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Residual effect of Biochars and their feedstock on growth and yield of Green gram in Acid soils

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Abstract
This paper evaluates the comparative residual effect of four types of biochar as well as their feedstocks (biomass material) in presence of 50% recommended dose of fertilizers (RDF) on growth and yield of green gram in acid soils. Soil was treated with four types of biochar and their feedstocks at different doses viz. 0, 2.25, and 4.50 g kg^{-1} of soil before filling the pots. The mustard was grown as a direct crop (data is not given) and green gram taken as residual crop after harvesting of mustard in same pots with recommended agronomic practices. Biochar application significantly increased the growth and yield of green gram compared with only 50% RDF. Biochar application at the rate of 4.50 g kg^{-1} along with 50% RDF showed similar results compared with only 75% RDF treatment, but lower than 100% RDF treatments. *Lantana* biochar (LB) and *Parthenium* biochar (PB) treatments showed significantly higher growth and yield compared with sugarcane bagasse biochar (SBB) and rice husk biochar (RHB) at both application rates. In general, residual effect of biochar on growth and yield of green gram was at par when compared with their feedstocks at similar application rates. However, growth and yield were obtained with *Parthenium* biochar, were significantly superior over their feedstock at similar rate of application.

Keywords: Biochar, Feedstocks, Growth, Yield, Green gram

1. Introduction

After onset of green revolution (1965-66), there has been significant increase in food production due to intensive farming and imbalance use of agrochemicals. On the other hand, this intensification of agricultural production systems has led to decline of soil quality in several cases. Soil quality plays an important role in regulation of crop productivity and thus is one of the key indicators of sustainability of any cropping system. Deterioration of soil quality is mainly due to nutrient depletion, nutrient mining, acidification, loss of soil organic matter and increase in toxic elements. The biological activities in soil which play major role in availability and recycling of nutrient also decline due to decrease in organic matter content. The decreased level of organic matter is responsible for reduction in soil fertility. Soil organic matter improves the physico-chemical and biological properties of soil and helps in conservation of soil surface from erosion and also acts as a reservoir of plant nutrients. In tropical conditions, the rapid decomposition of soil organic matter makes it difficult to maintained optimum level of soil organic matter. Further, soil cultivation also decreased organic matter content due to increased decomposition rates by the prevailing agricultural practices. One of the main reasons for stagnation in yield is the reduction in quality and quantity of soil organic matter (Yadav *et al.*, 2000) [1]. It is important to maintain a threshold level of soil organic matter for maintaining soil quality and sustaining agricultural productivity.

In this context, application of biochar is good options for maintaining the soil quality as well as crop productivity. Biochar is a carbon rich solid substance, prepared by pyrolysis of biomass under controlled conditions, having potential to be used for soil health enhancement as well as long term soil carbon sequestration by storing atmospheric carbon (Srinivasarao *et al.*, 2013) [2]. Biochar have condensed aromatic structure which make its resistant against decomposition and store carbon in soils for long time, and can be an appropriate approach to increase carbon in the soil (Lehmann and Rondon, 2006) [3]. The impact of biochar application on crop yield and soil health has been observed to be different, but is generally positive. Most of the of the research trials were carried out in degraded soils, low fertility soils (including acidic tropical soils) and in general, improvement in crop yield was reported, when such type of soil was treated with biochar (Van zwieten *et al.*, 2010) [4].

Green gram is an important pulse crop in India and assumed to be originated from India. It is short duration crop and is simply incorporated into any cropping system.

Green gram increases nitrogen content in soils. India contributes more than 70 per cent of world's green gram production. India has first rank in the production as well as in consumption of green gram in the world (www.commoditiescontrol.com/eagritrader/staticpages/index.php?id=89). Hence, this study was conducted to investigate the residual effect of biochars and their feedstock on growth and yield of green gram in acid soils.

2 Material and methods

2.1 Experimental site

The pot experiment was conducted in the glass house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India. Varanasi is situated between 25.14° and 25.23°N latitude and 82.56° and 83.03°E longitude and comes under semi-arid to sub humid climate. Table 1 shows the chemical properties of soil before the experiment.

2.2 Experimental detail

To conduct pot experiment, acid soil was collected from Naugarh, Chandauli, India and pots were filled with 10 kg of air-dried soil. Experiment was conducted in randomized complete block design using twenty treatments with three replications. Treatments comprising different dose of fertilizers, different quantity and types of biochars and their feedstock's in different combinations. Biochars and their feedstock's were applied to mustard crop before 25 days of mustard sowing (05 November, 2014) and green gram was taken (from 25 March, 2015-19 May, 2015) as residual crop after harvesting of mustard (Data is not given). Initially the soil samples was air dried and passed through 2 mm sieve. All the biochar and their feedstocks were added to the pots in three ratios i.e. 0, 2.25 g kg^{-1} and 4.50 g kg^{-1} of soil. The powdered biochar and their feedstocks were applied and mixed with the soil before filling the pots. Fertilizers were applied at the rate of 0%, 50%, 75% and 100% of recommended dose (100% RDF means 45:30:20:20 mg kg^{-1} corresponding to 90: 60: 40: 40: kg ha^{-1} of N, P_2O_5, K_2O & S, respectively in case of mustard). In green gram, biochar and feedstocks were not applied, only nitrogen and phosphorus was applied in each pot as a starter dose (100% RDF means 10:25:0 mg kg^{-1} corresponding to 20, 50, and 0 kg ha^{-1} of N, P_2O_5 & K_2O, respectively).

