E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(9): 236-242
Received: 09-06-2025
Accepted: 11-07-2025

Raghu HB
University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India

Aditya KT
CSIR-National Environmental Engineering Research Institute, Nehru Marg, Nagpur, Maharashtra, India

MN Thimmegowda
University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India

MR Jagadeesh
College of Forestry, UASD, Sirsi, Uttarakannada, Karnataka, India

Corresponding Author:
Raghu HB
University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India

Response of maize crop to biochar produced at varied temperature in eastern dry zone of Karnataka

Raghu HB, Aditya KT, MN Thimmegowda and MR Jagadeesh

DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i9d.3755

Abstract
In recent years, there has been a substantial increase in the widespread application of agrochemicals to enhance crop yields, thereby posing a considerable risk to soil health. In this regard, biochar application has gained considerable interest due to its potential to enhance crop growth and yield by improving fertilizer use efficiency and reducing use of agrochemicals. However, there is limited understanding how biochar produced at different temperature affects crop growth and yield. Pot experiment was conducted with maize crop to study the impact of biochars from simarouba seed coat produced at different pyrolysis temperatures (300, 400, and 500 °C), integrated with different proportions of inorganic and organic fertilizers. Results showed that, integrated application of biochar produced at 300 °C, combined with 75 per cent RDF, and 25 per cent Simarouba seed cake (T_5), exhibited notablyhigher plant height, number of leaves, leaf area per plant at 60 and 90 DAS. This ultimately resulted in improved yield parameters like cob length (16.93 cm), cob girth (12.78 cm), number of seeds per cob (474.90), test weight of kernels (24.03 g), grain yield per plant (114.09 g), and overall dry matter production per plant (207.21 g) in the treatment. Grain yield and stover yield per hectare was calculated and found highest in T_5 (6339 and 7762 kg respectively). The results of T_5 were on par with T_2 where biochar produced at 300 °C and 100 per cent RDF was applied. Among all the treatments employed, T_5 was concluded to be the most effective and cost-efficient, offering a reduction in the use of chemical fertilizers by 25 percent, coupled with an approximate 30 percent increase in grain yield per hectare of maize crop.

Keywords: Simarouba seed coats, biochar, different temperatures, nutrient management, maize, growth and yield

Introduction
The ongoing rapid growth in the global economy due to enhancing factors like industrialization, urbanization and burgeoning population is gradually reducing arable land. A key challenge for the agriculture sector is to feed the growing population, while at the same time to maintain soil health. In recent years, the extensive use of agrochemicals has risen significantly, posing a threat to soil health and the delicate balance of ecological cycles, including the food chain. Intensive crop farming on agricultural soils without organic matter addition is a major reason for deterioration of soil fertility and productivity (Lal, 2006) [13]. So, it becomes necessary todevelop novel and environmentally benign technologies that improve soil health and resilience (Gisladottir & Stocking, 2005) [7]. Application of biochar to soils is one such approach to improve degraded soils (Coomes & Miltner, 2016) [3]. Biochar is a carbon-rich substance produced by pyrolysis of agricultural or forest biomass characterized by its porous structure, higher stability, and capacity to enhance soil quality and sequester carbon.

Simarouba (*Simarouba glauca* DC) belonging to family Simaroubaceae, is a medium-sized multipurpose evergreen tree. The average yield of fruit from a 10-year-old plantation of Simarouba will be about 6000 to 8000 kg ha^{-1}(Joshi and Hiremath, 2001) [11]. Its seed consists of 71 per cent woody seed coat and 29 per cent kernel. The tree is having immense value in biodiesel production due to high oil content (61.04%) in seed kernels (Dash *et al.*, 2008) [4]. After recovery of kernels for biodiesel production, seed shells obtained in huge quantity are considered as waste due to its slow decomposition rate. In this regard, thermochemical conversion of this waste-to-bioenergy can help to enhance the specie bio-energy value chain. The most popular, easy, and efficient method is pyrolysis *i.e.*, thermal decomposition of biomass at elevated temperatures in an inert atmosphere that produces three products: biochar, liquid-bio-oil, and gas-syngas.

