

The measurement of phosphorus content in plant by vanodo molybdo phosphoric yellow colour method (Pipper, 1966) was rendered using a suitable aliquot of the extracted sample.

3.6.1.4 Potassium (%)

The plant samples were tested for potassium content by feeding the diacid digested samples to the flame photometer (Pipper, 1966) after diluting it to appropriate concentration.

3.6.1.5 Calcium and magnesium (%)

As described by Pipper (1966), the di-acid digested plant samples were tested for Calcium and Magnesium using versenate titration process. 3.6.1.6 Sulphur (%) content of field bean In di-acid digested plant sample, sulphur was measured by using the process called turbidometry. The turbidity intensity produced in the sample was calculated at 420 nm wavelength using a spectrophotometer, as outlined by Pipper (1966).

3.6.1.7 Micronutrients (mg kg^{-1}) content of paddy straw

Micronutrients (Zn, Cu, Mn and Fe) in plants were measured by feeding the digested extract samples after being diluted to an appropriate concentration of the Perkin Elmer atomic absorption spectrophotometer using correct hallow cathode lamps and presented as mg kg^{-1} in plant and seed sample (Jackson 1973).

3.7 Methodology for soil analysis

The soil samples collected initially (Table 3) and after the harvest of field bean were analyzed for physical and chemical characteristics employing standard methods of analysis.

3.7.1 Physical properties

3.7.1.1 Particle size analysis

Particle size distribution in soil samples was determined by international pipette method as described by Pipper (1966) using sodium hydroxide as a dispersing agent. From the dispersed suspension an aliquot of clay + silt and clay were pipetted out from specified depth at their specific time intervals depending on the suspension temperature. The total sand obtained by repeated decantation of silt and clay was passed through 0.05 mm sieve. The fraction that was finer than 0.05 mm was added to silt determined initially by pipetting to have particle size classes as per USDA system.

3.7.2 Chemical properties

3.7.2.1 pH and Electrical conductivity

The soil pH was determined in 1: 2.5 soil: water suspensions using digital pH meter with glass electrode (Jackson, 1973). The electrical conductivity of soil was determined using clear extract of soil: water suspension using conductivity bridge (Jackson, 1973).

3.7.2.2 Organic carbon (%)

The dry soil samples were powdered using pestle and mortar and passed through 0.2 mm sieve. A known weight of finely powdered sample was treated with excess known volume of standard $K_2Cr_2O_7$ and concentrated H_2SO_4. The unused $K_2Cr_2O_7$ was quantified by back titration with standard ferrous ammonium sulphate using ferroin as an indicator (Jackson, 1973).

3.7.2.3 Available nitrogen

Available nitrogen was determined by macro distillation of the sample following alkaline permanganate method as suggested by Subbiah and Asija (1956).

3.7.2.4 Available phosphorus

Available phosphorus was extracted with Bray's No.1 extractant (0.03 N NH_4F + 0.025 N HCl). The phosphorus in the extract was determined by Chlorostannous reduced molybdo-phosphoric blue colour method in HCl acid medium. The intensity of blue colour was read at 660 nm using a spectrophotometer (Bray and Kurtz, 1945).

3.7.2.5 Available potassium

Available potassium was determined flame photometrically after extracting the soil with neutral normal ammonium acetate (Jackson, 1973).

3.7.2.6 Exchangeable calcium and magnesium

Calcium and magnesium in the digested plant materials were determined by Versenate titration method as outlined by Pipper (1966).

3.7.2.7 Available sulphur

Sulphur in the digested plant materials was determined turbidometrically. The intensity of turbidity was measured using spectrophotometer at 420 nm of wavelength as outlined by Pipper (1966).

3.7.2.8 DTPA extractable micronutrients

The method developed by Lindsay and Norwell (1978) using DTPA extractant (Diethylene triamine penta acetic acid) was followed for the estimation of Zn, Cu, Mn and Fe. Ten grams of soil was shaken with 20 ml of DTPA extractant for 2 hours for the extraction of micronutrient cations. Atomic absorption spectrophotometer with appropriate hallow cathode lamp was used for measuring the concentration.

3.7.2.9 Exchangeable aluminium

For the same solution, one drop of 0.1 N HCl was added to bring back to colourless condition. Then NaF was added to the solution which formed a stable Sodium fluroaluminate liberating equivalent quantity of NaOH. Titration was made with 0.1 N HCl which gave an estimate of exchangeable aluminium in the extract.

3.8 Statistical analysis of data

The comparative study of experimentally collected results was carried out by implementing Fisher's system of measurement of variance as described by Gomez and Gomez (1984). The significance level used in the 'F' evaluation was offered at 5 per cent. Critical difference (CD) values are presented at a significance level of 5 per cent in the table, wherever the 'F' measure was found to be relevant at 5 per cent.

IV RESULTS AND DISCUSSION

The research work entitled "**Utilization of products obtained from pyrolysis of paddy straw"** was carried out during 2020-2021. The experiment was carried out in organic farming field, UAS, GKVK, Bangalore – 560065. The results and discussion of the study are presented in this chapter.

4.1 Characterization of biochar

The Paddy straw was procured from Punjab, India and biochar was prepared at a higher temperature (500 °C) in oxygen limited condition / absence of oxygen.

Characterization of biochar was done by various standardized analytical procedures for its proximate and ultimate analysis and other properties such as bulk density, water holding capacity, pH, EC. and biooil was analyzed by GC-MS.

Representative samples were taken from paddy straw biochar. The paddy straw biochar was ground to move through a sieve of 2 mm and tested for various chemical parameters and findings are shown in Table 4.1.

Table 4.1: Pyrolysis details

Parameter	Value
Temperature	500^{o}C
Time	6 hours
Straw filled in the unit	3.4 kg
Biochar	2.29 kg
Bio oil	12 ml
Syngas	101.48 L
Conversion ratio for biochar	67.35 %

The Paddy straw biochar was characterized for various physical (Bulk Density, Maximum Water Holding Capacity) and chemical (pH and Electrical Conductivity) properties, and total concentration of nutrients. The properties of the Paddy straw biochar used in the present study greatly varied. The variation in Paddy straw biochar's physico-chemical properties may be due to influence of the type of feedstock and the temperature of pyrolysis. Gaskin *et al*. (2008) and Singh *et al*. (2010) published similar findings of variation of physico-chemical properties according to type of feedstock and the temperature of pyrolysis.

The paddy straw biochar was found as 13% Ash content, 9.5% moisture content, 71.4% volatile matter and 6.1% fixed carbon. In agreement with Wang *et al*. (2014) and Phuong *et al*. (2015), who reported similar results in proximate analysis.

The pH of paddy straw biochar was found to be 10.29 is organically alkaline with EC value 3.2 dSm^{-1} Kannan *et al*. (2013) reported the pH of the biochar produced from different agricultural feed stock materials ranged from 7.9 to11.8 which are of alkaline range. Bagreev *et al.* (2001) recorded that the biochar of *Prosopis juliflora* had an 8.57 pH and a paddy straw biochar had a higher pH of 9.68. For biochar produced at 200 and 400ºC, Wabel *et al.* (2013) observed EC values of 0.76 and 1.34 dSm^{-1}, respectively which shows increase in pyrolysis temperature increases the EC of biochar.

The lower bulk density of 0.56 g cm^{-3} was recorded in the biochar produced from paddy straw. Similar results of BD of biochar produced from different feedstocks ranged from 0.25 to 0.6 gcm^{-3} were also recorded by Pastor-Villegas *et al*. (2006) and Brewer *et al*. (2014) in a study from natural fire site.

In this study the concentration of total nitrogen, phosphorus and potassium were found to be 0.41, 0.04 and 3.83 per cent, respectively. The biochar contains total calcium, magnesium, sulphur content of 2.39, 0.24, and 0.07 per cent, respectively.

Table 4.2: Characterization of biochar

Sl. No.	PARAMETERS	VALUES
PROXIMATE ANALYSIS		
1	ASH (%)	13
2	FIXED CARBON (%)	6.1
3	MOISTURE CONTENT (%)	9.5
4	VOLATILE MATTER (%)	71.4
ULTIMATE ANALYSIS		
1	CARBON (%)	35.15
2	NITROGEN (%)	0.41
3	PHOSPHORUS (%)	0.04
4	POTASSIUM (%)	3.83
5	OXYGEN (%)	46.21
6	CALCIUM (%)	2.39
7	MAGNESIUM (%)	0.24
8	SULFUR (%)	0.07
9	HYDROGEN (%)	4.16
10	CARBON:NITROGEN (C:N)	85.7
11	O:C	1.31
12	H:C	0.12
13	C:N:P	35.15: 0.41: 0.04
OTHER PROPERTIES		
1.	pH	10.29
2.	EC	3.287 (dSm^{-1})
3.	Bulk density	0.56 ($Mg\ m^{-3}$)
4.	Water holding capacity	64.35%

Table 4.3: Characterization of input materials

Particulars	Gana jeevamrutha	Vermi compost	FYM	Biochar
pH	6.8	7.06	6.6	10.29
Electrical conductivity (dS m^{-1})	7.03	3.26	3.17	3.287
Organic carbon (%)	14.2	13.6	11.8	35.15
Available Nitrogen (%)	3.81	2.63	1.03	0.41
Available Phosphorus (%)	10.7	9.17	6.59	0.04
Available Potassium (%)	3.48	2.95	1.55	3.83
Exchangeable Calcium (ppm)	55	49	38.6	2.39%
Exchangeable Magnesium (ppm)	21.8	14.5	11.6	0.24%
Available Sulphur (ppm)	0.18	0.13	0.11	0.07%

The paddy straw biochar contained higher carbon content exchangeable bases, Mn and Cu. Gaskin *et al. (*2008) and Singh *et al*. (2010) found similar values of different nutrients in biochar similar to those reported in literature. The N content of 0.41 per cent was recorded in the paddy straw biochar, which might be attributed to the heat used during pyrolysis. Similar results were reported by Cheng *et al*. (2006), Novak *et al*. (2009) and Rondon *et al*. (2007).

4.2 To evaluate the performance of paddy Biochar Application on Field Bean.

4.2.1 Quality analysis:

The pH of inputs used for research were neutral pH of 6.8, 7.06 and 6.6 in Ganajeevamrutha, VC and FYM respectively. Ganajeevamrutha contain more soluble salts resulted in higher EC value.

Available nitrogen, phosphorus, potassium are rich in Ganajeevamrutha compared to other sources of input with 3.81, 10.7, 3.48 per cent respectively.

4.2.2 Growth parameters:

4.2.2.1 Plant height

Table 4.4 presents data retrieved for field bean plant height (cm) affected by various levels of biochar at different growth stages. Plant height differed significantly in all growth stages with various treatments. Plant height gradually increased with increasing crop age up to 90 days after sowing.

Significantly higher plant height (15.5 cm) was recorded at 30 days after sowing (DAS) in T_{21} which received 25 tons of Biochar + FYM + VC + Ganajeevamrutha. On par data was found with T_{20} (14.5 cm) , T_{18} (14.5 cm) and T_9 (14.5 cm) which received 20 tons of Biochar + FYM + VC + Ganajeevamrutha, 25 tons of Biochar + VC+ Ganajeevamrutha and 25 tons of Biochar + Ganajeevamrutha respectively. Followed by T_6 (13.5 cm) which received 20 tons of Biochar + Ganajeevamrutha. Lowest height was recorded in T_{22} (7.75 cm) which received 15tons of Biochar alone.

Table 4.4: Effect of biochar on plant height (cm) of field bean at 30 DAS, 60 DAS and at harvest stages.

Treatment details	Plant height (cm)		
	30 DAS	**60 DAS**	**At harvest**
T_1: 15 tons of BC + FYM	8.50	26.00	39.75
T_2: 15 tons of BC + VC	9.75	28.25	40.75
T_3: 15 tons of BC + Ganajeevamrutha	11.50	32.50	47.25
T_4: 20 tons of BC + FYM	9.75	28.00	41.25
T_5: 20 tons of BC + VC	10.50	34.25	46.00
T_6: 20 tons of BC + Ganajeevamrutha	13.50	39.00	54.00
T_7: 25 tons of BC + FYM	10.75	31.00	46.00
T_8: 25 tons of BC + VC	11.50	33.00	57.50
T_9: 25 tons of BC + Ganajeevamrutha	14.50	40.25	61.50
T_{10}: 15 tons of BC + FYM+ VC	9.75	29.50	45.50
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	10.00	33.00	46.75
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	11.00	34.00	48.00
T_{13}: 20 tons of BC + FYM +VC	10.50	31.00	50.00
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	12.00	34.50	57.00
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	12.50	39.00	61.00
T_{16}: 25 tons of BC + FYM + VC	11.75	32.50	47.00
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	12.50	34.50	49.75
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	14.50	39.50	54.50
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	13.00	36.00	53.50
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	14.50	41.50	60.00
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	15.50	45.50	66.00
T_{22}: 15 tons of BC	7.75	26.00	34.00
T_{23}: 20 tons of BC	9.50	29.00	38.50
T_{24}: 25 tons of BC	11.75	32.00	46.50
S. Em ±	0.78	1.02	1.77
C.D@ 5%	2.28	3.00	5.20

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure, DAS-Days after sowing.