2.3 Preparation of biochars

Biochar was prepared from different types of feedstock viz. sugarcane bagasse, rice husk, *Parthenium* and *Lantana*. All the feedstocks were air dried and *Parthenium* and *Lantana* were cut to small pieces (30-50 mm). Sugarcane bagasse and rice husk were used as such. All the feedstocks were heated at a temperature of around 400 ˚C for 2h in a cylindrical pyrolysis kiln.

2.4 Soil analysis

Soil pH and EC were determined in 1:2.5 soils to water suspension. Cation-exchange capacity was determined using sodium acetate solution (pH 8.2) with the help of centrifuge as described by Jackson (1973) [5]; Available N (0.32% alkaline KMnO4 oxidizable N) was determined by Subbiah and Asija (1956) method and soil available P (0.03 N NH_4F in 0.025 N HCl) as described by Bray & Kurtz (1945) [7]. Available K (1 N neutral NH_4OAc extractable) was estimated by the method of Hanway and Heidel (1952) [8]. Organic carbon was determined by Walkley and Black (1934) [9] method.

2.5 Statistical Analysis

Statistical analysis was done by the analysis of variance (ANOVA, RCBD) and comparison among the treatments was done by using Duncan's Multiple Range Test (at P=0.05) using pdglm800.sas (SAS software package), which can be accessed from server of IASRI, New Delhi, India (http://animalscience.ag.utk.edu/FacultyStaff/ArnoldSaxton.html #software).

3 Results and discussions

3.1 Growth attributes of green gram

3.1.1 Plant height

Data related to the plant height at 20, 40 DAS and at harvesting of green gram as affected by chemical fertilizers, different types and quantity of biochar as well as their feedstock are presented in table 2. Increasing dose of fertilizers from 0% RDF (T_1) to 100% RDF (T_4) significantly increased height of green gram at 20, 40 DAS and at harvesting. Application of all the biochar (T_5-T_{12}) @ 2.25 g kg^{-1} and 4.50 g kg^{-1} of soil have resulted significantly higher plant height over 50% RDF (T_2). However, application of SBB (T_5) and RHB (T_6) at lower rates (2.25 g kg^{-1} of soil) showed comparable value of plant height as obtained with 50% RDF. Plant height obtained with application of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} soil were comparable as recorded with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). LB and PB addition showed significantly higher value of plant height over SBB and RHB at similar application rates. Height of green gram obtained from LB and PB was statistically at par with each other at similar application rates, while SBB and RHB also have comparable results with each other at similar application rates. Application of feedstock (T_{13}-T_{16}) @ 2.25 g kg^{-1} soil showed statistically similar plant height as obtained with 50% RDF. But, feedstock addition (T_{17}-T_{20}) @ 4.50 g kg^{-1} soil significantly increased plant height over 50% RDF. Furthermore, feedstock (T_{17}-T_{20}) application at higher dose (4.50 g kg^{-1} of soil) showed statistically similar height of green gram as obtained with 75% RDF, except PF treatment (T_{19}) which showed significantly lower value than 75% RDF. Application of all types of biochar at higher dose gave significantly higher value of plant height over their lower dose. Application of feedstock (T_{17}-T_{20}) at higher dose (4.50 g kg^{-1} soil) also gave significantly higher value of plant height when compared with their lower dose (2.25 g kg^{-1} of soil). Biochar treatments (T_5-T_{12}) showed comparable results with their respective feedstock (T_{13}-T_{20}) at low as well as at higher application rates. However, PB treated soils @ 2.25 g kg^{-1} and 4.50 g kg^{-1} of soil, showed significantly higher value of plant height when compared with its feedstock at similar rates. LF (T_{20}) application at higher dose (4.50 g kg^{-1} soil) has resulted significantly higher plant height when compared with PF (T_{19}) application at similar dose. Addition of biochar increased plant height might be due to reduced aluminum toxicity to green gram roots, therefore nutrients acquisition improved. Biochar application significantly increased microbial activity in soil, these improved microbial activity could be improved N-fixation in green gram. Jha *et al*. (2016) [10] also reported that addition of biochar improved nitrification process in acidic soils.

3.1.2 Number of trifoliate leaves

Data pertaining to the number of trifoliate leaves of green gram at 20, 40 DAS and at harvesting of green gram are presented in table 2. Increasing dose of fertilizers from 0%

RDF (T_1) to 100% RDF (T_4) significantly increased number of trifoliate leaves in green gram at 20, 40 DAS and at harvesting. Biochar amended soil (T_5-T_{12}) at low as well as at higher application rates, have resulted significantly higher number of trifoliate leaves over 50% RDF (T_2). However application of SBB (T_5) and RHB (T_6) at lower rates (2.25 g kg^{-1} soil) showed statistically similar number of trifoliate leaves as recorded with 50% RDF. Number of trifoliate leaves obtained with applications of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} soil were comparable with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). LB and PB treated soils showed significantly higher number of trifoliate leaves over SBB and RHB treated soils at similar application rates. Number of trifoliate leaves in green gram obtained from LB and PB treated soils was comparable with each other at similar application rates, while SBB and RHB treatments also have statistically similar results with each other at similar rate of application. Application of feedstock (T_{13}-T_{16}) @ 2.25 g kg^{-1} of soil, showed statistically similar number of trifoliate leaves as obtained with 50% RDF. But, feedstock addition (T_{17}-T_{20}) @ 4.50 g kg^{-1} soil significantly increased number of trifoliate leaves over 50% RDF. Furthermore, feedstock (T_{17}-T_{20}) application at higher dose (4.50 g kg^{-1} of soil) showed statistically similar number of trifoliate leaves in green gram as obtained with 75% RDF, except PF treatments (T_{19}) which were significantly lower than 75% RDF. Application of biochar at higher dose gave significantly higher number of trifoliate leaves than their lower dose. Feedstock addition at higher dose (4.50 g kg^{-1} soil) showed significantly higher number of trifoliate leaves than their application at lower dose (2.25 g kg^{-1} soil). Application of LF (T_{20}) at higher dose gave significantly higher number of trifoliate leaves when compared with PF (T_{19}) at similar dose.