Biochar due to its porous nature helps to retain water and minerals in upper soil layer. Biochar treatments significantly increases soil cation exchange capacity (Laird *et al.*, 2010) [12] that helps to reduce leaching of the essential nutrients from plant root zone and keeps them accessible to the plants, improving their uptake. Biochar contains various nutrients essential for crop growth. Due to its physio-chemical characteristics, biochar promotes the growth of plant roots, enhancing the absorption of nutrients and water. This ultimately results in increased crop growth and yield. Nutrient contents in biochars are determined greatly by feedstock source and pyrolytic temperature (Ding *et al.*, 2016) [6]. The temperature at which pyrolysis occurs plays crucial role in deciding structure and physicochemical properties of biochar (Jindo *et al*., 2014) [10].

Biochar application integrated with inorganic and organic fertilizers, can significantly improve crop growth and yield (Dawar *et al.*, 2022; Bai *et al.*, 2022) [5, 2]. So, Biochar *via* pyrolysis from biowaste could be a promising option to use in organic or inorganic compound fertilizers for enhancing both soil productivity (Qian *et al.*, 2014) [19]. Therefore, the present study aimed to examine the influence of biochars produced from Simarouba seed coat at different pyrolysis temperatures (*viz.* 300, 400 and 500 °C) integrated with inorganic and organic (Simarouba seed cake) fertilizers on crop growth and yield parameters of maize crop.

Materials and Methods

Biochar production

Slow pyrolysis of Simarouba seed coat was performed in the fixed-bed tubular reactor at three different temperatures ranging from 300 to 500 °C with a constant heating rate of 10 °C min^{-1}. The reaction time was fixed for four hours and the material was run six times at three different temperatures that made up to a total of 18 runs. The treatment details are given below.

BC_1: Biochar produced at 300 °C
BC_2: Biochar produced at 400 °C
BC_3: Biochar produced at 500 °C.

Pot study

A pot experiment was conducted to know the effect of biochars produced at different temperatures on growth and yield of maize (MAH 14-5). Total 13 treatments were taken (Table 1) with 3 replicates (for each replicate, 3 observations were taken). Study was conducted by filling 10 kg of soil collected from the Mahatma Gandhi Botanical Garden, UAS, GKVK, Bangalore in each polybag. The collected soil was air-dried and ground to pass through 2-mm sieve. The soil was analysed for various physiochemical properties. The soil texture was sandy loam (60.73% sand; 20.41% silt; 16.86% clay) having pH 6.73; EC, 0.22 dS m^{-1}; organic carbon, 0.46 per cent; bulk density, 1.42 Mg m^{-3}; maximum water holding capacity, 39.70 per cent; available N, 328.70 kg ha^{-1}; available P, 27.51 kg ha^{-1} and available K, 286.32 kg ha^{-1}.The polybags were arranged in completely randomized design (CRD) in a polyhouse in the National Seed Project, UAS, GKVK, Bangalore. For each polybag, biochars produced at different temperatures were applied at the rate 15 t ha^{-1}. To ensure crop nutrient requirement, different proportions of recommended doses of fertilizers (150 kg N ha^{-1}, 75 kg P_2O_5 ha^{-1}, 40 kg $K_2 0$ and 10 kg Zn ha^{-1} [POP, UASB, 2020]) and Simarouba seed cake (7.9% N and 1.07% P_2O_5) were given. N dose was given in two split doses (75 kg at sowing time and remaining 75 kg, 21 DAS). Two seeds of maize were sown into polybags and thinned to one seedling after one week of germination. Moisture content was maintained at field capacity to avoid draught stress to plants.

Growth and yield parameters of maize

Growth parameters including plant height, number of leaves and leaf area per plant were recorded at 30, 60 and 90 DAS. At the time of harvest, the plants were separated into leaf, stem, root, and cob and dried at 65 ^{0}C until they attained constant dry weight and the overall weight of all plant parts was recorded as dry matter production in g plant^{-1}. Yield parameters including number of cobs per plant, cob length (cm), cob girth (cm), number of rows per cob and number of seeds per cob were recorded at harvest of the crop. The harvested grains from cob of each plant were dried in an oven at 60 °C for 20-24 hours to get constant weight. One hundred seeds were taken from produce of each treatment, weighed on electronic balance, and expressed as 100 grains weight in grams *i.e.*, test weight of kernels. The grains from sun dried cob of each plant were separated and weighed and the average weight was recorded as grain yield per plant (g). Grain yield ha^{-1} was computed from grain yield plant^{-1}, which was expressed in kg ha^{-1}.The dry weight of stover from each plant (g plant^{-1}) at harvest was recorded after complete sun drying and expressed in kg ha^{-1}.