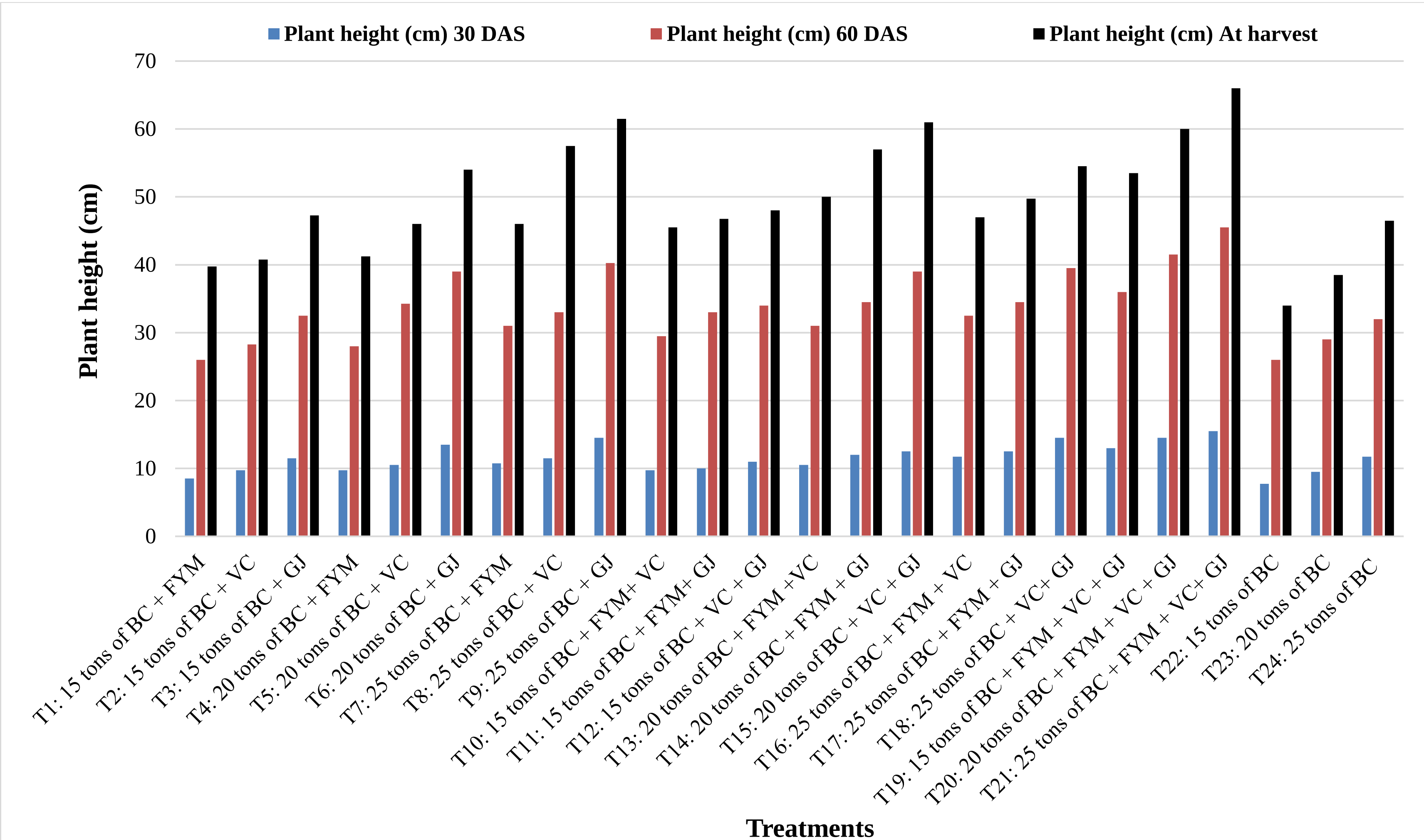


Fig. 4.1: Effect of biochar on plant height (cm) of field bean at 30 DAS, 60 DAS and at harvest stages

Note: BC-Biochar, VC-Vermicompost, FYM- Farm yard manure and GJ-Ganajeevamrutha

The plant height significantly varied with different treatments having different combinations of biochar levels at 60 DAS. Among which T_{21} (45.5 cm) showed higher value which received 25 tons of Biochar + FYM + VC + Ganajeevamrutha, followed by T_{20} (41.5 cm) received 20 tons of Biochar + FYM + VC + Ganajeevamrutha and T_9 (40.25 cm) received 25 tons of Biochar + Ganajeevamrutha. Lowest value was recorded in T_{22} (26 cm) which received 15tons of Biochar alone.

Significantly higher plant height was observed in T_{21} (66 cm) at harvest stage which received 25 tons of Biochar + FYM + VC + Ganajeevamrutha and was on par with T_9 (61.5 cm) which received 25 tons of Biochar + Ganajeevamrutha. The lower value was recorded in T_{22} (34 cm) which received 15tons of Biochar.

4.2.2.2 Number of leaves

Influence of different dosage of biochar on number of leaves of field bean at different stages of plant growth is presented in Table 4.5.

Application of 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}) recorded highest number of leaves (32.5) followed by T_{15} (28) and T_{24} (28) which received 20 tons of BC + VC + Ganajeevamrutha and 25tons of BC respectively followed by T_9 (26.5) with 25 tons of BC + Ganajeevamrutha at 30 DAS. The lower value was recorded in T_{17} (14) which received 25 tons of BC + FYM + Ganajeevamrutha.

At 60 DAS treatment with 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}) recorded significantly higher number of leaves (72) followed by T_{15} (68) and T_{20} (66.5) which received 20 tons of BC + VC + Ganajeevamrutha and 20 tons of BC + FYM + VC + Ganajeevamrutha, respectively. The lower value was recorded in T_{22} (43.5) which received 15tons of Biochar.

During harvest, data on the number of leaves shows a similar pattern to that of 60 days. Maximum number of leaves was noticed in T_{21} (80) with 25 tons of BC + FYM + VC + Ganajeevamrutha.

Table 4.5: Effect of biochar on number of leaves at 30 DAS, 60 DAS and at harvest stages

Treatment details	NUMBER OF LEAVES		
	30 DAS	**60 DAS**	**At harvest**
T_1: 15 tons of BC + FYM	18.50	46.50	51.00
T_2: 15 tons of BC + VC	23.00	54.00	60.00
T_3: 15 tons of BC + Ganajeevamrutha	24.00	55.50	64.50
T_4: 20 tons of BC + FYM	21.50	49.50	55.50
T_5: 20 tons of BC + VC	23.00	55.50	61.50
T_6: 20 tons of BC + Ganajeevamrutha	26.50	58.50	64.50
T_7: 25 tons of BC + FYM	22.00	51.00	55.50
T_8: 25 tons of BC + VC	24.00	54.00	60.00
T_9: 25 tons of BC + Ganajeevamrutha	26.50	63.00	67.50
T_{10}: 15 tons of BC + FYM+ VC	21.50	55.50	63.00
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	23.00	60.00	67.50
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	24.50	61.50	63.00
T_{13}: 20 tons of BC + FYM +VC	18.50	58.50	64.50
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	24.50	61.50	69.00
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	28.00	68.00	70.50
T_{16}: 25 tons of BC + FYM + VC	19.00	63.00	61.50
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	14.00	54.00	64.50
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	21.50	58.50	66.00
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	19.50	64.50	72.00
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	26.00	66.50	74.00
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	32.50	72.50	80.00
T_{22}: 15 tons of BC	21.50	43.50	51.00
T_{23}: 20 tons of BC	22.50	46.50	55.50
T_{24}: 25 tons of BC	28.00	49.50	54.00
S. Em ±	1.68	2.29	2.25
C.D@ 5%	4.92	6.68	6.58

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure, DAS-Days after sowing.

On par with T_{20} (74) which received 20 tons of Biochar + FYM + VC + Ganajeevamrutha followed by T_{19} (72) received 15 tons of BC+FYM+VC+ Ganajeevamrutha. The lower value was recorded in T_{22} (51) which received 15tons of Biochar alone.

4.2.2.3 Number of branches

Application of biochar in combination with other organic manures had significant difference between the treatments. However, application of 20 tons of BC + FYM + VC + Ganajeevamrutha (T_{20}) and 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}) recorded the highest number of branches (6) compared to T_{22} (3) which had 15tons of BC showing lowest number of branches.

Treatment receiving of 20 tons of BC + FYM + VC + Ganajeevamrutha (T_{20}) and 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}) recorded significantly higher numbers of branches per plant (12) followed by T_{17} (11) received 25 tons of BC + FYM + Ganajeevamrutha and the lowest value was recorded in T_4, T_7 and T_{22} (7.5) that received 20 tons of BC + FYM, 25 tons of BC + FYM and 15tons of BC respectively.

At the time of harvest, treatment receiving recommended 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}), the number of branches per plant (14) was significantly higher, followed by T_{20} (13.5) received 20 tons of BC + FYM + VC + Ganajeevamrutha and the lowest value was recorded in T_4 (9) that received 20 tons of BC + FYM.

Due to application of 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}), significant increase in growth parameters such as plant height, number of branches of fieldbean plant was reported. With biochar use in combination with other organic manures, there were several variables relating to the crop growth attributes. Those factors will operate either individually or in combination needs to be addressed. Indeed, a reduction in soluble Al and Fe led to increase in pH, Regulated and gradual nutrient release and because of biochar specific physical-chemical properties with low bulk density. This will improve the porosity and aeration status of the soil, which would

Table 4.6: Effect of biochar on number of branches at 30 DAS, 60 DAS and at harvest stages

Treatment details	No. of branches		
	30 DAS	**60 DAS**	**At harvest**
T_1: 15 tons of BC + FYM	3.50	9.00	10.50
T_2: 15 tons of BC + VC	4.50	8.50	10.00
T_3: 15 tons of BC + Ganajeevamrutha	5.00	10.50	12.50
T_4: 20 tons of BC + FYM	3.50	7.50	9.00
T_5: 20 tons of BC + VC	4.50	8.50	10.00
T_6: 20 tons of BC + Ganajeevamrutha	5.00	8.00	10.50
T_7: 25 tons of BC + FYM	4.50	7.50	12.50
T_8: 25 tons of BC + VC	5.00	9.50	11.50
T_9: 25 tons of BC + Ganajeevamrutha	4.50	8.50	9.50
T_{10}: 15 tons of BC + FYM+ VC	3.50	9.50	10.50
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	5.50	10.50	12.00
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	4.50	10.00	12.00
T_{13}: 20 tons of BC + FYM +VC	3.50	10.00	11.00
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	4.50	10.00	12.00
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	4.50	9.50	10.50
T_{16}: 25 tons of BC + FYM + VC	5.50	8.50	12.00
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	5.50	11.00	11.50
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	4.50	9.50	11.50
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	5.50	10.00	11.50
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	6.00	12.00	13.50
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	6.00	12.00	14.00
T_{22}: 15 tons of BC	3.50	7.50	10.50
T_{23}: 20 tons of BC	4.00	8.50	10.00
T_{24}: 25 tons of BC	4.50	9.50	12.00
S. Em ±	0.47	0.83	0.86
C.D@ 5%	1.39	2.43	2.52

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure, DAS-Days after sowing.

indirectly increase the available plant water and boost microbial function, should have led to the improvement of growth parameters. Most of these changes in soil's physical and chemical properties in biochar transformed soils similar research findings were also found (Warnock *et al*.2007, Amonette and Joseph 2009).

4.2.3 Yield parameters

The data pertaining to yield and yield parameters as influenced by the levels of paddy straw biochar on soil are presented in Table 4.7 and Fig 4.2.

4.2.3.1 Number of pods

The highest number of pods per plant was observed in T_{20} (16) which received 20 tons of BC + FYM + VC + Ganajeevamrutha similar result was found in T_{21} received 25 tons of BC + FYM + VC + Ganajeevamrutha which was on par with T_{18} (15) which received 25 tons of BC + VC+ Ganajeevamrutha which is on par with T_{17} (14) receiving 25 tons of BC + FYM + Ganajeevamrutha and the lowest number of pods per plant was recorded in T_{22} (6), which did not receive an external source of nutrients but 15 tons of biochar only.

The highest amount of pod weight was observed in T_{20} (24) which received 20 tons of BC + FYM + VC + Ganajeevamrutha followed by T_{18} (22.5) which received tons of 25 BC + VC+ Ganajeevamrutha and the lowest pods yield was recorded in T_1 (9.6), which received 15 tons of BC + FYM only.

Significant increase in yield parameters such as number of pods and pod weight was reported highest using 20 tons of BC + FYM + VC + Ganajeevamrutha (T_{20}). It could be attributed to improved nutrient demand and supply through the introduction of elevated biochar levels. Biochar has been found to improve the productivity and fertilizer usage as stated by Dong *et al*. (2015) and Taghizadeh- Toosi *et al*. (2012). Paddy straw biochar contains a large amount of total carbon, potassium, phosphorus, calcium and magnesium, which improves the physical, chemical and biological properties of the soil, increasing the performance of yield parameters significantly. Chan *et al*. (2007) took into account identical results.

Table 4.7: Effect of biochar on number pods and pod weight.