3.1.3 Number of primary branches

Data related to number of primary branches of green gram at 40 DAS and at harvest of green gram are presented in table 3. Increasing dose of fertilizers from 0% RDF (T_1) to 100% RDF (T_4) significantly increased number of primary branches in green gram at 40 DAS and at harvesting. Application of biochar (T_5-T_{12}) at low as well as at higher rates showed significantly higher number of primary branches over 50% RDF (T_2). However, application of SBB (T_5) and RHB (T_6) at lower rates (2.25 g kg^{-1} soil) showed comparable results as recorded with 50% RDF. Application of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} soil showed statistically similar number of primary branches as obtained with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). LF application (T_{20}) @ 4.50 g kg^{-1} soil significantly increased number of primary branches over 50% RDF and have comparable results with 75% RDF. Application of all types of biochar at higher dose gave significantly higher number of primary branches over their lower dose. Feedstock treated soil @ 4.50 g kg^{-1} soil gave significantly higher number of primary branches when compared with their application @ 2.25 g kg^{-1} soil. Biochar treatments (T_5-T_{12}) showed comparable result with their respective feedstock (T_{13}-T_{20}) at low as well as at higher application rates. However, application of PB gave significantly higher number of primary branches when compared with its feedstock at both application rates. Application of LF at higher dose (4.50 g kg^{-1} soil) showed significantly higher number of primary branches when compared with PF (T_{19}) application at similar rates.

3.1.4 Number of secondary branches

Data related to the number of secondary branches at 40 DAS and at harvest of green gram showed in table 3. Increasing dose of fertilizers from 0% RDF (T_1) to 100% RDF (T_4) significantly increased number of secondary branches in green gram at 40 DAS and at harvesting. Biochar treatments (T_5-T_{12}) have resulted significantly higher number of secondary branches over 50% RDF (T_2). However, application of SBB (T_5) and RHB (T_6) at lower rates showed comparable results as obtained with 50% RDF. Applications of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} soil showed statistically similar number of secondary branches as obtained with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). LB and PB amended soils showed significantly greater number of secondary branches over SBB and RHB amended soils at similar application rates. Number of secondary branches in green gram obtained from LB and PB treatments was statistically at par with each other at similar application rates, while SBB and RHB treatments also have comparable results with each other. Application of feedstock (T_{13}-T_{16}) @ 2.25 g kg^{-1} of soil showed statistically similar number of secondary branches as obtained with 50% RDF. But, feedstock addition (T_{17}-T_{20}) @ 4.50 g kg^{-1} soil significantly increased number of secondary branches over 50% RDF. Application of biochar at higher dose (4.50 g kg^{-1} soil) gave significantly higher number of secondary branches over their lower dose (2.25 g kg^{-1} soil). Application of feedstock (T_{17}-T_{20}) at higher dose gave significantly higher number of secondary branches when compared with their lower dose (T_{13}-T_{16}). Biochar treatments (T_5-T_{12}) showed comparable results with their respective feedstock (T_{13}-T_{20}) at low as well as at higher application rates. However, application of PB showed significantly higher number of secondary branches when compared with its feedstock at similar rates. LF (T_{20}) application at higher dose showed significantly higher number of secondary branches when compared with PF (T_{19}) application at similar rates.

3.2 Yield attributes of green gram

3.2.1 Number of seed per pod

The data contained in table 4 pertaining to the number of seed per pod of green gram showed that significant variations occurred due to application of fertilizers, different types of biochar as well as their feedstocks. As expected, increasing dose of fertilizers from 0% RDF (T_1) to 100% RDF (T_4) significantly increased number of seed per pod in green gram. Applications of all the biochar (T_5-T_{12}) have resulted significantly higher number of seed per pod over 50% RDF (T_2). However, application of SBB (T_5) and RHB (T_6) at lower rates showed similar number of seed per pod as recorded with 50% RDF. The number of seed per pod recorded with applications of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} soil were comparable with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). Addition of LB and PB showed significantly higher number of seed per pod over addition of SBB and RHB at similar rates. Number of seed per pod in green gram obtained from LB and PB amended soil, was statistically at par with each other at similar application rates, while SBB and RHB amended soil also have comparable results with each other at similar application rates. Application of feedstock (T_{13}-T_{16}) showed statistically similar number of seed per pod as recorded with 50% RDF. But, feedstock addition (T_{17}-T_{20}) @ 4.50 g kg^{-1} soil significantly increased number of seed per pod over 50% RDF, except PF treatments which was comparable with 50% RDF. Application of all types of biochar at higher dose (4.50 g kg^{-1} soil) showed significantly higher number of seed per pod over their lower dose (2.25 g kg^{-1} of soil). Application of feedstock @ 4.50 g kg^{-1} soil also showed significantly higher number of seed per pod when compared with their lower dose. However, both the levels of PF had similar results. Application of LF (T_{20}) at higher dose has produced significantly higher number of seed per pod when compared with PF (T_{19}) at similar rates.