Table 1: Treatment details of study on the influence of biochars produced at different temperatures on growth and yield parameters of maize

T_1	Control – 100% RDF without Biochar
T_2	100%RDF+ BC_1
T_3	100% RDF + BC_2
T_4	100% RDF + BC_3
T_5	75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP
T_6	75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP
T_7	75% RDF + BC_3 + 25% Simarouba seed cake on N basis + SSP
T_8	50% RDF + BC_1 + 50% Simarouba seed cake on N basis + SSP
T_9	50% RDF + BC_2 + 50% Simarouba seed cake on N basis + SSP
T_{10}	50% RDF + BC_3 + 50% Simarouba seed cake on N basis + SSP
T_{11}	25% RDF + BC_1 + 75% Simarouba seed cake on N basis + SSP
T_{12}	25% RDF + BC_2 + 75% Simarouba seed cake on N basis + SSP
T_{13}	25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP

Note: T = Treatment, RDF= Recommended doses of fertilizers, BC = Biochar @ 15 t ha, BC_1= Biochar obtained at 300 °C, BC_2 = Biochar obtained at 400°C, BC_3 = Biochar obtained at 500 °C, N = Nitrogen, and SSP = Single super phosphate (application of SSP is to balance P requirement of the crop).

Results and Discussion

a) Influence of application of biochars produced at different temperatures on growth parameters of maize

Plant height

Significant difference in maize plant height were observed at 60 and 90 days after sowing (DAS) as a result of the application of biochars produced at three different temperatures applied in integration with different levels of RDF and Simarouba seed cake (Table 2). At 30 DAS, there was no significant difference found in plant height of the crop.

At 60 DAS, higher plant height, measuring 168.83 cm, was shown by T_5 (75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP), which was on par with T_2 (100%RDF+ BC_1), measuring 166.77 cm. While, the shorter plant height, measuring 134.40 cm, was observed in T_1*i.e.*, Control (100% RDF without biochar). While at 90 DAS, T_5 showed significantly higher plant height, measuring 187.01 cm which was on par with T_2 (185.13). Conversely, the shorter plant height *i.e.*, 148.66 cm was observed in T_1.

Number of leaves

At 30 DAS, the treatments showed no statistically significant variations on the number of leaves per plant (Table 3). But at 60 DAS, there was a noticeable variation in number of leaves per plant among the treatments. However, T_5 (75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP), T_6 (75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP), T_2 (100%RDF+ BC_1) and T_3 (100%RDF+ BC_2) exhibited a significantly higher number of leaves per plant i.e., 10.56. The lowest leaf count per plant (8.89) was observed in T_1 and T_{13} (25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP). At 90 DAS, the higher leaf count per plant was observed in T_5 and T_6 (14.00). these values were on par with T_3 and T_6 (13.89). Conversely, lower leaf count was recorded in T_1 and T_{13} (12.45).

Leaf area per plant

Influence of application of biochars produced at different temperatures with application of different proportion of recommended dose of fertilizers and Simarouba seed cake on leaf area per plant of maize are mentioned in Table 4.

At 30 DAS, there was no noticeable variations in the treatments. But there was significant difference in leaf area per plant between treatments at 60 DAS. At the time, significantly higher value was observed in T_5 (4304 cm^2) which was on par with T_2 (4258 cm^2). Conversely, lower value was seen in control treatment *i.e.*, T_1 (3512 cm^2). Similarly at 90 DAS, higher leaf area per plant was observed in T_5 (5361 cm^2) which was on par with T_2 (5316 cm^2). The lowest value was found in T_1 (4374 cm^2) *i.e.*, in control treatment.

Table 2: Influence of biochars produced at three different temperatures on maize plant height.