Treatment details	No. of pods	Pod weight (g/plant)	Yield (q/ha)
T_1: 15 tons of BC + FYM	7.00	9.60	22.53
T_2: 15 tons of BC + VC	7.50	12.00	28.16
T_3: 15 tons of BC + Ganajeevamrutha	12.00	19.25	45.17
T_4: 20 tons of BC + FYM	11.00	17.50	41.06
T_5: 20 tons of BC + VC	13.00	21.25	49.86
T_6: 20 tons of BC + Ganajeevamrutha	10.00	14.00	32.85
T_7: 25 tons of BC + FYM	9.00	12.60	29.57
T_8: 25 tons of BC + VC	9.50	13.00	30.50
T_9: 25 tons of BC + Ganajeevamrutha	13.50	18.80	44.11
T_{10}: 15 tons of BC + FYM+ VC	10.00	14.00	32.85
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	11.00	15.40	36.14
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	11.50	15.90	37.31
T_{13}: 20 tons of BC + FYM +VC	12.00	17.00	39.89
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	10.00	14.00	32.85
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	11.50	16.75	39.30
T_{16}: 25 tons of BC + FYM + VC	12.00	19.00	44.58
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	14.00	21.00	49.28
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	15.00	22.50	52.80
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	13.50	20.25	47.52
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	16.00	24.00	56.32
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	15.00	21.00	49.28
T_{22}: 15 tons of BC	6.00	10.50	24.64
T_{23}: 20 tons of BC	10.00	14.75	34.61
T_{24}: 25 tons of BC	9.50	14.25	33.44
S. Em ±	1.25	1.82	4.28
C.D@ 5%	3.66	5.32	12.50

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure.

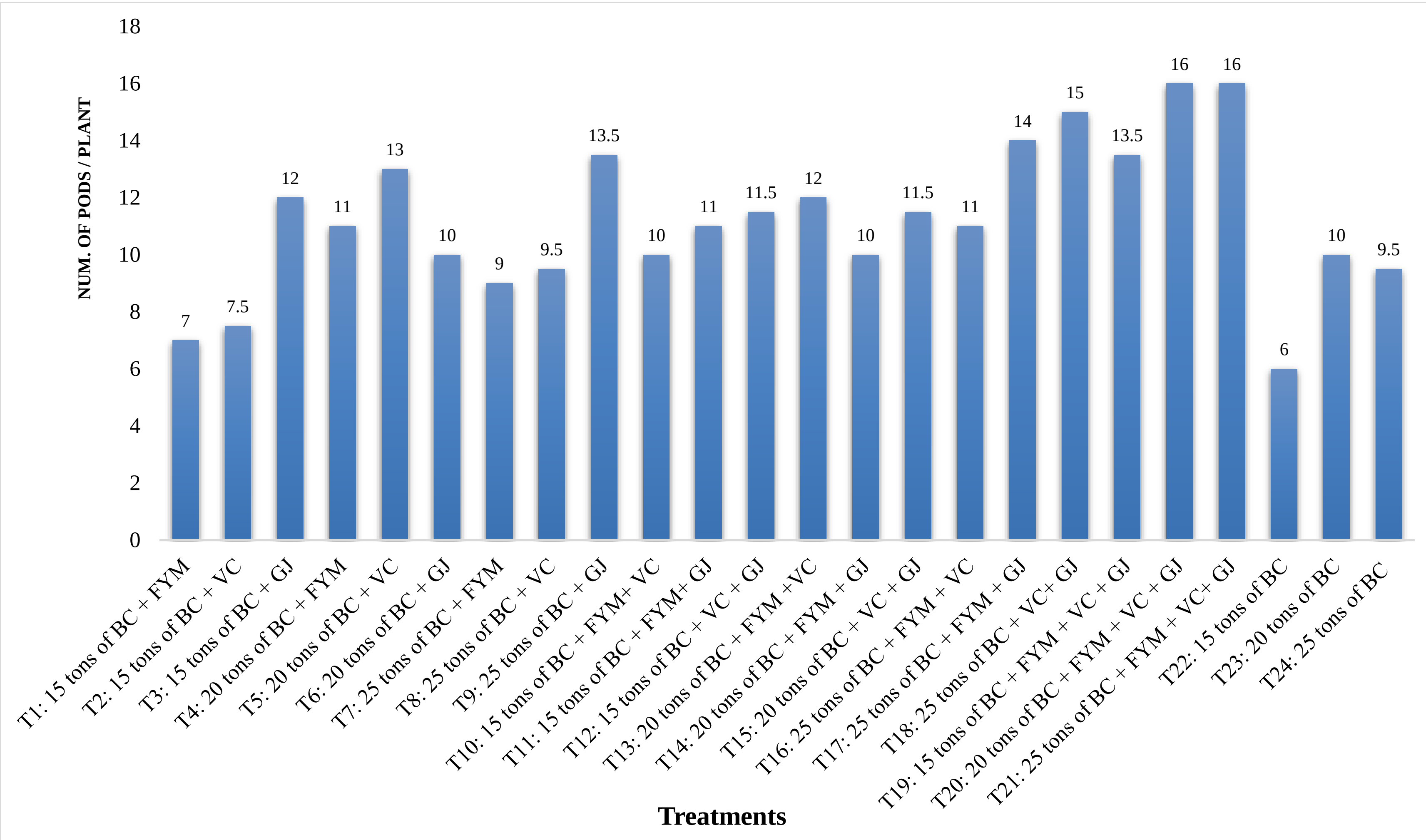


Fig. 4.2: Effect of biochar on number of pods / plant

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure., GJ-Ganajeevamrutha

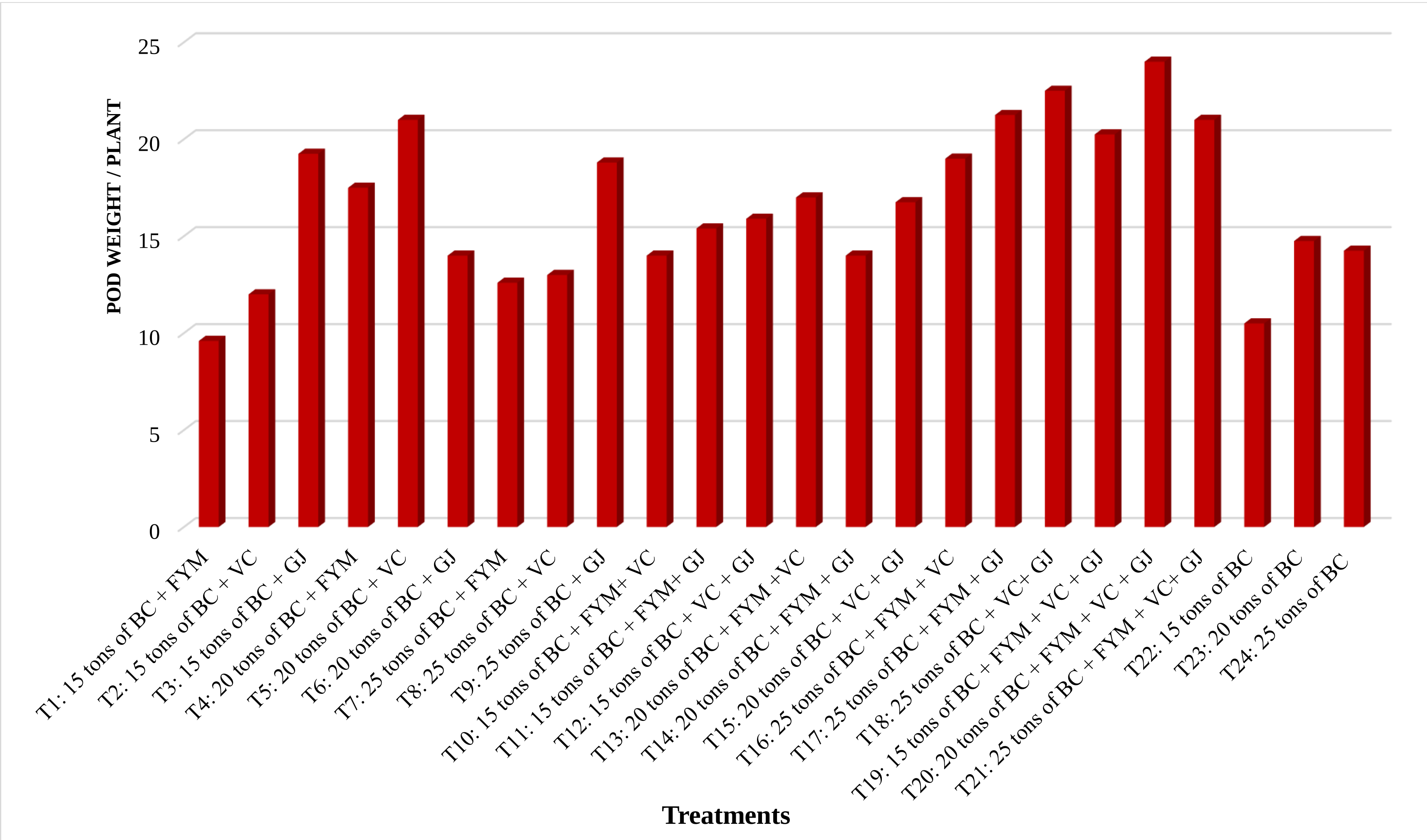


Fig. 4.3: Effect of biochar on pod weight / plant

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure., GJ-Ganajeevamrutha

4.2.4 Physical parameters of soil

Table 4.8 represents the effect of different dosage of biochar on bulk density and maximum water holding capacity of soil. Significantly higher soil bulk density (1.4 Mg m^{-3}) was recorded in T_{22}, which received 15tons of BC alone. Significantly lower BD (1.29 Mg m^{-3}) was observed inT_7 (25 tons of BC + FYM), T_9 (25 tons of BC + Ganajeevamrutha), T_{18} (25 tons of BC + VC+ Ganajeevamrutha), followed by T_{17} showing 1.30 Mg m^{-3} (25 tons of BC + FYM + Ganajeevamrutha).

Significantly higher maximum water holding capacity was recorded in T_{18} (42.03%) 25 tons of BC + VC+ Ganajeevamrutha, followed by T_{22} (42.00%) which received 25 tons of BC + FYM + VC + Ganajeevamrutha, and lower soil water holding capacity was observed in T_{22} (34.5%) which received 15tons of BC alone.

Biochar application (Table 4.8) has had a significant influence on the physical properties of soil like bulk density and maximum water holding capacity. Among the various treatments, the treatment which received 25 tons of BC + VC+ Ganajeevamrutha recorded lower bulk density and higher maximum water holding capacity values over the rest of treatments This may be due to the high carbon content in biochar, which acts as a cementitious material when stable soil aggregates are formed. The porous structure of biochar has shown to impact soil, with reference to water retention capacity and adsorption efficiency (Yu *et al*. 2006, Gundale and Deluca 2006.) biochar has a large density that is much lower than that of mineral soils and therefore biochar application can reduce the overall density of the soil. The biochar application reduced the bulk density by 12 to 25 per cent and the water holding capacity was increased compared to at all biochar application rates (Emmanuel *et al*., 2010).

4.2.5 Chemical parameters of soil

The data in Table 4.9 revealed that after harvest of the Field bean, there was a substantial difference in soil pH condition. pH of the soil increased with increasing rate of biochar and combination with lime has slight increase than biochar alone.

Table 4.8: Effect of biochar on soil physical properties.

Treatment details	BD (Mg m^{-3})	MWHC (%)
T_1: 15 tons of BC + FYM	1.40	35.65
T_2: 15 tons of BC + VC	1.39	36.36
T_3: 15 tons of BC + Ganajeevamrutha	1.39	35.60
T_4: 20 tons of BC + FYM	1.37	35.13
T_5: 20 tons of BC + VC	1.38	35.05
T_6: 20 tons of BC + Ganajeevamrutha	1.38	35.31
T_7: 25 tons of BC + FYM	1.29	41.77
T_8: 25 tons of BC + VC	1.32	41.07
T_9: 25 tons of BC + Ganajeevamrutha	1.30	42.03
T_{10}: 15 tons of BC + FYM+ VC	1.36	36.25
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	1.36	36.82
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	1.39	35.77
T_{13}: 20 tons of BC + FYM +VC	1.36	36.34
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	1.37	36.60
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	1.38	36.46
T_{16}: 25 tons of BC + FYM + VC	1.30	41.31
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	1.30	40.50
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	1.30	42.00
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	1.39	35.80
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	1.36	36.70
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	1.34	39.64
T_{22}: 15 tons of BC	1.40	34.50
T_{23}: 20 tons of BC	1.38	35.03
T_{24}: 25 tons of BC	1.37	36.50
S. Em ±	0.0075	0.207
C.D@ 5%	0.0218	0.605

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure.

Table 4.9: Effect of biochar application on soil pH, EC and Organic carbon content of post-harvest soil of field bean crop.

Treatment details	pH	EC (dSm^{-1})	OC ($g\ kg^{-1}$)
T_1: 15 tons of BC + FYM	7.20	0.10	5.48
T_2: 15 tons of BC + VC	7.97	0.12	5.46
T_3: 15 tons of BC + Ganajeevamrutha	8.02	0.11	5.40
T_4: 20 tons of BC + FYM	7.52	0.12	5.60
T_5: 20 tons of BC + VC	7.33	0.12	5.66
T_6: 20 tons of BC + Ganajeevamrutha	7.85	0.13	5.72
T_7: 25 tons of BC + FYM	7.24	0.15	5.86
T_8: 25 tons of BC + VC	7.44	0.16	5.98
T_9: 25 tons of BC + Ganajeevamrutha	8.20	0.18	6.11
T_{10}: 15 tons of BC + FYM+ VC	7.47	0.12	5.63
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	7.77	0.12	5.46
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	7.92	0.12	5.45
T_{13}: 20 tons of BC + FYM +VC	7.53	0.14	5.87
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	7.30	0.14	5.83
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	7.26	0.16	6.15
T_{16}: 25 tons of BC + FYM + VC	7.52	0.16	6.12
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	7.41	0.15	5.88
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	7.36	0.17	6.18
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	7.60	0.16	6.13
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	8.98	0.18	6.20
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	9.50	0.19	6.42
T_{22}: 15 tons of BC	6.76	0.10	5.47
T_{23}: 20 tons of BC	7.65	0.12	5.72
T_{24}: 25 tons of BC	8.03	0.16	6.11
S. Em ±	0.01	0.0066	0.03
C.D@ 5%	0.02	0.0193	0.09

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure.