3.2.2 Number of pod per plant
Table 4 showed that number of pod per plant of green gram significantly varied due to application of fertilizers, different types of biochar as well as their feedstock. Increasing dose of fertilizers from 0% RDF (T_1) to 100% RDF (T_4) significantly increased number of pod per plant in green gram. Biochar treatments (T_5-T_{12}) have produced significantly higher number of pod per plant when compared to 50% RDF (T_2). However, application of SBB (T_5) and RHB (T_6) at lower rates (2.25 g kg^{-1} of soil) showed statistically similar number of pod per plant as recorded with 50% RDF. Applications of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} soil showed comparable results with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). LB and PB treated soil showed significantly higher number of pod per plant over SBB and RHB at similar application rates. Number of pod per plant in green gram obtained from LB and PB treated soils was comparable with each other at similar application rates, while SBB and RHB treated soil also have statistically similar results with each other. Application of SBF (T_{13}) and RHF (T_{14}) @ 2.25 g kg^{-1} soil, showed statistically similar number of pod per plant as obtained with 50% RDF. However, application of PF (T_{15}) and LF (T_{16}) caused significantly higher number of pod per plant over 50% RDF. Feedstock addition (T_{17}-T_{20}) @ 4.50 g kg^{-1} soil significantly increased number of pod per plant over 50% RDF. Application of all types of biochar at higher dose (4.50 g kg^{-1} soil) gave significantly higher number of pod per plant over their lower dose (2.25 g kg^{-1} soil). Feedstock amended soil @ 4.50 g kg^{-1} soil also showed significantly higher number of pod per plant when compared with its application at lower dose (2.25 g kg^{-1} soil). Biochar treatments (T_5-T_{12}) showed statistically similar number of pod per plant when compared with their respective feedstock (T_{13}-T_{20}) at similar rates. However, application of PB at low as well as at higher rates have resulted significantly higher number of pod per plant when compared with its feedstock at similar rates. Application of LF (T_{20}) at higher dose has resulted significantly higher number of pod per plant when compared with PF (T_{19}) at similar dose.

3.2.3 Pod length
Data related to pod length of green gram showed in table 4. Increasing dose of fertilizers from 0% RDF (T_1) to 100% RDF (T_4) significantly increased pod length in green gram. Applications of biochar (T_5-T_{12}) @ 2.25 g kg^{-1} and 4.50 g kg^{-1} soil showed significantly higher pod length over 50% RDF (T_2). However, application of SBB (T_5) and RHB (T_6) at lower rates showed comparable results as recorded with 50% RDF. The pod length were recorded with applications of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} of soil were comparable with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). LB and PB addition showed significantly higher pod length over SBB and RHB at similar application rates. Pod length in green gram obtained from LB and PB treatments was statistically at par with each other at similar application rates, while SBB and RHB treatments also have comparable results with each other at similar application rates. Application of feedstock (T_{13}-T_{16}) @ 2.25 g kg^{-1} soil showed statistically similar pod length as recorded with 50% RDF. But, application of feedstock (T_{17}-T_{20}) @ 4.50 g kg^{-1} soil significantly increased pod length over 50% RDF. Application of all types of biochar at higher dose (4.50 g kg^{-1} soil) gave significantly higher pod length than their lower dose (2.25 g kg^{-1} soil). Addition of feedstock at higher dose also showed significantly higher pod length when compared with their lower dose. Biochar treatments (T_5-T_{12}) showed comparable results with their respective feedstock (T_{13}-T_{20}) at low as well as at higher application rates. However application of PB at low as well as at higher rates have resulted significantly higher pod length compared with its feedstock (PF) at similar dose. Application of LF (T_{20}) at higher dose has resulted significantly higher pod length compared with PF (T_{19}) at similar rates.

3.3 Grain and straw yield
Table 5 showed that grain and straw yield of green gram varied significantly due to application of different treatments. As expected increasing doses of fertilizers from 0% RDF (T_1) to 100% RDF (T_4) significantly increased grain and straw yield of green gram. Applications of biochar (T_5-T_{12}) at low as well as at higher rates have produced significantly higher grain and straw yield of green gram when compared to 50% RDF (T_2). However, application of SBB (T_5) and RHB (T_6) at lower rates (2.25 g kg^{-1} soil) showed similar grain and straw yield as obtained with 50% RDF. The grain and straw yield obtained with applications of biochar (T_9-T_{12}) @ 4.50 g kg^{-1} soil were comparable with 75% RDF (T_3), but were significantly lower than 100% RDF (T_4). LB and PB addition have resulted significantly higher grain and straw yield over SBB and RHB at similar application rates. Among the biochar treatments, LB treated soils produced highest yield of green gram, while it was lowest in SBB treated soil. Grain and straw yield of green gram obtained from LB and PB treated soils was statistically at par with each other at similar application rates, while SBB and RHB treated soils showed comparable results with each other at similar application rates. In case of grain yield, addition of feedstock (T_{13}-T_{16}) @ 2.25 g kg^{-1} of soil have produced comparable results as obtained with 50% RDF, except LF treatments (T_{16}) which produced significantly higher value than 50% RDF. But feedstock applications (T_{17}-T_{20}) at higher dose, showed comparable grain yield as obtained with 75% RDF, except PF (T_{19}), which produced significantly lower value when compared with 75% RDF. In case of straw yield, application of feedstock (T_{13}-T_{16}) @ 2.25 g kg^{-1} soil showed statistically similar results as obtained with 50% RDF. While in case of higher dose (4.50 g kg^{-1} soil), feedstock (T_{17}-T_{20}) amended soil have resulted similar straw yield as obtained with 75% RDF. Application of biochar at higher dose (4.50 g kg^{-1} soil) has produced significantly higher grain yield as well as straw yield of green gram than their lower dose (2.25 g kg^{-1} soil). Application of feedstocks (T_{17}-T_{20}) @ 4.50 g kg^{-1} soil has produced significantly higher yield of green gram than their application (T_{13}-T_{16}) @ 2.25 g kg^{-1} soil. Biochar treatments (T_5-T_{12}) showed statistically similar results compared with their respective feedstock (T_{13}-T_{20}) at similar rates. However application of PB at low as well as at higher application rates have resulted significantly higher yield as obtained with its feedstock at similar rates. Highest grain and straw yield of green gram were obtained from 100% RDF treatments (T_4), followed by LB application

@ 4.50 g kg^{-1} soil along with 50% RDF (T_{12}).