Treatment details	Plants height (cm)		
	30 DAS	60 DAS	90 DAS
T_1: Control (100% RDF without biochar)	21.67	134.40	148.66
T_2: 100% RDF + BC_1	23.00	166.77	185.13
T_3: 100% RDF + BC_2	22.45	159.20	178.49
T_4: 100% RDF + BC_3	21.67	152.30	168.85
T_5: 75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP	23.45	168.83	187.01
T_6: 75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP	22.67	162.97	180.56
T_7: 75% RDF + BC_3 + 25% Simarouba seed cake on N basis + SSP	21.67	156.07	172.22
T_8: 50% RDF + BC_1 + 50% Simarouba seed cake on N basis + SSP	20.56	143.80	163.41
T_9: 50% RDF + BC_2 + 50% Simarouba seed cake on N basis + SSP	20.56	143.70	163.27
T_{10}: 50% RDF + BC_3 + 50% Simarouba seed cake on N basis + SSP	20.56	141.87	160.98
T_{11}: 25% RDF + BC_1 + 75% Simarouba seed cake on N basis + SSP	20.22	140.47	160.88
T_{12}: 25% RDF + BC_2 + 75% Simarouba seed cake on N basis + SSP	19.56	139.73	157.42
T_{13}: 25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP	20.11	136.03	152.79
S. Em±	0.93	0.86	0.97
C.D.@ 5%	NS	2.49	2.82
C.V (%)	2.24	3.09	2.60

Table 3: Influence of application of biochars produced at different temperatures on number of leaves $plant^{-1}$ of maize.

Treatment details	No. of leaves $plant^{-1}$		
	30 DAS	60 DAS	90 DAS
T_1: Control (100% RDF without biochar)	5.56	8.89	12.45
T_2: 100% RDF + BC_1	6.56	10.56	14.00
T_3: 100% RDF + BC_2	6.56	10.56	13.89
T_4: 100% RDF + BC_3	6.34	10.11	13.34
T_5: 75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP	6.56	10.56	14.00
T_6: 75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP	6.56	10.56	13.89
T_7: 75% RDF + BC_3 + 25% Simarouba seed cake on N basis + SSP	6.34	10.11	13.67
T_8: 50% RDF + BC_1 + 50% Simarouba seed cake on N basis + SSP	6.34	10.11	13.34
T_9: 50% RDF + BC_2 + 50% Simarouba seed cake on N basis + SSP	6.34	9.89	13.34
T_{10}: 50% RDF + BC_3 + 50% Simarouba seed cake on N basis + SSP	5.67	9.67	13.00
T_{11}: 25% RDF + BC_1 + 75% Simarouba seed cake on N basis + SSP	5.56	9.11	12.67
T_{12}: 25% RDF + BC_2 + 75% Simarouba seed cake on N basis + SSP	5.56	9.11	12.67
T_{13}: 25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP	6.56	8.89	12.45
S. Em±	0.31	0.11	0.12
C.D.@ 5%	NS	0.31	0.36
C.V (%)	2.69	3.17	2.61

Table 4: Influence of application of biochars produced at different temperatures on leaf area per plant of maize.

Treatment details	Leaf area per plant (cm^2)		
	30 DAS	60 DAS	90 DAS
T_1: Control (100% RDF without biochar)	1284	3512	4374
T_2: 100% RDF + BC_1	1383	4258	5316
T_3: 100% RDF + BC_2	1357	4133	5191
T_4: 100% RDF + BC_3	1345	4081	5135
T_5: 75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP	1395	4304	5361
T_6: 75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP	1371	4169	5230
T_7: 75% RDF + BC_3 + 25% Simarouba seed cake on N basis + SSP	1348	4118	5180
T_8: 50% RDF + BC_1 + 50% Simarouba seed cake on N basis + SSP	1328	4036	4903
T_9: 50% RDF + BC_2 + 50% Simarouba seed cake on N basis + SSP	1323	3886	4802
T_{10}: 50% RDF + BC_3 + 50% Simarouba seed cake on N basis + SSP	1309	3780	4645
T_{11}: 25% RDF + BC_1 + 75% Simarouba seed cake on N basis + SSP	1299	3659	4520
T_{12}: 25% RDF + BC_2 + 75% Simarouba seed cake on N basis + SSP	1297	3649	4498
T_{13}: 25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP	1288	3533	4397
S. Em±	22.48	22.71	28.24
C.D.@ 5%	NS	66.02	82.10
C.V (%)	2.42	3.17	2.73

Total dry matter production per plant (g)

The total dry matter production per plant after harvest showed a significant difference among the treatments in which the T_5 showed higher value *i.e.*, 207.21 g (Table 5). This was on par with T_2 (205.27 g). While the lower value *i.e.*, 160.33 g was observed in T_1 which was on par with (156.45 g).