Significantly higher pH (9.5) was reported in treatment receiving 25 tons of BC + FYM + VC + Ganajeevamrutha and was on par with T_{20} (8.98) receiving 20 tons of BC + FYM + VC + Ganajeevamrutha. In addition, the lower pH value in soil was reported in T_{22} (6.76) followed by T_1 (7.20) which was 15 tons of BC + FYM.

The increase in pH of the soil that is very much in excess is due to the application of the biochar, the high surface area and the porous nature of the biochar can increase the cation exchange capacity (CEC) of the soil. It is also due to the presence of the interchangeable alkaline and high bases of the biochar. It is known that bio-accumulation increases the pH of acidic and efficient acidic soil improvement. The basic cations in biochar are interchangeable with the interchangeable to Al^{3+} and H^+ in soil exchange complexes, thus reducing replaceable acidity in acid and neutral soils. Such an observation that matches Chintala *et al*. (2014), Anteneh *et al*. (2014) and Hass *et al.* (2012) revealed the alkalinity of Biochar is an important factor that affects its capacity for limitation, and the largest alkalinity of the biochar led to a greater decrease in acidity. The incorporation of biochar reduces the Replaceable soil acidity, increasing the base of replaceable and improves base saturation, thus improving soil fertility.

The data on electrical conductivity (EC) in Table 4.9 showed that there was significant difference among the different treatments with respect to electrical conductivity of soil after harvest. The EC (0.19 dSm^{-1}) was significantly higher in treatment imposed with 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}). Further there was a gradual increase in EC with respect to increasing levels of biochar.

Numerically higher value of EC was recorded in T_{21} received 25 tons of BC + FYM + VC + Ganajeevamrutha and lowest EC was recorded in 15 tons of BC(T_{22}) and 15 tons of BC + FYM (T_1). This may be due to the increase in salt concentration and exchangeable cations in paddy straw biochar which can increase the EC in treated plot compared to untreated plot. Significant increase in EC with varied levels of biochar application was often reported by Chintala *et al*. (2014), Gundale and De luca (2006) and Chan *et al*. (2008).

The organic carbon data in Table 4.9 indicated that there was a significant difference in soil organic carbon content among the various treatments after field bean harvest. Soil organic carbon content after field bean harvest varied from 5.47 (g kg^{-1}) to 6.42 (g kg^{-1}). Numerically higher organic carbon value (6.42 g kg^{-1}) was recorded in T_{21} with 25 tons of BC + FYM + VC + Ganajeevamrutha followed by T_{20} (6.2 g kg^{-1}) receiving 20 tons of BC + FYM + VC + Ganajeevamrutha. The lowest soil organic carbon value (5.4 g kg^{-1}) was reported in T_3 which received 15 tons of BC + Ganajeevamrutha.

Increasing the amount of biochar applied increased the organic carbon content in the soil. Higher levels of organic carbon in biochar-treated soils indicate that recalcitrant organic carbon in biochar is not affected by mineralization and is further lost. Soil organic carbon storage called carbon sequestration will be improved. Lehmann and Randon (2005) and Solomon *et al*. (2009) also reported high organic carbon content in soils using biochar. The special properties of stable carbon in biochar and the high surface area, the high charge per unit area, the appearance of specific functional surface groups and the ash content have beneficial effects on the chemical properties of the soil. The application of biochar increased the SOC, pH, EC, CEC and interchangeable alkalis in the soil to which the biochar was applied. (Hass *et al*., 2012 and Anteneh *et al*., 2014).

4.2.6 Nutrient status of the soil after the harvest of field bean.

4.2.6.1 Available nitrogen

The nutrient status of available N, P_2O_5, K_2O, exchangeable Ca and Mg, available S and DTPA extractable micronutrients Zn, Cu, Mn and Fe of the soil after harvest of field bean was analyzed and the results are presented in Table 4.10, 4.11, 4.12.

After the harvest of field bean, the available nitrogen content in soil differed significantly due to different rates of biochar application (Table 4.10). Significantly higher available nitrogen (297 kg ha^{-1}) was recorded in T_{21} where 25 tons of BC + FYM + VC + Ganajeevamrutha was added. The lowest available nitrogen content was reported T_{22} (255.5 kg ha^{-1}) where 15tons of BC. This might be due to incorporation of biochar in combination with organic manures has made nitrogen available to the soil. Lehmann and Randon (2005) reported that biochar changes soil dynamics of N. The abundance and intensity of organic nitrogen mineralization contained in biochar added to the soil provides an indicator of biochar's potential as a slow-release nitrogen fertilizer stated by Chan and Xu (2013) and Steiner *et al*. (2007).

4.2.6.2 Available phosphorus

The phosphorus content available in soil after field bean harvest varied significantly among the treatments imposed (Table 4.10). Significantly higher available soil phosphorus content was observed in T_{21} (63.25 kg ha^{-1}) which received 25 tons of BC + FYM + VC + Ganajeevamrutha compared to T_{20} (63.1 kg ha^{-1}) which received 20 tons of BC + FYM + VC + Ganajeevamrutha. That may be due to the high levels of available P found in the biochar. Van Zwieten *et al*. (2010) also showed an increase in available P to the soil after biochar application. The reason that the abundance of P_2O_5 is improved by the application of the soil biochar may be due to the presence of soluble exchangeable phosphates in the soil. Parvage *et al*. (2013) and Hass *et al*. (2012) also reported that the addition of biochar increased the available amount of P_2O_5.

4.2.6.3 Available potassium

Due to biochar application the available potassium content in soil increased significantly (Table 4.10). Application of 25 tons of BC + FYM + VC + Ganajeevamrutha (T_{21}) substantially reported significantly higher available potassium (173.95 kg ha^{-1}) that was on par with treatment T_{20} which received 20 tons of BC + FYM + VC + Ganajeevamrutha (172.95 kg ha^{-1}) compared to T_{15} (170.5 kg ha^{-1}) that 20 tons of BC + VC + Ganajeevamrutha. The lowest value was recorded in absolute control T_{22} (158 kg ha^{-1}) where it received 15tons of BC.

The increased proportion of biochar combined with other organic manures increased the potassium content of in the soil, which can be attributed to the high K concentration present in the biochar (Chan *et al*. 2007).

Table 4.10: Effect of biochar application on available major nutrient status of soil after the harvest of field bean

Treatment details	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
T_1: 15 tons of BC + FYM	265.50	53.00	159.05
T_2: 15 tons of BC + VC	269.00	55.50	159.00
T_3: 15 tons of BC + Ganajeevamrutha	270.50	56.75	160.75
T_4: 20 tons of BC + FYM	271.00	56.12	159.00
T_5: 20 tons of BC + VC	273.00	58.60	163.50
T_6: 20 tons of BC + Ganajeevamrutha	273.00	60.14	166.00
T_7: 25 tons of BC + FYM	274.00	59.12	165.85
T_8: 25 tons of BC + VC	277.50	60.92	167.95
T_9: 25 tons of BC + Ganajeevamrutha	278.50	61.60	167.75
T_{10}: 15 tons of BC + FYM+ VC	266.00	55.00	169.10
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	265.00	56.25	167.50
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	268.50	54.25	169.00
T_{13}: 20 tons of BC + FYM +VC	272.00	58.50	168.10
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	272.50	59.35	169.50
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	271.50	59.95	170.50
T_{16}: 25 tons of BC + FYM + VC	274.50	59.00	168.35
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	277.00	60.25	170.10
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	279.50	61.60	169.50
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	286.00	60.10	169.80
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	291.50	63.10	172.95
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	297.00	63.25	173.95
T_{22}: 15 tons of BC	255.50	48.85	158.55
T_{23}: 20 tons of BC	258.00	52.45	159.20
T_{24}: 25 tons of BC	261.50	53.15	158.00
S. Em ±	2.36	0.94	1.24
C.D@ 5%	6.89	2.75	3.64

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure.

Increased potassium is primarily responsible for the immediate beneficial effects of nutrient-rich biochar input (Lehmann *et al*. 2003). Since biochar produces high ash, it has higher potassium content than other major nutrients, so adding ash-rich biochar to the soil significantly improved potassium levels.

4.2.6.4 Exchangeable calcium

The exchangeable calcium significantly increased from 2.56 (c mol (p+) kg^{-1}) due to the application of paddy straw biochar. Significantly higher exchangeable calcium content was recorded in T_{21} (4.22 c mol (p+) kg^{-1}) 25 tons of BC + FYM + VC + Ganajeevamrutha. However, it was found on par with T_{20} (4.07 c mol (p+) kg^{-1}) which received 20 tons of BC + FYM + VC + Ganajeevamrutha and followed by T_{18} (3.85 c mol (p+) kg^{-1}) received 25 tons of BC + VC+ Ganajeevamrutha. The lower value was recorded in T_{22} (3.07 c mol (p+) kg^{-1}) received 15 tons of BC alone.

The exchangeable bases such as soil Ca content differed significantly due to the high cation exchange capacity in the application of various levels of biochar. Elevated biochar levels increased the calcium content of the soil post-harvest. This is likely due to the elevated Ca concentration and the exchangeable biochar base. It is likely due to the high porosity and surface/volume, and likely to increase the supply of Ca (Chan *et al*. 2007 and Yamato *et al*. 2006).

4.2.6.5 Exchangeable magnesium

Data on exchangeable soil magnesium content showed substantial difference between treatments due to the application of different soil biochar levels (Table 4.11). However, a numerically higher value of exchangeable magnesium in soil (2.98 c mol (p+) kg^{-1}) was found in T_{21}, which received 25 tons of BC + FYM + VC + Ganajeevamrutha, comparable to T_{20} (2.96 c mol (p+) kg^{-1}), which received 20 tons of BC + FYM + VC + Ganajeevamrutha. The numerically lower amount of exchangeable magnesium (1.91 c mol (p+) kg^{-1}) was found in application of 15tons of BC alone.

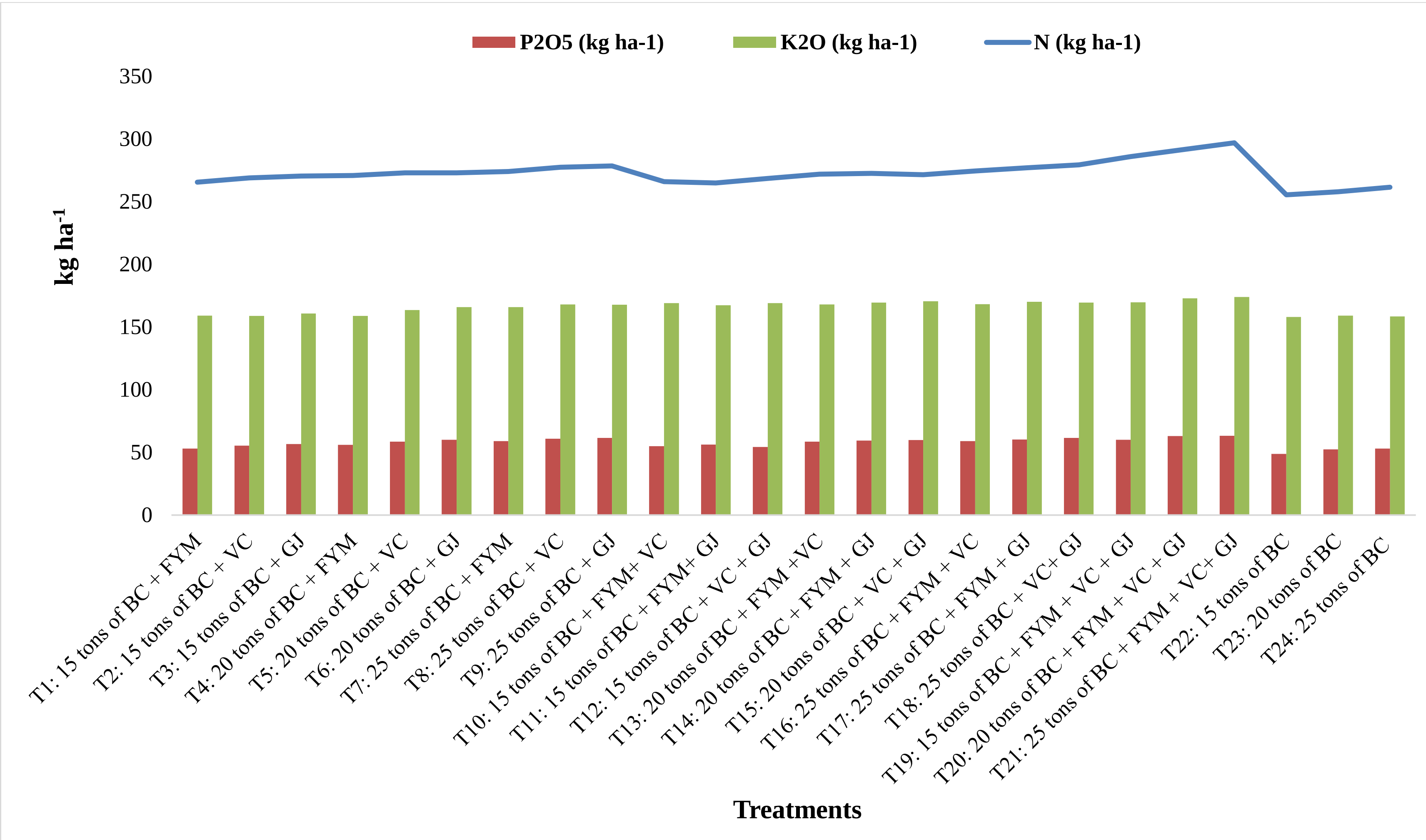


Fig. 4.4: Effect of biochar application on available major nutrient status of soil after the harvest of field bean

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure., GJ-Ganajeevamrutha

Table 4.11: Effect of biochar application on secondary nutrient status of soil after the harvest of field bean.