The effects of biochar application are seen more clearly in highly degraded acidic or nutrient depleted soils. Crop yields, particularly on tropical soils can be increased if biochar is applied in combination with inorganic or organic fertilizers (Schmidt and Noack, 2000; Woolf, 2008) [12, 13]. Combined application of rice husk biochar @ 3.6 g kg^{-1} soil along with plant growth promoting rhizobacteria significantly increased the rice yield (Singh *et al*., 2016) [11]. Oguntunde *et al*. (2004) [14] reported that grain and biomass yield of maize increased by 91% and 44%, respectively on charcoal site soils compared to adjacent field soils. Application of biochar along with inorganic fertilizer made it possible to increase crop productivity; therefore it generates extra incomes, and decreasing the magnitude of inorganic fertilizer use and importation (De Gryze *et al*., 2010; Quayle, 2010) [15, 16].

3.4 Harvest index and seed index

Data pertaining to harvest index and seed index of green gram have been presented in table 5. All the doses of fertilizers (T_2-T_4) were significantly increased harvest index over 0% RDF. Application of 100% RDF have resulted higher value of harvest index over 50% RDF, but were similar as obtained with 75% RDF. Application of all the biochar and feedstock (T_5-T_{20}) showed comparable value of harvest index as obtained with 75% RDF. In case of seed index of green gram, 0% fertilizer only treatments (T_1) have significant lower value of seed index when compared with other treatments (T_2-T_{20}). Except 0% RDF, all other treatments showed comparable value of seed index with each other.

4 Conclusions

Application of biochar significantly improved growth and yield of green gram. Biochar can help in reducing chemical fertilizer requirement to some extent depending upon their characteristics. Effects were varied from biochar to biochar on growth as well as on yields. Feedstock showed statistically similar growth and yield of green gram when compared with their biochar. Therefore, yield benefit in acid soil due to application of biochar and feedstocks should be carefully monitored under field experiments.

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Table 1: Physicochemical properties of initial soil used for pot experiments

Parameters	Value
Soil Texture	Sandy clay loam
Soil pH (1:2.5)	5.5
Electrical conductivity (dS m^{-1}) (1:2.5)	0.030
CEC (cmol (p^+) kg^{-1})	08.83
Organic carbon (%)	0.50
Available N (kg ha^{-1})	147.2
Available P (kg ha^{-1})	17.5
Available K (kg ha^{-1})	121.5
Available S (mg kg^{-1})	9.8

Table 2: Effect of different biochar and their feedstocks on plant height and number of trifoliate leaves of green gram