Studies have consistently demonstrated that the joint use of biochar, chemical fertilizers and organic manure results in improved nutrient retention and root development, resulting in increased nutrient uptake and plant growth (Dawar *et al.*, 2022; Badu *et al.*, 2019, Glaser *et al.*, 2015; and Partey *et al.*, 2014) [5, 1, 9, 18]. With increasing of pyrolysis temperature, plant nutrients in biochar become less available to plants (Tag *et al.*, 2016; Yuan *et. al.*, 2016; Zornoza *et al.*, 2016) [21, 22, 23]. Naeem *et al.* (2017) [16] reported that, higher nutrient concentrations in shoot and root of maize plants were observed with the wheat straw biochar produced at lower temperature compared to biochar produced at higher temperatures. This may be due to decrease in ion exchange functional groups with increase in pyrolysis temperature due to dehydration and decarboxylation (Glaser *et al.* 2002) [8]. So, the biochars produced at lower pyrolysis temperature can effectively improve crop growth and yield, when compared to biochars produced at higher temperatures.

Table 5: Influence of application of biochars produced at different temperatures on total dry matter production per plant of maize

Treatment details	Total dry matter production per plant (g)
T_1: Control (100% RDF without biochar)	156.45
T_2: 100% RDF + BC_1	205.27
T_3: 100% RDF + BC_2	198.63
T_4: 100% RDF + BC_3	192.57
T_5: 75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP	207.21
T_6: 75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP	201.25
T_7: 75% RDF + BC_3 + 25% Simarouba seed cake on N basis + SSP	196.36
T_8: 50% RDF + BC_1 + 50% Simarouba seed cake on N basis + SSP	178.42
T_9: 50% RDF + BC_2 + 50% Simarouba seed cake on N basis + SSP	175.31
T_{10}: 50% RDF + BC_3 + 50% Simarouba seed cake on N basis + SSP	170.97
T_{11}: 25% RDF + BC_1 + 75% Simarouba seed cake on N basis + SSP	165.22
T_{12}: 25% RDF + BC_2 + 75% Simarouba seed cake on N basis + SSP	163.93
T_{13}: 25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP	158.61
S. Em±	1.06
C.D.@ 5%	3.07
C.V (%)	2.02

Nitrogen is very essential for chlorophyll synthesis in leaves, which helps in more photosynthesis and production of dry matter. Initial requirement of N was met from the inorganic source and subsequent requirement of N from organic source assuring continuous N supply throughout different growth stage favouring increase in growth parameters. Maurya *et al.* (2022) [14], reported that maximum plant height and leaf area in wheat was observed with the treatment receiving, 75 per cent RDF and 25 per cent poultry manure. Similarly, Mishra *et al.* (2020) [15], observed that, application of 75 per cent RDF and 25 per cent neem oil cake on N basis showed maximum plant height, number of leaves and leaf area in okra ultimately increasing overall dry matter production. Furthermore, Paikara and Pandey (2018) [17] observed that, at 60 and 90 DAS, significantly superior leaf area index and crop growth rate of maize was noted in treatment receiving 75 per cent N through RDF and 25 per cent N through vermicompost ultimately producing higher dry matter production.

b) Effect of application of biochars produced at different temperatures on yield parameters of maize

Number of cobs per plant

All the treatments showed one cob per plant irrespective of the application of biochars produced at different temperatures with integrated application of RDF and Simarouba seed cake in different proportions.

Cob length

A significant difference in the cob length of maize was observed among various treatments (Table 6). Longer cobs were observed in T_5 (16.93 cm), it was on par with T_2 (16.71 cm). While, the shorter cobs were found in $T_1$and T_{13} (14.19 cm).

Cob girth

Effect of varied temperature biochars with integrated application of RDF and Simarouba seed cake in different proportions on cob girth of maize was studied and a significant difference was observed in cob girth between the different treatments (Table 6). The maximum cob girth was exhibited by T_5 (12.78 cm), it was on par with T_2 (12.68 cm). The minimum cob girth was found in T_1(11.40 cm).

Number of rows per cob

There was no significant difference in number of rows per cob of maize among the treatments.

Number of seeds per cob

The number of seeds per cob exhibited significant variations among the treatments (Table 6). T_5 exhibited the maximum value among all treatments (474.90), was on par with T_2 (471.90). While, the minimum number of seeds per cob were found in T_1 (379.79).