Treatment details	Ca (c mol (p+) kg^{-1})	Mg (c mol (p+) kg^{-1})	S (mg kg^{-1})
T_1: 15 tons of BC + FYM	3.23	2.03	32.80
T_2: 15 tons of BC + VC	3.28	2.16	33.00
T_3: 15 tons of BC + Ganajeevamrutha	3.43	2.17	33.12
T_4: 20 tons of BC + FYM	3.57	2.20	33.15
T_5: 20 tons of BC + VC	3.56	2.19	33.65
T_6: 20 tons of BC + Ganajeevamrutha	3.60	2.35	34.15
T_7: 25 tons of BC + FYM	3.85	2.39	33.76
T_8: 25 tons of BC + VC	3.73	2.45	34.41
T_9: 25 tons of BC + Ganajeevamrutha	3.81	2.40	34.49
T_{10}: 15 tons of BC + FYM+ VC	3.49	2.10	34.55
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	3.51	2.13	34.54
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	3.53	2.16	34.73
T_{13}: 20 tons of BC + FYM +VC	3.64	2.43	34.73
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	3.62	2.51	35.10
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	3.70	2.74	35.55
T_{16}: 25 tons of BC + FYM + VC	3.78	2.85	36.30
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	3.80	2.87	36.78
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	3.85	2.85	36.90
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	3.82	2.95	37.75
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	4.07	2.96	37.76
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	4.22	2.98	37.82
T_{22}: 15 tons of BC	3.07	1.91	32.55
T_{23}: 20 tons of BC	3.16	1.93	32.60
T_{24}: 25 tons of BC	3.20	1.94	32.75
S. Em ±	0.043	0.07	0.11
C.D@ 5%	0.12	0.21	0.34

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure.

Exchangeable bases such as the Mg content of the soil varied considerably with the application of different levels of biochar. The increase in exchangeable bases (Mg) in soil could be due to the release of essential cations from biochar at different time intervals. The ash from biochar easily releases free bases such as Ca, Mg and K into the soil solution, thus increasing not only the pH of soil, but also the exchangeable bases. Lehmann *et al*. (2003) and Chan *et al*. (2008) also documented such observations.

4.2.6.6 Exchangeable sulphur

As per the application of various amounts of biochar, the available soil sulphur content was found to vary substantially between the treatments (Table 4.11). Significantly higher value of available sulphur was reported in T_{21} (37.82 mg kg^{-1}) which received 25 tons of BC + FYM + VC + Ganajeevamrutha compared to T_{20} (37.76 mg kg^{-1}) which received 20 tons of BC + FYM + VC + Ganajeevamrutha. In the treatment 15tons of BC(T_{22}) the lowest value was recorded (32.55 mg kg^{-1}).

Soil sulphur concentration varies considerably with the application of various biochar amounts. This may be due to the contribution of the available sulphur to soil after mineralization of organic sulphur in biochar. The findings indicate that biochar also increases Sulphur bioavailability, which is primarily based on mineralizing organic sources of sulphur in soils. (Deluca *et al*. 2009).

4.2.6.7 DTPA extractable iron

The iron content of post-harvest soil showed significant difference due to different levels of biochar application represented in Table 4.12. The numerically lower value of Fe (18.34 mg kg^{-1}) was observed in T_{21} which received 25 tons of BC + FYM + VC + Ganajeevamrutha, followed by T_{18} (18.35 mg kg^{-1}) received 25 tons of BC + VC+ Ganajeevamrutha. The highest value of Fe (19.60 mg kg^{-1}) was found in found 15tons of BC alone (T_{22}).

Table 4.12: Effect of biochar application DTPA micronutrient status of soil after the harvest

Treatment details	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
T_1: 15 tons of BC + FYM	19.35	9.87	0.38	0.19
T_2: 15 tons of BC + VC	19.35	9.83	0.42	0.26
T_3: 15 tons of BC + Ganajeevamrutha	19.00	9.85	0.43	0.22
T_4: 20 tons of BC + FYM	18.83	9.77	0.42	0.22
T_5: 20 tons of BC + VC	18.82	9.77	0.42	0.26
T_6: 20 tons of BC + Ganajeevamrutha	18.65	9.55	0.40	0.20
T_7: 25 tons of BC + FYM	18.45	9.35	0.39	0.21
T_8: 25 tons of BC + VC	18.27	9.43	0.39	0.20
T_9: 25 tons of BC + Ganajeevamrutha	18.50	9.40	0.39	0.21
T_{10}: 15 tons of BC + FYM+ VC	18.65	8.85	0.42	0.26
T_{11}: 15 tons of BC + FYM+ Ganajeevamrutha	18.55	8.47	0.41	0.22
T_{12}: 15 tons of BC + VC + Ganajeevamrutha	18.60	8.50	0.43	0.22
T_{13}: 20 tons of BC + FYM +VC	18.35	9.30	0.44	0.27
T_{14}: 20 tons of BC + FYM + Ganajeevamrutha	18.50	8.80	0.37	0.22
T_{15}: 20 tons of BC + VC + Ganajeevamrutha	18.45	8.60	0.36	0.19
T_{16}: 25 tons of BC + FYM + VC	18.60	8.55	0.43	0.25
T_{17}: 25 tons of BC + FYM + Ganajeevamrutha	18.45	9.84	0.34	0.17
T_{18}: 25 tons of BC + VC+ Ganajeevamrutha	18.35	9.25	0.35	0.18
T_{19}: 15 tons of BC + FYM + VC + Ganajeevamrutha	18.55	8.95	0.36	0.19
T_{20}: 20 tons of BC + FYM + VC + Ganajeevamrutha	18.50	8.89	0.39	0.20
T_{21}: 25 tons of BC + FYM + VC+ Ganajeevamrutha	18.34	8.45	0.39	0.22
T_{22}: 15 tons of BC	19.60	9.95	0.41	0.26
T_{23}: 20 tons of BC	19.40	9.88	0.42	0.26
T_{24}: 25 tons of BC	19.25	9.77	0.40	0.25
S. Em ±	0.079	0.11	0.02	0.012
C.D@ 5%	0.23	0.33	NS	0.036

Note: BC-Biochar, VC-Vermicompost and FYM- Farm yard manure.

4.2.6.7 DTPA extractable manganese

After the harvest of field bean, soil manganese content revealed the significant gap between the treatments at various biochar levels. Manganese's numerically higher significance (9.95 mg kg^{-1}) was observed in T_{22} treatment where 15tons of BC was added. The lower manganese content (8.45 mg kg^{-1}) was found in treatment (T_{21}), which received 25 tons of BC + FYM + VC + Ganajeevamrutha followed by T_{11} (8.47 mg kg^{-1}), which received 15 tons of BC + FYM+ Ganajeevamrutha.

4.2.6.8 DTPA extractable zinc

The zinc content of post-harvest soil did not differ significantly due to application of varied levels of biochar (Table 4.12). The higher value of Zn (0.44 mg kg^{-1}) was found in treatment T_{13}, where 20 tons of BC + FYM +VC was applied followed by T_{16} (0.43 mg kg^{-1}) where 25 tons of BC + FYM + VC was applied. The lower zinc content (0.34 mg kg^{-1}) was noticed in treatment (T_{17}) which received 25 tons of BC + FYM + Ganajeevamrutha followed by T_{18} (0.35 mg kg^{-1}) received 25 tons of BC + VC+ Ganajeevamrutha.

4.2.6.9 DTPA extractable copper

The DTPA extractable copper content was found to be significantly varying between the treatments in soil due to the application of varied levels of biochar (Table 4.12). Significantly higher value of available copper was recorded in T_{13} (0.27 mg kg^{-1}) received 20 tons of BC + FYM +VC and was on par with T_{22} (0.26 mg kg^{-1}) received 15tons of BC. The lower value of copper was recorded in T_{17} (0.17 mg kg^{-1}) which received 25 tons of BC + FYM + Ganajeevamrutha alone.

The significant increase in copper content of soil by application of biochar could increase the soluble organic carbon; thereby resulting in the mobilization of Cu. Copper is strongly chelated by organic carbon and is less subjected to adsorption process. Beesley and Marmiroli (2011) also reported dependence of Cu content on soluble C and pH.

There was no clear trend in micronutrient content associated with the application of various types and levels of biochar modified in neutral pH soils. Changes in micronutrient content in soils to which various biochars have been applied can be attributed to physical and chemical properties. Biochars have high surface area, high metal affinity, high nutrient retention capacity, presence of acidic and basic functional groups, which can immobilize micronutrients in soil due to their ability to alkalinize soil. The mechanism of metal immobilization by applying these biochars were also reported by Park *et al*. (2011), Vithanage *et al*. (2014), Cao *et al*. (2009), Novak *et al*. (2009) and PazFerreiro *et al*. (2014).

4.3 To study the characterization of Paddy Bio oil.

Bio oil was separated from the liquid mixture using 4 ml toluene and the bio oil was analyzed using GCMS and the result is represented in the Table 4.13.

Wang *et al*. (2004) analyzed the composition of bio-oils from the pyrolysis of *Fraxinus mandshurica* by gas chromatography-mass spectrometry (GC-MS) and illustrated the similarities of the main contents, which are flakes, such as furfural, dimethyl phenol, 2 methoxy 4 methyl phenol, eugenol, cedrol, furanone, etc. constitute a large proportion of each bio-oil. Most of the components identified were phenol with the ketone and aldehyde groups attached, and almost all of the functional groups showed the widespread presence of oxygen. On the other hand, the analysis showed that the abundant aldehydes and ketones make the substance particularly hydrophilic and highly hydrated, which makes it difficult to remove water. Luo *et al*. (2004) showed that the relevant information on rice straw bio oil was not available, the bio-oil from *Prunus indicus* comprised of laevoglucose, furfural, phenols (with methyl, methoxy and/or propenyl groups), aldehydes (including benzaldehyde with methyl and/or hydroxyl) and vanillin according to the GC–MS analysis.

Table 4.13: Relative content of main compounds in organic composition of bio-oil produced from Paddy straw by GC-MS.

Peak No.	Wt %	Name
1	2.24	2-Cyclopenten-1-one, 2-methyl-
2	2.85	Butanoic acid, 4-hydroxy-
3	4.50	2-Cyclopenten-1-one, 3-methyl-
4	27.23	Phenol
5	1.77	2-Furanone, 2,5-dihydro-3,5-dimethyl-
6	4.76	2-Cyclopenten-1-one, 2,3-dimethyl-
7	6.50	2-methyl- Phenol
8	16.95	p-Cresol
9	8.41	Phenol, 2-methoxy-
10	1.93	4-Hexen-3-one, 4,5-dimethyl-
11	1.64	2,3-dimethyl- Phenol
12	8.99	4-ethyl- Phenol
13	2.12	Phenol,3,5-dimethyl-
14	1.79	2-Methoxy-5-methylphenol
15	1.52	L-.alpha.-Terpineol
16	1.97	4-ethyl-2-methoxy- Phenol
17	3.25	2,6-dimethoxy- Phenol
18	1.59	Apiol

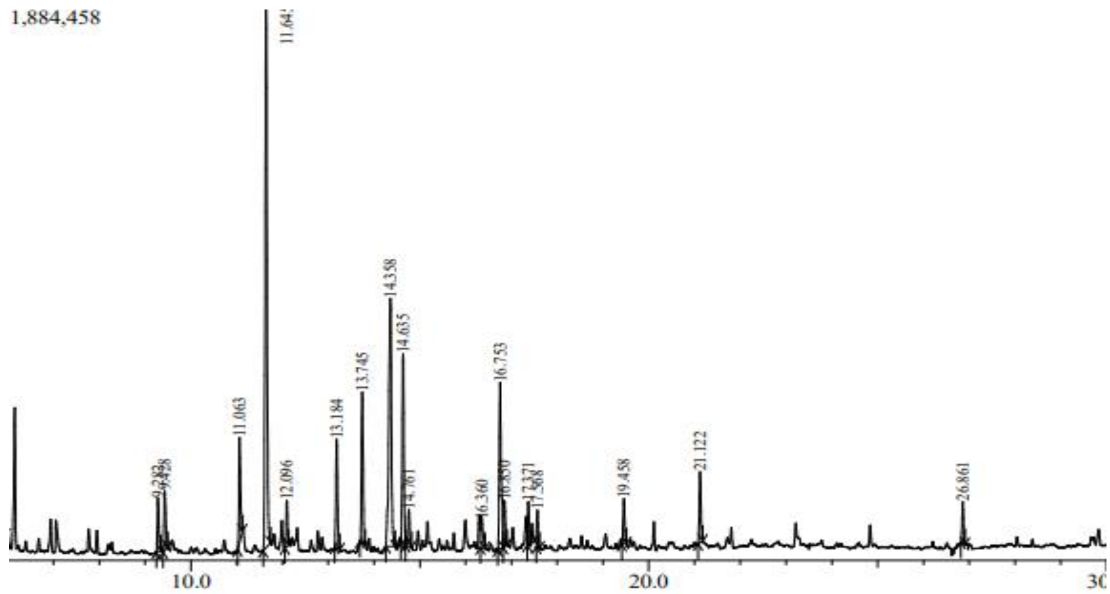


Fig. 4.5: GC-MS graph for bio oil.