Treat-ments No.	Treatments details	Plant height at 20 DAS	Plant height at 40 DAS	Plant height at harvest	Number of trifoliate leaves at 20 DAS	Number of trifoliate leaves at 40 DAS	Number of trifoliate leaves at harvest
T_1	0% RDF	15.0±0.60^{h}	32.3±0.82^{g}	34.5±0.77^{g}	3.17±0.29^{f}	6.00±0.50^{h}	4.33±0.58^{h}
T_2	50% RDF	20.0±0.78^{g}	37.1±0.74^{f}	39.3±0.75^{f}	5.00±0.25^{e}	7.83±0.14^{g}	6.33±0.14^{g}
T_3	75% RDF	22.7±0.53^{bc}	39.9±0.54^{bc}	42.1±0.49^{bc}	6.25±0.25^{bc}	9.17±0.14^{bc}	7.58±0.14^{bc}
T_4	100% RDF	24.5±0.66^{a}	41.6±0.62^{a}	43.8±0.59^{a}	7.17±0.14^{a}	10.08±0.14^{a}	8.50±0.25^{a}
T_5	SBB(2.25g kg^{-1} soil)+50% RDF	20.1±0.51^{g}	37.2±0.51^{f}	39.4±0.45^{f}	5.00±0.25^{e}	7.92±0.29^{g}	6.33±0.38^{g}
T_6	RHB (2.25 g kg^{-1} soil)+50% RDF	20.2±0.51^{g}	37.4±0.47^{f}	39.6±0.47^{f}	5.08±0.14^{e}	8.00±0.25^{g}	6.42±0.14^{g}
T_7	PB (2.25 g kg^{-1} soil) +50% RDF	21.3±0.55^{ef}	38.5±0.47^{de}	40.6±0.49^{de}	5.50±0.25^{d}	8.42±0.14^{ef}	6.92±0.14^{de}
T_8	LB(2.25 g kg^{-1} soil) +50% RDF	21.3±0.20^{def}	38.5±0.35^{de}	40.6±0.40^{de}	5.50±0.25^{d}	8.50±0.25^{de}	6.92±0.29^{de}
T_9	SBB(4.50 g kg^{-1} soil) +50% RDF	22.3±0.79^{c}	39.4±0.77^{c}	41.6±0.82^{c}	6.00±0.25^{c}	9.00±0.25^{c}	7.42±0.14^{c}
T_{10}	RHB(4.50 g kg^{-1} soil)+50% RDF	22.3±0.75^{c}	39.5±0.72^{c}	41.7±0.69^{c}	6.08±0.14^{c}	9.00±0.25^{c}	7.42±0.14^{c}
T_{11}	PB (4.50 g kg^{-1} soil) +50% RDF	23.4±0.38^{b}	40.5±0.40^{b}	42.7±0.36^{b}	6.58±0.29^{b}	9.42±0.14^{b}	7.83±0.29^{b}
T_{12}	LB (4.50 g kg^{-1} soil) +50% RDF	23.4±0.47^{b}	40.6±0.45^{b}	42.8±0.52^{b}	6.58±0.14^{b}	9.50±0.25^{b}	7.92±0.14^{b}
T_{13}	SBF (2.25 g kg^{-1} soil)+50% RDF	20.6±0.53^{fg}	37.7±0.49^{ef}	39.9±0.51^{ef}	5.00±0.25^{e}	7.92±0.29^{g}	6.33±0.14^{g}
T_{14}	RHF(2.25 g kg^{-1} soil) +50% RDF	20.7±0.40^{fg}	37.9±0.40^{ef}	40.1±0.35^{ef}	5.08±0.14^{e}	8.00±0.25^{g}	6.42±0.29^{g}
T_{15}	PF (2.25 g kg^{-1} soil) +50% RDF	20.2±0.40^{g}	37.3±0.37^{f}	39.5±0.40^{f}	4.92±0.38^{e}	7.83±0.29^{g}	6.25±0.25^{g}
T_{16}	LF (2.25 g kg^{-1} soil) +50% RDF	20.9±0.25^{fg}	38.0±0.81^{ef}	40.1±0.81^{ef}	5.17±0.38^{de}	8.08±0.29^{fg}	6.50±0.43^{fg}
T_{17}	SBF (4.50 g kg^{-1} soil) +50% RDF	22.1±0.49^{cde}	39.3±0.45^{cd}	41.5±0.47^{cd}	5.92±0.14^{c}	8.83±0.29^{cd}	7.25±0.25^{cd}
T_{18}	RHF(4.50 g kg^{-1} soil) +50% RDF	22.2±0.38^{cd}	39.4±0.57^{cd}	41.5±0.36^{cd}	5.92±0.14^{c}	8.83±0.14^{cd}	7.25±0.25^{cd}
T_{19}	PF (4.50 g kg^{-1} soil) +50% RDF	21.3±0.46^{def}	38.4±0.43^{de}	40.6±0.51^{de}	5.50±0.25^{d}	8.42±0.29^{ef}	6.83±0.14^{ef}
T_{20}	LF (4.50 g kg^{-1} soil) +50% RDF	22.8±0.50^{bc}	39.9±0.47^{bc}	42.1±0.44^{bc}	6.25±0.25^{bc}	9.17±0.29^{bc}	7.58±0.14^{bc}

Values (mean ± standard deviation) in each column followed by dissimilar lower case letters are significant according to Duncan's Multiple Range Test at P =0.05.

RDF=Recommended dose of fertilizers; SBB=Sugarcane bagasse biochar; RHB= Rice husk biochar; PB; *Parthenium* biochar; LB=*Lantana* biochar; SBF=Sugarcane bagasse feedstock; RHF= Rice husk feedstock; PF= *Parthenium* feedstock and LF= *Lantana* feedstock

Table 3: Effect of different biochar and their feedstocks on number of primary branches and secondary branches of green gram

Treatments No.	Treatments details	Number of primary branches at 40 DAS	Number of primary branches at harvest	Number of secondary branches at 40 DAS	Number of secondary branches at harvest
T_1	0% RDF	6.83±0.58^{g}	7.33±0.58^{g}	2.33±0.14^{i}	4.00±0.25^{h}
T_2	50% RDF	11.42±0.72^{de}	12.00±0.66^{de}	4.17±0.38^{h}	5.83±0.38^{g}
T_3	75% RDF	12.75±0.66^{bc}	13.25±0.66^{bc}	5.67±0.29^{bc}	7.33±0.38^{bc}
T_4	100% RDF	14.42±0.38^{a}	14.83±0.52^{a}	6.50±0.25^{a}	8.25±0.25^{a}
T_5	SBB(2.25 g kg^{-1} soil)+ 50% RDF	10.08±0.52^{f}	10.58±0.52^{f}	4.17±0.29^{h}	5.83±0.38^{g}
T_6	RHB (2.25 g kg^{-1} soil)+50% RDF	10.25±0.66^{f}	10.83±0.38^{f}	4.25±0.25^{h}	5.92±0.38^{g}
T_7	PB (2.25 g kg^{-1} soil) +50% RDF	11.33±0.58^{de}	11.83±0.58^{de}	4.75±0.25^{fg}	6.42±0.38^{ef}
T_8	LB(2.25 g kg^{-1} soil) +50% RDF	11.42±0.52^{de}	11.92±0.38^{de}	4.83±0.29^{efg}	6.58±0.29^{de}
T_9	SBB(4.50 g kg^{-1} soil) +50% RDF	12.42±0.80^{c}	13.00±0.66^{bc}	5.33±0.29^{cd}	7.08±0.29^{c}
T_{10}	RHB(4.50 g kg^{-1} soil)+50% RDF	12.33±0.63^{c}	13.08±0.72^{bc}	5.42±0.14^{cd}	7.17±0.14^{c}
T_{11}	PB (4.50 g kg^{-1} soil) +50% RDF	13.33±0.38^{b}	13.75±0.50^{b}	5.92±0.14^{b}	7.67±0.14^{b}
T_{12}	LB (4.50 g kg^{-1} soil) +50% RDF	13.42±0.38^{b}	13.83±0.52^{b}	6.00±0.25^{b}	7.75±0.25^{b}
T_{13}	SBF (2.25 g kg^{-1} soil)+50% RDF	10.67±0.52^{ef}	11.17±0.52^{ef}	4.17±0.29^{h}	5.92±0.29^{g}
T_{14}	RHF(2.25 g kg^{-1} soil) +50% RDF	10.83±0.52^{ef}	11.25±0.43^{ef}	4.25±0.25^{h}	6.00±0.25^{fg}
T_{15}	PF (2.25 g kg^{-1} soil) +50% RDF	10.33±0.38^{f}	10.67±0.38^{f}	4.08±0.38^{h}	5.83±0.29^{g}