Test weight of kernels

The weight of 100 kernels showed a significant variation across the different treatments (Table 6). The T_5 showed the highest test weight for 100 kernels (24.03 g) which was on par with T_2 (24.00 g) and T_6 (23.85 g). Lowest value for test weight of 100 kernels weight was found in T_1 (22.95 g).

Grain yield per plant (g)

The grain yield per plant exhibited a noticeable variation across the different treatments (Table 6). The highest value was observed in T_5 (114.09 g) which was on par with T_2 (113.23 g). While the T_1 showed lowest grain yield per plant (87.15 g).

Though determining grain yield per hectare using grain yield per plant data obtained from a pot experiment may not precisely reflect real field conditions, conversions were employed to gain insights into grain yield per unit area under experimental conditions

Table 6: Influence of application of biochars produced at different temperature on yield parameters of maize per plant

Treatments	Cob length (cm)	Cob girth (cm)	No. of rows per cob	No. of seeds per cob	100 kernels weight (g)	Grain yield per plant (g)
T_1: Control (100% RDF without biochar)	14.19	11.40	12.00	379.79	22.95	87.15
T_2: 100%RDF+ BC_1	16.71	12.68	14.00	471.90	24.00	113.23
T_3: 100% RDF + BC_2	16.53	12.48	14.00	460.12	23.62	108.66
T_4: 100% RDF + BC_3	16.03	12.24	13.33	438.56	23.42	102.69
T_5: 75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP	16.93	12.78	14.00	474.90	24.03	114.09
T_6: 75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP	16.55	12.53	14.00	461.56	23.85	110.09
T_7: 75% RDF + BC_3 + 25% Simarouba seed cake on N basis + SSP	16.15	12.44	14.00	453.67	23.54	106.78
T_8: 50% RDF + BC_1 + 50% Simarouba seed cake on N basis + SSP	15.25	11.91	13.33	418.45	23.25	97.28
T_9: 50% RDF + BC_2 + 50% Simarouba seed cake on N basis + SSP	15.05	11.81	13.33	416.01	23.24	96.67
T_{10}: 50% RDF + BC_3 + 50% Simarouba seed cake on N basis + SSP	14.95	11.75	12.67	408.45	23.22	94.82
T_{11}: 25% RDF + BC_1 + 75% Simarouba seed cake on N basis + SSP	14.64	11.64	12.67	395.01	23.04	91.00
T_{12}:25% RDF + BC_2 + 75% Simarouba seed cake on N basis + SSP	14.64	11.63	12.67	393.01	23.04	90.54
T_{13}: 25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP	14.19	11.45	12.00	381.56	23.01	87.78
S. Em±	0.09	0.07	0.45	1.68	0.13	0.60
C.D @5%	0.26	0.21	NS	4.89	0.38	1.74
C.V (%)	2.24	1.61	3.26	2.84	2.16	2.38

Grain yield per hectare

As there was a significant difference in grain yield per plant (Table 11) within given treatments, ultimately it showed a significant difference in the data of grain yield per hectare (Table 7). The higher value for grain yield per hectare was found in T_5(6339 kg ha^{-1}) which was on par with T_2 (6291 kg ha^{-1}). While the lower grain yield per hectare was found in T_1 *i.e.*, control, receiving only 100 per cent RDF (4842 kg ha^{-1}).

Stover yield per hectare

A notable variation was observed in the maize stover yield per hectare when using different temperature biochars in combination with various proportions of RDF and Simarouba seed cake application (Table 7). The higher stover yield was observed in T_5 (7762 kg ha^{-1}) which was on par with T_2 (7714 kg ha^{-1}). While, the lower stover yield was shown by T_1 (6265 kg ha^{-1}).

In the present study, significantly higher values of yield parameters such as cob length, cob girth, number of seeds per cob, test weight of 100 kernels, grain yield per plant, grain yield per hectare and stover yield per hectare were observed in treatment receiving, 75 per cent RDF + BC_1 + 25 per cent Simarouba seed cake on N basis + SSP (T_5). Studies have shown that the use efficiency of inorganic fertilizer and organic inputs was enhanced when applied with biochar (Glaser *et. al.*, 2015; Partey *et al.*, 2014) [9, 18] due to its higher porosity, water holding capacity and higher CEC. Dawar *et al.* (2022) [5] showed that treatment with combined application vermicompost, biochar and chemical fertilizers performed significantly better for improvement in maize plant height, 1000 grains weight, biological yield and grains yield compared to treatment receiving only chemical fertilizers and control. With increasing of pyrolysis temperature, plant nutrients in biochar become less available to plants (Tag *et al.*, 2016) [21], so the biochars produced at lower pyrolysis temperature effectively improve crop growth and yield, when compared to biochars produced at higher temperatures.