The bio oil indicates that the bio-oil is a complicated organic compound that mainly consists of water, acids and heterocyclic substances and found to be rich in phenol with 27.23% by weight followed by p-cresol 16.95% on par with 4-ethyl- Phenol having 8.99%, and the lowest amount of L-.alpha.-Terpineol (1.52%) was recorded.

Bio-oils have received extensive recognition from international energy organizations around the world for their characteristics as fuels used in combustors, engines or gas turbines and resources in chemical industries. Many substances can be extracted from biooil, such as phenol used in the plastics industry, volatile organic acid to form a film forming agent, laevoglucose, hydroxyl acetaldehyde and some additives are applications in the pharmaceutical industry, synthetic fibres or fertilizers and flavouring agents in food products.

Yan *et al.,* (2001) The 99.7% of bio-oil, a complex mixture containing carbon, hydrogen and oxygen, is composed of acids, alcohols, aldehydes, esters, ketones, sugars, phenols, guaiacols, syringols, furans, lignin derived phenols and extractible terpene with multi-functional groups.

V SUMMARY

The research entitled "**Utilization of products obtained from pyrolysis of paddy straw.**" was undertaken during 2020-2021. In this study, a potted experiment was conducted in the GKVK at Bangalore. The observations obtained in the investigation are presented below.

The chemical study revealed that paddy straw biochar reported a strongly alkaline fraction having pH of 10.29 with an electrical conductivity of 3.287 dSm^{-1} and a fixed C content of 6.1 per cent. Nitrogen, phosphorus, and potassium concentrations were 0.41, 0.04 and 3.83 per cent, respectively. Paddy straw biochar also recorded good Ca, Mg and S values of 2.39, 0.24 and 0.07 percent respectively.

Different soil physical properties namely bulk density (BD) and maximum water holding capacity (MWHC) varied significantly due to different biochar dosage application. Between the various treatments, treatments receiving 25 tons of BC + VC+ Ganajeevamrutha documented lower bulk density (1.29 Mg m^{-3}) and higher water holding capacity (42.03%) over the rest of the other treatments.

The chemical properties of soil have been significantly influenced due to the use of paddy straw biochar at varied levels in combination with organic manures. The soil pH (9.50) and EC (electrical conductivity) (0.19 dSm^{-1}) were recorded significantly higher in T_{21} treatment, which received 25 tons of BC + FYM + VC+ Ganajeevamrutha in the present research.

The available organic carbon per cent in the present study has significantly recorded high in treatment T_{21} (6.42 g kg^{-1}) which received 25 tons of BC + FYM + VC+ Ganajeevamrutha. The lower percentage was recorded in T_3 (5.4 g kg^{-1}) which received 15 tons of BC + Ganajeevamrutha as an amendment.

Available soil nitrogen, phosphorus and potassium content differed considerably due to application of paddy straw biochar. The available nitrogen (297 kg ha^{-1}), phosphorus (63.25 kg ha^{-1}) and potassium (173.95 kg ha^{-1}) recorded the highest in T_{21}

treatment, which received 25 tons of BC + FYM + VC+ Ganajeevamrutha. Significantly lower amount of nitrogen, phosphorus, and potassium were observed in T_{22} (255.5, 48.85, 158 kg ha^{-1}) which received 15 tons of BC alone.

Exchangeable calcium, magnesium and available sulphur contents of soil varied significantly due to paddy straw biochar. Highest exchangeable Calcium (4.22 c mol (p+) kg^{-1}), Magnesium (2.98 c mol (p+) kg^{-1}) and available Sulphur (37.82 mg kg^{-1}) concentration observed in treatment receiving nutrients 25 tons of BC + FYM + VC+ Ganajeevamrutha (T_{21}) and significantly low value was observed in which received 15 tons of BC only.

Significant variation in micronutrient content was observed with application of varied levels of paddy straw biochar amended in neutral pH soil. Application of paddy straw biochar in neutral soil reduced micronutrient. Significantly, higher value of Iron (19.6 mg kg^{-1}), manganese (9.94 mg kg^{-1}) was recorded in T_{22} which received 15 tons of BC only, zinc (0.44 mg kg^{-1}), and Cu (0.27 mg kg^{-1}) was recorded in T_{13} receiving 20 tons of BC + FYM +VC.

In the present experiment, growth parameters like plant height, number of leaves and number of branches of field bean were significantly recorded highest at 30, 60 and at harvest of the crop growth stage in the treatment T_{21} receiving 25 tons of BC + FYM + VC+ Ganajeevamrutha.

The number of pods per plant (16) was recorded significantly highest in treatment (T_{21}) which consists of 25 tons of BC + FYM + VC+ Ganajeevamrutha and weight of pods per plant (24g) was recorded significantly highest in T_{20} which received 20 tons of BC + FYM + VC + Ganajeevamrutha and significantly lowest value was recorded in T_{22} (6), which did not receive an external source of nutrients but 15 tons of biochar and T_1 (9.6g) received 15 tons of BC + FYM respectively.

This study shows the effects of paddy straw biochar combined with organic inputs on neutral soil and crop yield providing positive responses. For other soil physical and chemical parameters, nutrient uptake and crop yield in all treatment combinations showed, higher the dosage of biochar, lead to increase in the soil nutrients and the yield as observed. T_{21} with 25 tons BC + FYM + VC + Ganajeevamrutha had the best results of all treatments. However, the field bean, in the T_{20} treatment which received 20 tons of BC + FYM + VC + Ganajeevamrutha had a higher overall yield. The use of paddy straw biochar in soil management and agricultural production has been shown to achieve higher field bean yields, improving the physical and chemical properties of the soil by increasing fertility and productivity of the soil.

Practical utility:

*T_{21} with 25 tons BC + FYM + VC + Ganajeevamrutha and T_{20} which received 20 tons of BC + FYM + VC + Ganajeevamrutha are required to be further studied under field condition.

*Along with that T_5 (20 tons of Biochar + VC), T_9 (25 tons of Biochar + Ganajeevamrutha), T_{17} (25 tons of Biochar + FYM + Ganajeevamrutha), T_{18} (25 tons of Biochar + VC+ Ganajeevamrutha), T_{19} (15 tons of Biochar + FYM + VC + Ganajeevamrutha) should be individually studied further.

Future line of work

- The effect of catalyst on pyrolysis at the same temperature need to be done with same feed stock.
- Much more study on Ganajeevamrutha influence on crop production and soil parameters in field condition has to be studied.
- Field experiments of same treatments can help in formulating the practical utility of the research and this has to be studied.
- There is need to evaluate the long-term effect of biochar on plant growth and yield.

VI REFERENCES

AHMAD, M., RAJAPAKSHA, A.U., LIM, J.E., ZHANG, M., BOLAN, N., MOHAN, D., VITHANAGE, M., LEE, S.S. AND OK, Y.S., 2014, Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere*, **99,** pp.19-33.

AHO, A., TOKAREV, A., BACKMAN, P., KUMAR, N., ERÄNEN, K., HUPA, M., HOLMBOM, B., SALMI, T. AND MURZIN, D.Y., 2011, Catalytic pyrolysis of pine biomass over H-Beta zeolite in a dual-fluidized bed reactor: effect of space velocity on the yield and composition of pyrolysis products. *Top.Catal.*, **54**(13-15), p.941.

ALIE KAMARA., HAWANATU SORIE KAMARA., MOHAMED SAIMAH KAMARA, 2015, Effect of Rice Straw Biochar on Soil Quality and the Early Growth and Biomass Yield of Two Rice Varieties. *Agri Sci.*, vol (6) 798-806.

AMIN, F.R., HUANG, Y., HE, Y., ZHANG, R., LIU, G. AND CHEN, C., 2016, Biochar applications and modern techniques for characterization. *Clean Technol Environ Policy*, **18**(5), pp.1457-1473.

AMONETTE, J. E. AND JOSEPH, S., 2009, Physical properties of biochar. In: Lehmann J, Joseph S (Eds) Biochar for environmental management science and technology. Earthscan, London. 53–62.

ANTAL, J., MAIVOLTA, G, M., TEKLIC, T., VRATARI, M., SUDARIC, A. AND KOVACEVIC, V., 2003, Relationships among Chloroplast Pigments Concentration and Readings in Soybean under Influence of Foliar Magnesium Application. *Commun., soil sci. plan.*,**40**(6):706-725.

ANTENEH, A., YITAFERU, B., YIHENEW, G. S. AND AMAR, T., 2014, The Role of Biochar on Acid Soil Reclamation and Yield of Teff (Eragrostistef [Zucc] Trotter) in Northwestern Ethiopia. Ethiopia *J. Agric. Sci.*, **6**(1): 126-138.

ARNOLDUS. H. AND NGUYEN. J. 2016, Effect of biochar and liming on soil nitrous oxide emissions from a temperate maize cropping system. *J. Integr. Agric*., **1**(2): 707-717.

ASAI, H., BENJAMIN, K., SAMSON HAEFELE, M., STEPHAN KHAMDOK. AND TAKESHI HORIEG. 2009, Biochar amendment techniques for upland rice production in Northern Laos: 1. Soil physical properties, leaf SPAD and grain yield. Field Crop Research. **111**(2): 81-84.

BAGREEV, A., BANDOSZ, T. J. AND LOCKE, D. C., 2001, Pore structure and surface chemistry of adsorbents obtained by pyrolysis of sewage sludge-derived fertilizer. Carbon., **39**: 71–79.

BATOOL, A., TAJ, S., RASHID, A., KHALID, A., QADEER, S., SALEEM, A.R. AND GHUFRAN, M.A., 2015, Potential of soil amendments (Biochar and Gypsum) in increasing water use efficiency of *Abelmoschus esculentus L. Moench*. *Front*. *Pl. Sci.*, **6**: 733-735.

BEESLEY, L. AND MARMIROLI, M., 2011, The immobilisation and retention of soluble arsenic, copper, cadmium and zinc by biochar. *Environ. Pollut*., **159**: 474–480.

BHATTACHARYYA, P., BHADURI, D., ADAK, T., MUNDA, S., SATAPATHY, B.S., DASH, P.K., PADHY, S.R., PATTANAYAK, A., ROUTRAY, S., CHAKRABORTI, M. AND BAIG, M.J., 2020, Characterization of rice straw from major cultivars for best alternative industrial uses to cutoff the menace of straw burning. *Ind. Crops and Prod.*, **143**:83-86.

BLACK, C. A., 1965, Methods of soil analysis part-1 physical and mineralogical properties. Agronomy Monograph No.9. *American Soc. Agron. Madison, Wisconsin, USA*, **7**: 18-25.

BRAY, R. H. AND KURTZ, L. T., 1945, Determination of total, organic , and available forms of phosphorus in soils. *Soil Sci*., **59** (1):39-46.

BREWER, C. E., SCHMIDT-ROHR, K., SATRIO, J. A. AND BROWN, R. C., 2014, An investigation into the reactions of bio char in soil. *J. Soil Res*., **48**(7): 501-515.

BRIDGWATER, A.V. AND PEACOCKE, G.V.C., 2000, Fast pyrolysis processes for biomass. *Renew. Sustain. Energy Rev.,* **4**(1), pp.1-73.

BRIDGWATER, A.V., 1999. Principles and practice of biomass fast pyrolysis processes for liquids. *J. Anal. Appl. Pyrolysis* **51**: 3–22.

BROWN, R. C., BREWER, C. E., SCHMIDT-ROHR, K., AND SATRIO, J. A. 2006, Characterization of biochar from fast pyrolysis and gasification systems. *Soil Sci.,***88**: 164-167.

BRUUN, E.W., HAUGGAARD-NIELSEN, H., IBRAHIM, N., EGSGAARD, H., AMBUS, P., JENSEN, P.A. AND DAM-JOHANSEN, K., 2011, Influence of fast pyrolysis temperature on biochar labile fraction and short-term carbon loss in a loamy soil. *Biomass Bioenergy*, **35**(3): 1182-1189.

CANTRELL, K.B., HUNT, P.G., UCHIMIYA, M., NOVAK, J.M. AND RO, K.S., 2012, Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. *Bioresour. Technol.*, **107:** .419-428.

CAO, X. D., MA, L. N., GAO, B. AND HARRIS, W., 2009, Dairy-manure derived biochar effectively sorbs lead and atrazine. *Environ. Sci. Tech.,***43**: 3285– 3291.

CHAMORRO, A. M., TAMAGNO, L. N., BEZUS, R. AND SARANDON, S. J., 2002, Nitrogen accumulation partition and nitrogen –use efficiency in canola under different nitrogen availabilities. *Soil Sci. Pl. Anal.,* **33**: 493-504.

CHAN, K. Y. AND XU, Z., 2013, Biochar: nutrient properties and their enhancement. Biochar for environmental management: *Sci. Technol. Earth scan, London*, vol. 67-84

CHAN, K. Y., VAN ZWIETEN, L., MESZAROS, I., DOWNIE, A. AND JOSEPH, S., 2007, Agronomic values of green waste biochar as a soil amendment. *J. Soil Res*., **45**: 629-634.