T_{16}	LF (2.25 g kg^{-1} soil) +50% RDF	$10.83±0.76^{ef}$	$11.33±0.76^{ef}$	$4.50±0.25^{gh}$	$6.25±0.25^{efg}$
T_{17}	SBF (4.50 g kg^{-1} soil) +50% RDF	$12.17±0.52^{cd}$	$12.67±0.52^{cd}$	$5.17±0.29^{def}$	$7.00±0.25^{cd}$
T_{18}	RHF(4.50 g kg^{-1} soil) +50% RDF	$12.17±0.29^{cd}$	$12.75±0.66^{cd}$	$5.25±0.25^{cde}$	$7.00±0.25^{cd}$
T_{19}	PF (4.50 g kg^{-1} soil) +50% RDF	$11.42±0.38^{de}$	$11.83±0.52^{de}$	$4.83±0.14^{efg}$	$6.58±0.14^{de}$
T_{20}	LF (4.50 g kg^{-1} soil) +50% RDF	$12.83±0.38^{bc}$	$13.33±0.52^{bc}$	$5.58±0.38^{bcd}$	$7.33±0.29^{bc}$

Values (mean ± standard deviation) in each column followed by dissimilar lower case letters are significant according to Duncan's Multiple Range Test at P =0.05.
RDF=Recommended dose of fertilizers; SBB=Sugarcane bagasse biochar; RHB= Rice husk biochar; PB; *Parthenium* biochar; LB=*Lantana* biochar; SBF=Sugarcane bagasse feedstock; RHF= Rice husk feedstock; PF= *Parthenium* feedstock and LF= *Lantana* feedstock

Table 4 Effect of different biochar and their feedstocks on yield attributes of green gram

Treatments No.	Treatments details	Number of seed per pod	Number of pod per plant	Pod length (cm)
T_1	0% RDF	$7.66±0.15^{h}$	$16.00±0.66^{h}$	$5.2±0.06^{h}$
T_2	50% RDF	$9.31±0.05^{g}$	$20.17±0.63^{g}$	$6.3±0.17^{g}$
T_3	75% RDF	$10.16±0.14^{bc}$	$23.75±0.25^{bc}$	$6.9±0.21^{bcd}$
T_4	100% RDF	$10.61±0.27^{a}$	$25.58±0.63^{a}$	$7.5±0.12^{a}$
T_5	SBB(2.25 g kg^{-1} soil)+ 50% RDF	$9.30±0.12^{g}$	$21.08±0.38^{fg}$	$6.3±0.15^{fg}$
T_6	RHB (2.25 g kg^{-1} soil)+50% RDF	$9.31±0.09^{g}$	$21.08±0.80^{fg}$	$6.4±0.12^{fg}$
T_7	PB (2.25 g kg^{-1} soil) +50% RDF	$9.65±0.16^{ef}$	$22.25±0.43^{e}$	$6.6±0.12^{e}$
T_8	LB(2.25 g kg^{-1} soil) +50% RDF	$9.66±0.16^{ef}$	$22.33±0.52^{de}$	$6.6±0.10^{e}$
T_9	SBB(4.50 g kg^{-1} soil) +50% RDF	$9.98±0.19^{cd}$	$23.50±0.50^{c}$	$6.8±0.06^{d}$
T_{10}	RHB(4.50 g kg^{-1} soil)+50% RDF	$9.98±0.15^{cd}$	$23.50±0.50^{c}$	$6.9±0.06^{d}$
T_{11}	PB (4.50 g kg^{-1} soil) +50% RDF	$10.28±0.05^{b}$	$24.58±0.52^{b}$	$7.1±0.06^{bc}$
T_{12}	LB (4.50 g kg^{-1} soil) +50% RDF	$10.30±0.11^{b}$	$24.58±0.52^{b}$	$7.1±0.10^{b}$
T_{13}	SBF (2.25 g kg^{-1} soil)+50% RDF	$9.26±0.30^{g}$	$21.00±0.87^{fg}$	$6.3±0.10^{g}$
T_{14}	RHF(2.25 g kg^{-1} soil) +50% RDF	$9.28±0.24^{g}$	$21.00±0.43^{fg}$	$6.3±0.15^{fg}$
T_{15}	PF (2.25 g kg^{-1} soil) +50% RDF	$9.20±0.22^{g}$	$21.25±0.66^{f}$	$6.3±0.10^{g}$
T_{16}	LF (2.25 g kg^{-1} soil) +50% RDF	$9.30±0.13^{g}$	$21.75±0.50^{ef}$	$6.5±0.06^{efg}$
T_{17}	SBF (4.50 g kg^{-1} soil) +50% RDF	$9.85±0.20^{de}$	$23.25±0.43^{cd}$	$6.9±0.10^{cd}$
T_{18}	RHF(4.50 g kg^{-1} soil) +50% RDF	$9.90±0.30^{cde}$	$23.58±0.80^{c}$	$6.9±0.10^{cd}$
T_{19}	PF (4.50 g kg^{-1} soil) +50% RDF	$9.37±0.18^{fg}$	$22.50±0.66^{de}$	$6.5±0.17^{ef}$
T_{20}	LF (4.50 g kg^{-1} soil) +50% RDF	$10.12±0.16^{bcd}$	$24.17±0.29^{bc}$	$7.1±0.12^{bc}$