Enhanced yield parameters in T_5can also be attributed to continuous nutrient supply to plants throughout different growth stage (Initially from inorganic and subsequently from organic amendments) favouring increased growth parameters like leaf count and leaf area per plant that ultimately enhanced photosynthesis rate resulting in increase in the yield parameters of the crop (Mishra *et al.*, 2020; Paikara and Pandey, 2018) [15, 17]. Sowjanya *et al.* (2022) [20], reported that 75 per cent RDF N through inorganic fertilizer and 25 per cent equivalent N through poultry manure recorded higher cob length, cob girth, no. of grains per cob, and green cob yield in sweet corn.

Table 7: Effect of application of different temperature biochars on grain yield and stover yield of maize per hectare

Treatments	Grain yield per hectare (kg)	Stover yield per hectare (kg)
T_1: Control (100% RDF without Biochar)	4842	6265
T_2: 100%RDF+ BC_1	6291	7714
T_3: 100% RDF + BC_2	6037	7460
T_4: 100% RDF + BC_3	5705	7129
T_5: 75% RDF + BC_1 + 25% Simarouba seed cake on N basis + SSP	6339	7762
T_6: 75% RDF + BC_2 + 25% Simarouba seed cake on N basis + SSP	6117	7540
T_7: 75% RDF + BC_3 + 25% Simarouba seed cake on N basis + SSP	5933	7356
T_8: 50% RDF + BC_1 + 50% Simarouba seed cake on N basis + SSP	5405	6828
T_9: 50% RDF + BC_2 + 50% Simarouba seed cake on N basis + SSP	5371	6794
T_{10}: 50% RDF + BC_3 + 50% Simarouba seed cake on N basis + SSP	5268	6691
T_{11}: 25% RDF + BC_1 + 75% Simarouba seed cake on N basis + SSP	5056	6479
T_{12}:25% RDF + BC_2 + 75% Simarouba seed cake on N basis + SSP	5030	6454
T_{13}: 25% RDF + BC_3 + 75% Simarouba seed cake on N basis + SSP	4877	6300
S. Em±	33.31	33.38
C.D @5%	96.83	97.02
C.V (%)	2.58	2.83

In the present study, T_5 showed 30.92 per cent higher grain yield per hectare when compared to control (T_1) *i.e.*, 100 per cent RDF without biochar. Therefore, integrated application of biochar produced at 300 °C, combined with 75 per cent RDF, and 25 per cent Simarouba seed cakecan help to reduce application of chemical fertilizers by 25 per cent and increase the grain yield by around 30 per cent per hectare of maize crop.

Conclusion

From the experimental results, the study concludes that, there were significant variations in the growth and yield parameters of maize crop due to application of biochars produced from Simarouba seed coat at different temperatures. Among different treatments employed, integrated application of biochar produced at 300 °C, combined with 75 per cent RDF, and 25 per cent Simarouba seed cake (T_5), was found most efficacious. The treatment exhibited notable enhancement in plant height, number of leaves, leaf area and overall dry matter per plant, ultimately resulting in improved yield parameters like cob length, cob girth, number of seeds per cob, test weight of kernels, grain yield and stover yield of the crop. The results of T_5 were on par with $T_2$where biochar produced at 300 °C and 100 per cent RDF was applied. Therefore, T_5has been considered as best treatment which can help to reduce use of chemical fertilizers by 25 per cent and increase the grain yield by around 30 per cent per hectare of maize crop.