CHAN, K.Y., JOSEPH, S., AND XU, A., 2008, Biochar: nutrients properties and their enhancement. *Soil Sci. Plant Anal.*,**8**: 67-84.

CHAN, K.Y., VAN ZWIETEN, L., MESZAROS, I., DOWNIE, A. AND JOSEPH, S., 2018, Using poultry litter biochars as soil amendments. *Soil. Res.*,**46**(5): 437-444.

CHEN, Y., SHINOGI, Y. AND TAIRA, M., 2010, Influence of biochar use on sugarcane growth, soil parameters and ground quality, Australian. *J. Soil Res.***48**: 526-530.

CHENG, C. H., LEHMANN, J., THIES, J. E., BURTON, S. D. AND ENGELHARD, M. H., 2006, Oxidation of black carbon by biotic and abiotic processes. *Org. Geochem.*,**37**: 1477–1488.

CHINTALA, R., MOLLINEDO, J., SCHUMACHER, T.E., MALO, D.D. AND JULSON, J.L., 2014, Effect of biochar on chemical properties of acidic soil. *Arch. Agron. Soil Sci*., **60**(3): 393-404.

CHOI, H.S., CHOI, Y.S. AND PARK, H.C., 2012, Fast pyrolysis characteristics of lignocellulosic biomass with varying reaction conditions. *Renew. Energy*, **42**: 131-135.

COUMARAVEL. R., KAYA, N., YILDIZ, Z. AND CEYLAN, S., 2015, Preparation and characterisation of bio char from hazelnut shell and its adsorption properties for methylene blue dye. *Polite. Dergi.*,**21**(4): 765-776.

COWIE, A.L., DOWNIE, A.E., GEORGE, B.H., SINGH, B.P., VAN ZWIETEN, L. AND O'CONNELL, D., 2012, Is sustainability certification for biochar the answer to environmental risks?. *Pesqui. Agropecu. Bras*, **47(**5): 637-648.

DAS, P., SREELATHA, T. AND GANESH, A., 2004, Bio oil from pyrolysis of cashew nut shell-characterisation and related properties. *Biomass bioenergy*, **27**(3): 265-275.

DELUCA, T. H., MACKENZIE, M. D. AND, M. J., 2009, Biochar effects on soil nutrient transformations. *Earth. scan*., **5**: 72-87.

DELUCA. H. AND APLET, H., 2008, Charcoal and carbon storage in forest soils of the Rocky Mountain West. Front. *Eco. Environ*., **6**: 18-24.

DONG, D., QIBO, F., KIM, M., YANG, M., WANG, H. AND WU, W., 2015, Effect of biochar amendment on rice growth and nitrogen retention in a waterlogged paddy field. *J. Soils Sediments*, **15**: 153-162.

DOWNIE, A., CROSKY, A. AND MUNROE, P., 2009, Physical properties of biochar, Chapter 2, In: Lehmann J, Joseph S (Eds) Biochar for environmental management science and technology. *Earth scan, London*, pp 13–32.

EL-HASSANIN, A.S., SAMAK, M.R., RADWAN, S.R. AND EL-CHAGHABY, G.A., 2020, Preparation and characterization of biochar from rice straw and its application in soil remediation. *Environ. Nat. Resour. J.,* **18**(3): 283-289.

EMMANUEL, D., ANNE, V., STEVE, R. AND SARANA, S., 2010, Biochar from saw dust, maize stover and charcoal: Impact on water holding capacity (WHC) of three soil from Ghana. *Bio. Geo. Sci*., **9**: 34-35.

EVANS, R.J., MILNE, T.A., 1987, Molecular characterization of the pyrolysis of biomass – 1. Fundamentals. *Energy Fuels* **1**: 123–138.

FAHMI R, BRIDGWATER AV, DONNISON I, YATES N, JONES JM,2008, The effect of lignin and inorganic species in biomass on pyrolysis oil yields, quality and stability. *Fuel***87**:1230–1240.

FENG, B., LEHMANN, J., KALBITZ, K., TENYWA, M., THIONĢO, M. AND NEUFELDT, H., 2014, Emissions intensity and carbon stocks of a tropical Ultisol after amendment with Tithonia green manure, urea and biochar. *Fld. Crop. Res.,* **209**: 179-188.

FIGUEREDO, N. A. D., COSTA, L. M. D., MELO, L. C. A., SIEBENEICHLERD, E. A. AND TRONTO, J., 2017, Characterization of biochars from different sources and evaluation of release of nutrients and contaminants. *Re. Cienc. Agron.,***48**(3): 38-43.

GAO, J., SHI, Z., WU, H. AND LV, J., 2020, Fluorescent characteristics of dissolved organic matter released from biochar and paddy soil incorporated with biochar. *RSC Advances*, **10**(10): 5785-5793.

GASKIN, J. W, STEINER, C., HARRIS, K., DAS, K. C AND BIBENS, B., 2008, Effect of low temperature pyrolysis conditions on biochar for agricultural use. *T. Asabe.,***51**: 2061-2069.

GLASER, B., LEHMANN, J. AND ZECH, W., 2002, Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A review. *Biol. Fertil. Soils,* **35**: 219-230.

GOKILA, B. AND BASKAR, K., 2015, Influence of biochar as a soil amendment on yield and quality of maize in alfisol of thoothukudi district of tamilnadu, India. *Int. J. Plant Anim. Environ. Sci*., **5**: 152-155.

GOMEZ, K. A. AND GOMEZ, A. A., 1984, Statistical Procedures for Agric. Res. 2nd Ed. John Wiley & Sons, New York.

GOYAL HB, SEAL D AND SAXENA RC, 2008, Bio-fuels from thermochemical conversion of renewable resources: A review. *Renew Sustain Energy Rev***12**:504–517.

GUNDALE, M. J., AND DELUCA, T. H. 2006, Temperature and substrate influence the chemical properties of charcoal in the ponderosa pine /Douglas-fir ecosystem, Forest *Eco. Manage*., **231**: 86-93.

HAIDER, G., STEFFENS, D., MÜLLER, C., KAMMANN, C.I., 2016, Standard extraction methods may underestimate nitrate stocks captured by field-aged biochar. *J. Environ. Qual*.**45**, 1196–1204.

HAMER., RAJKOVICH, S., ENDERS, A., HANLEY, K., HYLAND, C., ZIMMERMAN, A. R. AND LEHMANN, J., 2004, Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biol. Fert. Soils*., **48**: 271-284.

HARTLEY L,. 1998, Secondary compounds within the Anacardiaceae, http://www.colostate.edu/Depts/Entomology/courses/en570/papers1998/hartley.htm.

HASS, A., GONZALEZ, J. M., LIMA, I. M., GODWIN, H. W., HALVORSON, J. J. AND BOYER, D. G., 2012, Chicken manure biochar as liming and nutrient source for acid Appalachian soil. *J. Environ. Qual.*,**41**(4): 1096-1106.

HEO, H.S., PARK, H.J., PARK, Y.K., RYU, C., SUH, D.J., SUH, Y.W., YIM, J.H. AND KIM, S.S., 2010, Bio-oil production from fast pyrolysis of waste furniture sawdust in a fluidized bed. *Bioresour. Technol.*, **101**(1): S91-S96.

HERNANDEZ, S. L. AND BARRERA-ZAPATA, R., 2017, Morphological and physicochemical characterization of biochar produced by gasification of selected forestry species. *Rev. Facu. De. Inge.*, **26**(46): 123-130.

HIEN, T. T., SHINOGI, Y., MISHRA, A. AND VIET, D. D., 2017, The effect of bamboo Biochar on Crop's productivity and quality in the field condition. *J. Fac. Agr. Kyushu. U.* **62**(2): 477-482.

HUANG, W., GONG, F., FAN, M., ZHAI, Q., HONG, C. AND LI, Q., 2012, Production of light olefins by catalytic conversion of lignocellulosic biomass with HZSM-5 zeolite impregnated with 6 wt.% lanthanum. *Bioresour. Technol.*, **121**: 248-255.

IPPOLITO J, NOVAK JM, BUSSCHER WJ., 2012, Switchgrass biochar affects two aridisols. *J Environ Qual* **41**: 1123–1130.

JACKSON, M.L., 1973, Soil chemical analysis. Prentice Hall of India, New Delhi, **1**: 485- 486

JACOBSON, K., MAHERIA, K.C. AND DALAI, A.K., 2013, Bio-oil valorization: a review. *Renew. Sust. Energ. Rev.*, **23**: 91-106.

JI-LU, Z., 2007, Bio-oil from fast pyrolysis of rice husk: Yields and related properties and improvement of the pyrolysis system. *J. Anal. Appl. Pyrolysis*, **80**(1): 30-35.

JINDO, K., MIZUMOTO, H., SAWADA, Y., SANCHEZ MONEDERO, M. A. AND SONOKI, T., 2014, Physical and chemical characterization of biochars derived from different agricultural residues. *Biosci*., **11**(23): 6613-6621.

KABIR, G. AND HAMEED, B.H., 2017, Recent progress on catalytic pyrolysis of lignocellulosic biomass to high-grade bio-oil and bio-chemicals. *Renew. Sust. Energ. Rev.*, **70**: 945-967.

KALYANI. K., MANIKANDAN, A. AND SUBRAMANIAN, K. S., 2016, Urea intercalated bio char—a slow release fertilizer production and characterisation. Indian. *J. Sci. Technol*., **6**(12): 5579-5584.

KANNAN, P., ARUNACHALAM, P., PRABUKUMAR, G. AND GOVINDARAJ, M., 2013, Biochar an alternate option for crop residues and solid waste disposal and climate change mitigation. *Afr. J. Agric. Res.*, **8**(21): 2403-2412.

KEUN, T. O., BONGSU, C., SCHMIDT, YOSHIYUKI, S. AND JIRO, C., 2012, Characterization of biochar derived from three types of biomass. *J. Fac. Agric. Kyushu Unive*., **57**: 61-66.

LAIRD, D.A., BROWN, R.C., AMONETTE, J.E. AND LEHMANN, J., 2009, Review of the pyrolysis platform for coproducing bio-oil and biochar. *Biofuels* Bioprod. *Biorefining*, **3**(5): 547-562.

LEE, J. W., HAWKINS, B., KIDDER, M. K., EVANS, B. R., BUCHANAN, A. C. AND DAY, D., 2016, Characterization of biochar produced from peanut hulls and pine wood with different pyrolysis conditions. *J. Biores. Biop*., **3**(1): 15-19.

LEE, Y., PARK, J., RYU, C., GANG, K.S., YANG, W., PARK, Y.K., JUNG, J. AND HYUN, S., 2013, Comparison of biochar properties from biomass residues produced by slow pyrolysis at 500 C. *Bioresour. Technol.*, **148**: 196-201.

LEHMANN AND JOSEPH., 2009, An investigation into the reactions of biochar in soil. *Soil Research*, **48**(7): 501-515.

LEHMANN, J. AND RONDON, M., 2005, Bio-char soil management on highlyweathered soils in the humid tropics, *Biological Approaches to Sustainable Soil Systems*, Boca Raton, CRC Press.

LEHMANN, J. D., SILVA J. R., J. P., STEINER, C., NEHLS, T., ZECH, W. AND GLASER, B., 2003, Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Pl. Soil.*,**249**: 343-357.

LEHMANN, J., 2007, Bio-energy in the black. Frontiers. *Ecol. Environ.*,**5**: 381-389.

LEI H, REN S AND JULSON J. 2009, The effects of reaction temperature and time and particle size of corn stover on microwave pyrolysis. *Energ Fuel*,**23**:3254–3261.

LINDSAY, W.L. AND NORWELL, W.A., 1978, Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Amer. J.*, **42**: 421-428.

LU, H., ZHANG, Y. Y., HUANG, X., WANG, S. AND QIU, R., 2012, Relative distribution of Pb2+ sorption mechanisms by sludge-derived biochar. *Water Res.*,**46**: 854-862.

LUO, L., WANG, G., SHI, G., ZHANG, M., ZHANG, J., HE, J., XIAO, Y., TIAN, D., ZHANG, Y., DENG, S. AND ZHOU, W., 2019, The characterization of biochars derived from rice straw and swine manure, and their potential and risk in N and P removal from water. *J. Environ. Manag.***245**: 1-7.

LUO, Z., WANG, S., LIAO, Y., ZHOU, J., GU, Y. AND CEN, K., 2004, Research on biomass fast pyrolysis for liquid fuel. *Biomass Bioenergy*, **26**(5): 455-462.

MAJOR, J., RONDON, M., MOLINA, D., RIHA, S.J. AND LEHMANN, J., 2010, Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and soil*. **333**(1): 117-128.

MAMATHA, D., GOWDA, R. C., AND SHIVAKUMARA M. N., 2018, Effect of basic slag on yield, nutrient status and uptake by paddy in acid soils. *Int. Soil .Scien.Natur*: **7**(2): 139-145.

MARY, G. S., SUGUMARAN, P., NIVEDITHA, S., RAMALAKSHMI, B., RAVICHANDRAN, P. AND SESHADRI, S., 2016, Production, characterization and evaluation of bio char from pod (Pisum sativum), leaf (Brassica oleracea) and peel (Citrus sinensis) wastes. *J. Int. Recycl. org. waste agric.*, **5**(1): 43-53.

MOHAN, D., PITTMAN JR, C.U. AND STEELE, P.H., 2006, Pyrolysis of wood/biomass for bio-oil: a critical review. *Energy & fuels*, **20**(3): 848-889.