Values (mean ± standard deviation) in each column followed by dissimilar lower case letters are significant according to Duncan's Multiple Range Test at P =0.05.
RDF=Recommended dose of fertilizers; SBB=Sugarcane bagasse biochar; RHB= Rice husk biochar; PB; *Parthenium* biochar; LB=*Lantana* biochar; SBF=Sugarcane bagasse feedstock; RHF= Rice husk feedstock; PF= *Parthenium* feedstock and LF= *Lantana* feedstock

Table 5: Effect of different biochar and their feedstocks on yield, harvest index and seed index of green gram

Treatments No.	Treatments details	Grain yield (g/pot)	Straw yield (g/pot)	Harvest Index	Seed index (g)
T_1	0% RDF	$15.04±0.09^{g}$	$79.57±1.87^{f}$	$15.90±0.39^{d}$	$2.97±0.050^{b}$
T_2	50% RDF	$25.53±0.99^{f}$	$102.61±4.08^{e}$	$19.93±0.68^{bc}$	$3.19±0.061^{a}$
T_3	75% RDF	$30.17±0.66^{bc}$	$118.73±4.64^{bc}$	$20.28±97^{abc}$	$3.28±0.041^{a}$
T_4	100% RDF	$33.95±0.61^{a}$	$129.52±3.11^{a}$	$20.77±0.28^{a}$	$3.28±0.029^{a}$
T_5	SBB(2.25 g kg^{-1} soil)+ 50% RDF	$26.70±0.46^{ef}$	$101.83±2.54^{e}$	$20.78±0.49^{a}$	$3.25±0.049^{a}$
T_6	RHB (2.25 g kg^{-1} soil)+50% RDF	$26.71±1.49^{ef}$	$102.22±4.82^{e}$	$20.73±1.13^{ab}$	$3.25±0.051^{a}$
T_7	PB (2.25 g kg^{-1} soil) +50% RDF	$28.25±0.24^{d}$	$109.30±1.24^{d}$	$20.54±0.26^{ab}$	$3.26±0.060^{a}$
T_8	LB(2.25 g kg^{-1} soil) +50% RDF	$28.27±0.74^{d}$	$109.55±3.12^{d}$	$20.51±0.08^{abc}$	$3.26±0.058^{a}$
T_9	SBB(4.50 g kg^{-1} soil) +50% RDF	$29.75±0.33^{c}$	$115.29±2.30^{c}$	$20.51±0.20^{abc}$	$3.26±0.043^{a}$

T_{10}	RHB(4.50 g kg^{-1} soil)+50% RDF	29.81±0.85^{c}	115.51±2.84^{c}	20.51±0.09^{abc}	3.26±0.053^{a}
T_{11}	PB (4.50 g kg^{-1} soil) +50% RDF	31.34±0.43^{b}	121.38±1.93^{b}	20.53±0.48^{abc}	3.26±0.049^{a}
T_{12}	LB (4.50 g kg^{-1} soil) +50% RDF	31.40±0.47^{b}	121.45±2.84^{b}	20.55±0.19^{ab}	3.27±0.044^{a}
T_{13}	SBF (2.25 g kg^{-1} soil)+50% RDF	26.71±0.49^{ef}	101.83±3.15^{e}	20.79±0.25^{a}	3.27±0.053^{a}
T_{14}	RHF(2.25 g kg^{-1} soil) +50% RDF	26.75±1.53^{ef}	101.89±2.59^{e}	20.78±0.68^{a}	3.27±0.047^{a}
T_{15}	PF (2.25 g kg^{-1} soil) +50% RDF	26.60±0.30^{ef}	101.63±0.45^{e}	20.74±0.14^{ab}	3.23±0.036^{a}
T_{16}	LF (2.25 g kg^{-1} soil) +50% RDF	27.28±0.71^{de}	106.59±3.38^{de}	20.38±0.51^{abc}	3.27±0.057^{a}
T_{17}	SBF (4.50 g kg^{-1} soil) +50% RDF	29.62±0.35^{c}	114.85±6.06^{c}	20.52±0.67^{abc}	3.27±0.061^{a}
T_{18}	RHF(4.50 g kg^{-1} soil) +50% RDF	29.79±0.78^{c}	115.09±1.18^{c}	20.56±0.28^{ab}	3.27±0.063^{a}
T_{19}	PF (4.50 g kg^{-1} soil) +50% RDF	28.36±0.73^{d}	115.56±3.47^{c}	19.70±0.11^{c}	3.26±0.055^{a}
T_{20}	LF (4.50 g kg^{-1} soil) +50% RDF	30.66±0.81^{bc}	121.12±1.67^{b}	20.20±0.54^{abc}	3.27±0.055^{a}

Values (mean ± standard deviation) in each column followed by dissimilar lower case letters are significant according to Duncan's Multiple Range Test at P =0.05.

RDF=Recommended dose of fertilizers; SBB=Sugarcane bagasse biochar; RHB= Rice husk biochar; PB; *Parthenium* biochar; LB=*Lantana* biochar; SBF=Sugarcane bagasse feedstock; RHF= Rice husk feedstock; PF= *Parthenium* feedstock and LF= *Lantana* feedstock

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