References

1. Badu E, Kaba JS, Abunyewa AA, Dawoe EK, Agbenyega O, Barnes RV. Biochar and inorganic nitrogen fertilizer effects on maize (*Zea mays* L.) nitrogen use and yield in moist semi-deciduous forest zone of Ghana. J Plant Nutr. 2019;42(19):2407-22.
2. Bai SH, Omidvar N, Gallart M, Kämper W, Tahmasbian I, Farrar MB, *et al*. Combined effects of biochar and fertilizer applications on yield: A review and meta-analysis. Sci Total Environ. 2022;808:152073.
3. Coomes OT, Miltner BC. Indigenous charcoal and biochar production: potential for soil improvement under shifting cultivation systems. Land Degrad Dev. 2017;28(3):811-21.
4. Dash AK, Pradhan RC, Das LM, Naik SN. Some physical properties of simarouba fruit and kernel. Int Agrophys. 2008;22(1):111-6.
5. Dawar K, Khan A, Mian IA, Khan B, Ali S, Ahmad S, *et al*. Maize productivity and soil nutrients variations by the application of vermicompost and biochar. PLoS One. 2022;17(5):e0267483.
6. Ding Y, Liu Y, Liu S, Li Z, Tan X, Huang X, *et al*. Biochar to improve soil fertility. A review. Agron Sustain Dev. 2016;36:1-18.
7. Gisladottir G, Stocking M. Land degradation control and its global environmental benefits. Land Degrad Dev. 2005;16(2):99-112.
8. Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal–a review. Biol Fertil Soils. 2002;35:219-30.
9. Glaser B, Wiedner K, Seelig S, Schmidt HP, Gerber H. Biochar organic fertilizers from natural resources as substitute for mineral fertilizers. Agron Sust Dev. 2015;35:667-78.
10. Jindo K, Mizumoto H, Sawada Y, Sanchez Monedero MA, Sonoki T. Physical and chemical characterization of biochars derived from different agricultural residues. Biosci. 2014;11(23):6613-21.
11. Joshi S, Hiremath S. Simarouba, oil tree. University of Agricultural Science, Bangalore and National Oil Seeds and Vegetable Oils Development Board, Gurgaon, India; 2001.
12. Laird DA, Fleming P, Davis DD, Horton R, Wang B, Karlen DL. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. Geoderma. 2010;158(3-4):443-9.
13. Lal R. Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. Land Degrad Dev. 2006;17(2):197-209.
14. Maurya NK, Singh NB, Kumar K, Kumar P, Kanaujia PR, Yadav P. Influence of organic farming packages on growth, yield attributes and yield of wheat (*Triticum aestivum* L.). Pharma Innov J. 2022;11(2):1155-9.
15. Mishra B, Sahu GS, Tripathy P, Mohanty S, Pradhan B. Impact of organic and inorganic fertilizers on growth, yield, nutrient uptake, and soil fertility in okra (*Abelmoschus esculentus* L. Moench) cv. Pusa A-4. Pharma Innov J. 2020;9(7):210-3.
16. Naeem MA, Khalid M, Aon M, Abbas G, Tahir M, Amjad M, *et al*. Effect of wheat and rice straw biochar produced at different temperatures on maize growth and nutrient dynamics of a calcareous soil. Arch Agron Soil Sci. 2017;63(14):2048-61.
17. Paikara BS, Pandey TD. To study the effect of integrated nutrient management on leaf area index (LAI) and crop

growth rate (CGR) of summer maize (*Zea mays* L.) in Chhattisgarh plains. J Pharmacogn Phytochem. 2018;7(2):2735-7.
18. Partey ST, Preziosi RF, Robson GD. Short-term interactive effects of biochar, green manure, and inorganic fertilizer on soil properties and agronomic characteristics of maize. Agric Res. 2014;3:128-36.
19. Qian L, Chen L, Joseph S, Pan G, Li L, Zheng J, *et al*. Biochar compound fertilizer as an option to reach high productivity but low carbon intensity in rice agriculture of China. Carbon Manag. 2014;5(2):145-54.
20. Sowjanya P, Rao PJ, Yamini S, Seetharamu P, Kumar MS. Conjunctive use of organic and inorganic sources of nitrogen on yield and yield attributes of sweet Corn (*Zea mays*). Andhra Agric J. 2022;69(4):568-72.
21. Tag AT, Duman G, Ucar S, Yanik J. Effects of feedstock type and pyrolysis temperature on potential applications of biochar. JAAP. 2016;120:200-6.
22. Yuan H, Lu T, Wang Y, Chen Y, Lei T. Sewage sludge biochar: Nutrient composition and its effect on the leaching of soil nutrients. Geoderma. 2016;267:17-23.
23. Zornoza R, Moreno-Barriga F, Acosta JA, Munoz MA, Faz A. Stability, nutrient availability, and hydrophobicity of biochars derived from manure, crop residues, and municipal solid waste for their use as soil amendments. Chemosphere. 2016;144:122-30.