MOKHLISSE, A. AND CHANÂA, M.B., 1999, Effect of water vapor on the pyrolysis of the Moroccan (Tarfaya) oil shale. *J. Anal. Appl. Pyrolysis*, **48**(2): 65-76.

MULLEN, C.A., BOATENG, A.A., GOLDBERG, N.M., LIMA, I.M., LAIRD, D.A. AND HICKS, K.B., 2010, Bio-oil and bio-char production from corn cobs and stover by fast pyrolysis. *Biomass bioenergy*, **34**(1): 67-74.

NAQVI, S.R., UEMURA, Y. AND YUSUP, S.B., 2014, Catalytic pyrolysis of paddy husk in a drop type pyrolyzer for bio-oil production: The role of temperature and catalyst. *J. Anal. Appl. Pyrolysis*, **106**: 57-62.

NOVAK, J. M., BUSSCHER, W. J., LAIRD, D. L., AHMEDNA, M., WATTS, D. W. AND NIANDOU, M. A. S., 2009, Impact of biochar amendment on fertility of a southeastern coastal plain soil. *Soil Sci*., **174**: 105-112.

ÖZBAY, N, PU¨TU¨N AE, PU¨TU¨N E., 2001, Structural analysis of bio-oils from pyrolysis and steam pyrolysis of cottonseed cake. *J. Anal. Appl. Pyrolysis*, **60**: 89–101.

ÖZBAY, N., APAYDIN-VAROL, E., UZUN, B.B. AND PÜTÜN, A.E., 2008, Characterization of bio-oil obtained from fruit pulp pyrolysis. *Energy*, **33**(8): 1233-1240.

PAGE, A. L, MILLER, R. H. AND KENAY, D. R., 1982, Methods of Soil Analysis, part – 2, *Soil Sci. Society of America*, Inc, Publishers, Madison, Wisconsin, USA.

PARK, J. H., CHOPPALA, G. H., BOLAN, N. S., CHUNG, J. W. AND CHUASAVATHI, T., 2011, Biochar reduces the bioavailability and phytotoxicity of heavy metals. *Plant & Soil*, **348**: 439-451.

PARVAGE, M. M., BARBRO, U., ERIKSSON, J., JEFFERY, S. AND HOLGER, K., 2013, Phosphorus availability in soils amended with wheat residue char. *Biol. Fert. Soils*, **49**(2): 245-250.

PASTOR-VILLEGAS, J., PASTOR-VALLE, J. F., MENESES RODRIGUEZ, J. M. AND GARCIA, M., 2006, Study of commercial wood charcoals for the preparation of carbon adsorbents. *J. Anal. Appl. Pyrol*., **76**: 103-108

PAZ-FERREIRO, J., LU, H., FU, S., ME´NDEZ, A. AND GASCO, G., 2014, Use of phytoremediation and biochar to remediate heavy metal polluted soils: a review. *Solid Earth*, **5**: 65-75.

PHUONG, H.T., UDDIN, M. AND KATO, Y., 2015, Characterization of biochar from pyrolysis of rice husk and rice straw. *J. Biobased Materials and Bioenergy*, **9**(4): 439-446.

PIPPER, C. S., 1966, *Soil Sci. Plant Anal.*, Hans Pub: Bombay,**7**: 368-369.

PÜTÜN, A.E., APAYDIN, E. AND PÜTÜN, E., 2004, Rice straw as a bio-oil source via pyrolysis and steam pyrolysis. *Energy*, **29**(12-15): 2171-2180.

RODRIGUEZ, L., SALAZAR, P. AND PRESTON, T.R., 2009, Effect of biochar and bio digester effluent on growth of maize in acid soils. *Livestock Res. Rural Develp*., **21**(7): 110.

RONDON, M., LEHMANN, J., RAMIREZ, J. AND HURTADO, M., 2007, Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with bio-char additions. *Biol. Fert. Soils*., **43**: 699-708.

RUMI, M., PABLO, S., VIDAL, B., JOSE, T., MARIA-DEL, C. C., ANTONIA, G. AND RAFAEL, V., 2015, Enhanced wheat yield by biochar addition under different mineral fertilization levels. *Agron. sustain*. Dev., **33**: 475-484.

SADAKA, S. AND BOATENG, A.A., 2009, *Pyrolysis and bio-oil*. [Cooperative Extension Service], University of Arkansas, US Department of Agriculture and county governments cooperating.

SCHMIDT, K. AND ANGELA G. NOACK., 2000, Black carbon in soils and sediments: Analysis, distribution, implications, and current challenges. *Global Biogeochem. Cycles*., **14**: 777-793.

SCOTT, D.S., PISKORZ, J., BERGOUGNOU, M.A., GRAHAM, R., OVEREND, R.P., 1988, The role of temperature in the fast pyrolysis of cellulose and wood. *Ind. Eng. Chem. Res*.,**27**: 8–15.

SHEN, D., JIN, W., HU, J., XIAO, R. AND LUO, K., 2015, An overview on fast pyrolysis of the main constituents in lignocellulosic biomass to valued-added chemicals: Structures, pathways and interactions. *Renew. Sust. Energ. Rev*., **51:** 761-774.

SHENBAGAVALLI, S. AND MAHIMAIRAJA, S., 2012, Production and characterization of biochar from different biological wastes. *Int. j. plant animal env. sci.*, **2**(1): 197-201.

SHI, L., YU, S., WANG, F.C. AND WANG, J., 2012, Pyrolytic characteristics of rice straw and its constituents catalyzed by internal alkali and alkali earth metals. *Fuel*, **96**: 586-594.

SHUN, T., ZHANG, Z., JIANPING, S. AND QINGWEN, W.A.N.G., 2013, Recent progress of catalytic pyrolysis of biomass by HZSM-5. *Chinese J. Catal*., **34**(4): 641-650.

SI, L., XIE, Y., MA, Q. AND WU, L., 2018, The short-term effects of rice straw biochar, nitrogen and phosphorus fertilizer on rice yield and soil properties in a cold waterlogged paddy field. *Sustainability*, **10**(2), 537.

SINGH, B., SINGH, B. P. AND ANNETTE, L. C., 2010, Characterisation and evaluation of biochars for their application as a soil amendment. Aus. *J. Soil Res*., **48**: 516-525.

SOHI SP, KRULL E, LOPEZ-CAPEL E, BOL R. 2010, A review of biochar and its use and function in soil. *AdvAgron*.,**105**:47–82.

SOLOMON, D., LIANG, B., LEHMANN, J., SOHI, S., THIES, J. E., SKJEMSTAD, J. O., LUIZAOD, F. J., ENGELHARDE, M. H., NEVESF, E. G. AND WIRICK, S. 2009, Stability of biomass derived black carbon in Soils. *Sci. Rep*., **72**: 6069-6078.

STEINBEISS., OGAWA, M., OKIMORI, Y. AND TAKAHASHI, F., 2009, Carbon sequestration, by carbonization of biomass and forestation: Three case studies. Mitigation and Adaptation Strategies for Global Change. *J. Sci. Repor*., **11**: 429-444.

STEINER, C., GLASER, B., TEIXEIRA, W. G., LEHMANN, J. AND BLUM WEH, ZECH, W., 2007, Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. *J. Pl. Nutr. Soil Sci*., **171**(6): 893–899.

SUBBAIAH, A. Y. AND ASIJA, G. K., 1956, A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci*., **25**: 270-280.

SUN, J., LIAN, F., LIU, Z., ZHU, L. AND SONG, Z., 2014, Biochars derived from various crop straws: characterization and Cd (II) removal potential. *Ecotoxicol. Environ. Saf.*, **106**: 226-231.

TAGHIZADEH-TOOSI, A., TIM, J. C., ROBERT, R. S. AND LEO, M. C., 2012, Biochar adsorbed ammonia is bioavailable. *Plant and Soil*, **350**: 57-69.

TSAI, W.T., LEE, M.K., CHANG, Y.M., 2007, Fast pyrolysis of rice husk: product yields and compositions. *Bioresour. Technol*., **98**, 22–28.

VAN ZWIETEN, L., KIMBER, S., DOWNIE, A., MORRI, S., PETTY, S., RUST, J. AND CHAN, K.Y., 2010, A glass house study on the interaction of low mineral ash biochar with nitrogen in a sandy soil. Australian *J. Soil Res*.,**48**:569-576.

VESES, A., AZNAR, M., LÓPEZ, J.M., CALLÉN, M.S., MURILLO, R. AND GARCÍA, T., 2015, Production of upgraded bio-oils by biomass catalytic pyrolysis in an auger reactor using low cost materials. *Fuel*, **141**: 17-22.

VITHANAGE, M., ZHANG, M., RAJAPAKSHA, A. U., THIELE-BRUHN, S., LEE, S. S. AND OK, Y. S., 2014, Acid-activated biochar increased sulfamethazine retention in soils. *Environ. Sci. Pollut. Res*., **22**(3): 1-12.

WABEL, M. I., HESHAM, M. I., USMAN, A. R. A. AND AL-OMRAN, A., 2013, Effect of Conocarpusbiochar application on hydraulic properties of a sandy loam soil. *Soil Sci.*, **178**: 163-173.

WALKY, A. J. AND BLACK, I. A., 1934, An examination of wet acid method for determining soil organic matter and proposed modification of chromic acid titration method. *J. Soil Sci*., **37**: 29-38.

WAN. J., ZHAO, X., WANG. S. AND XING. G., 2014, Successive straw biochar application as a strategy to sequester carbon and improve fertility: A pot experiment with two rice/wheat rotations in paddy. *Soil Plant Res*., **3**(78): 279–294.

WANG, S., ZHAO, X., XING, G. AND YANG, L., 2013, Large-scale biochar production from crop residue: A new idea and the biogas-energy pyrolysis system. *J. Bio. Res*., **8**(1): 8-11.

WANG, S.R., LUO, Z.Y., TAN, H., HONG, J., DONG, L.J., FANG, M.X. AND CEN, K.F., 2004, The analyses of characteristics of bio-oil produced from biomass by flash pyrolysis. *J. Eng. Thermophys*, **25**(6): 1049-1052.

WANG, Y., YIN, R. AND LIU, R., 2014, Characterization of biochar from fast pyrolysis and its effect on chemical properties of the tea garden soil. *J Anal Appl Pyrolysis*, **110**: 375-381.

WARNOCK, D. D., LEHMANN, J., KUYPER, T. W. AND RILLIG, M. C., 2007, Mycorrhizal responses to biochar in soil-concepts and mechanisms. *Plant and Soil*, **300**: 9-20.

WU, W., YANG, M., FENG, Q., MC GROUTHER, K., WANG, H., LU, H. AND CHEN, Y., 2012, Chemical characterization of rice straw-derived biochar for soil amendment. *Biomass Bioenergy*, **47:** 268-276.

YAMATO, M., OKIMORI, Y., WIBOWO, I. F., ANSHIORI, S. AND OGAWA, M., 2006, Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea and peanut, and soil chemical properties in south Sumatra, Indonesia. Soil. *Sci. Pl. Nutr*., **52**: 489-495.

YAN, G., YAO, W., FEI, W. AND YONG, J., 2001, Research progress in biomass flash pyrolysis technology for liquids production. *Chem. Eng. Prog.*, **8:** 13-17.

YANG, X., NG, W., WONG, B.S.E., BAEG, G.H., WANG, C.H. AND OK, Y.S**.**, 2019, Characterization and ecotoxicological investigation of biochar produced via slow pyrolysis: effect of feedstock composition and pyrolysis conditions. *J. Hazard. Mater*., **365**: 178-185.

YILDIZ, G., PRONK, M., DJOKIC, M., VAN GEEM, K.M., RONSSE, F., VAN DUREN, R. AND PRINS, W., 2013, Validation of a new set-up for continuous catalytic fast pyrolysis of biomass coupled with vapour phase upgrading. *J. Anal. Appl. Pyrolysis*, **103**: 343-351.

YU, L.Y., SHAO, H. B. AND CHANG, S. X., 2006, Engineered carbon (biochar) prepared by direct pyrolysis of Mg-accumulated tomato tissues: Characterization and phosphate removal potential. *Bio.resou. Tech.*, **138**: 8–13.

ZHANG, B., ZHONG, Z., DING, K., CAO, Y. AND LIU, Z., 2014, Catalytic upgrading of corn stalk fast pyrolysis vapors with fresh and hydrothermally treated HZSM-5 catalysts using Py-GC/MS. *Ind. Eng. Chem. Res.*, **53**(24): 9979-9984.

ZHANG, H., XIAO, R., WANG, D., HE, G., SHAO, S., ZHANG, J. AND ZHONG, Z., 2011, Biomass fast pyrolysis in a fluidized bed reactor under N2, CO2, CO, CH4 and H2 atmospheres. *Bioresour. Technol.*, **102**(5): 4258-4264.

ZHANG, H., YUE, X., LI, F., XIAO, R., ZHANG, Y. AND GU, D., 2018, Preparation of rice straw-derived biochar for efficient cadmium removal by modification of oxygen-containing functional groups. *Sci. Total Environ*., **631**: 795-802.

ZHENG, H., WANG, Z., XIA, D., ZHAO, J., LUO, Y., NOVAK, J., STEPHEN, H., AND XING, B., 2013, Characteristics and nutrient values of biochars produced from giant reed at different temperatures. *Bioresour. Tech*., **130**: 463-471.

ZIMMERMAN AR., 2010, Abiotic and microbial oxidation of laboratory-produced black carbon (biochar). *Environ Sci Technol*, **44**: 179-183.