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Effect of organic manures, fertilizers and biochar on growth, yield attributes, yield and economics of *Bt* Cotton (*Gossypium hirsutum* L.)

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Abstract
A field experiment was conducted during *kharif* 2025-26 at Bheemarayanagudi, University of Agricultural Sciences, Raichur, Karnataka, India, to evaluate the effect of biochar applied along with organic manures and fertilizer levels on the growth, yield attributes, yield and economics of *Bt* cotton (*Gossypium hirsutum* L.). The experiment was laid out in a Randomized Complete Block Design (RCBD) with thirteen treatments replicated thrice. The treatments consist of vermicompost @ 2.5t ha^{-1}, FYM @ 10 t ha^{-1} and press mud @ 5.0 t ha^{-1} which were used individually in combination with 100% RDCF, 75% RDCF and 50% RDCF. Biochar @ 0.5 t ha^{-1} was used for all the treatments with constant rate of application. 100% RDCF alone + biochar @ 0.5 t ha^{-1} was also included to know the effect of biochar along with chemical fertilizers. The results revealed that application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} recorded significantly higher plant height (134.1 cm), leaf area (136.63 dm2 plant^{-1}) and total dry matter production (352.05 g) among all the treatments except 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + press mud @ 5 t ha^{-1} + biochar 0.5 t ha^{-1}, 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} and 100 per cent RDCF + FYM @ 10 t ha^{-1}. Further, this treatment known to produce significantly higher number of bolls per plant (28.1), boll weight (4.63 g boll^{-1}), seed cotton yield (127.8 g plant^{-1}) seed cotton yield (2367 kg ha^{-1}), stalk yield (4593 kg ha^{-1}) and net returns (Rs 96,313 ha^{-1}). The highest net returns (Rs 1,01,045 ha^{-1}) were obtained with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, whereas the highest benefit cost ratio (2.35) was recorded with 100 per cent RDCF + FYM @ 10 t ha^{-1} owing to its lower cost of cultivation. Reducing RDCF to 75 or 50 per cent lowered yield and returns even when biochar was added. Biochar @ 0.5 t ha^{-1} is therefore best used as a supplement to full RDCF and organic manures rather than as a substitute for fertilizer.

Keywords: Biochar, Vermicompost, Press mud, FYM, Yield attributes, Economics

Introduction
Cotton (*Gossypium hirsutum* L.) is an important fibre and cash crop of India, and the adoption of *Bt* hybrids has strongly shaped its production over the past two decades (Kranthi and Stone, 2020; Anonymous, 2025a) [2, 19]. India covering 11.48 million hectares during 2024-25, with production of approximately 29.724 million bales and productivity 440 kg lint ha^{-1} (Anonymous, 2025a) [2]. Karnataka has 0.68 million hectares of cotton cultivation area with a production of 2.27 million bales and productivity of 570 kg lint ha^{-1} (Anonymous, 2025b and 2025c) [3, 4]. Sustaining cotton productivity depends not only on high-yielding, pest-resistant cultivars but also on the fertility of the soils in which the crop is grown. Soil fertility is often degraded through poor soil management, and declining organic carbon in cotton-growing regions limits crop growth and yield.

Integrated nutrient management that combines inorganic fertilizers with organic sources such as FYM, vermicompost and press mud has been shown to improve the number of bolls, boll weight and seed cotton yield of cotton were observed by Ramesh *et al*., 2017 [24] and Subramanian *et al*., 2020 [27]. Organic sources release nutrients gradually and add organic matter, but their cost and the quantity needed can reduce the net gain from their use.

Biochar, a carbon-rich product obtained by pyrolysis of crop residues and other biomass, has attracted attention as a soil amendment because it can improve soil structure, water-holding capacity, nutrient retention, organic carbon and biological activity reported by Berihun *et al*., 2017 [6] and Singh *et al*., 2022 [26]. Converting crop residues into biochar is also an alternative to residue burning, which remains a policy concern in India were similar findings to Bhuvaneshwari *et al*., 2019 [8].

Field studies on cotton have reported higher boll number, boll weight and yield following biochar application, particularly when it is combined with fertilizers or manures was observed by Elangovan and Sekaran (2014a) [10]. The response is not uniform, however. Pinnamaneni *et al.* (2023) [22] observed no significant yield effect during the first two years of biochar application, with significant gains appearing only in the third year, and the profitability of

biochar depends strongly on its price were observed by Galinato *et al*., 2011 [13]. Organic inputs can likewise lower net returns when their cost is high (Aruna and Reddy, 2010) [5]. Information on how a low rate of biochar interacts with different organic manures and fertilizer levels in *Bt* cotton, in terms of both yield and economics, is therefore needed.

The present investigation is undertaken to study the effect of biochar applied along with FYM, vermicompost, press mud and fertilizers levels on growth, yield, yield attributes and economics of Bt cotton under irrigated conditions.

Materials and Methods

The field experiment was conducted during *kharif* 2025-26 at the experimental block of the College of Agriculture, Bheemarayanagudi, (UAS, Raichur, Karnataka, India). The rainfall received from June 2025 to May 2026 was 1145.5 mm against a normal of 844.3 mm. The highest monthly rainfall (309.5 mm) was received in September and rainfall exceeded the normal by 138.2, 109.7 and 130.2 mm in July, August and September, respectively. The experimental soil was deep clay with a pH of 8.21, electrical conductivity of 0.33 dS m^{-1} and organic carbon content of 0.42 per cent. The initial available nitrogen, phosphorus and potassium contents were 210.2, 31.6 and 332.8 kg ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) with thirteen treatments replicated thrice. The recommended dose of chemical fertilizers (RDCF) was (180 N: 90 P_2O_5: K_2O kg ha^{-1}). The US7067 (SWCH 4749 BG-II) *Bt* cotton was sown at a spacing of 90 x 60 cm spacing, with a gross plot size of 7.2 m x 6.0 m and a net plot size of 3.6 m x 4.8 m. Organic manures and biochar were applied before a week prior to sowing as per the treatments.

The remaining agronomic practices and plant protection measures were followed as per the package of practices. The observations on growth parameters *viz*., plant height, leaf area and total dry matter production and yield parameters *viz*., number of bolls per plant, boll weight (g) per boll and seed cotton yield per plant (g) were recorded from randomly five tagged plants per plot at harvest or final picking. Seed cotton yield and stalk yield were recorded from the net plot area and expressed in kg ha^{-1}. The data were analysed following the analysis of variance procedure for the experimental design as described by Panse and Sukhatme (1978) [21]. The critical difference (C.D.) was computed at the 5 per cent level of probability where the F-test was significant, and treatments differing from the best treatment by less than the C.D. are described as being on par with it. NS denotes non-significant differences. The paired comparisons for biochar were interpreted against the same C.D. values.

Results and Discussion

Growth parameters

Plant height, leaf area and total dry matter production at harvest differed significantly among the different treatments (Table 1; Fig. 1). The application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} recorded significantly higher plant height (134.1 cm), leaf area (136.63 dm^2 $plant^{-1}$) and total dry matter production (352.05 g), followed by 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, which recorded 129.3 cm plant height, 131.50 dm^2 $plant^{-1}$ leaf area and 342.00 g total dry matter production respectively. However, the differences between the application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} and 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, were not statistically significant for any of these growth parameters. The treatment received 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} was found *at par* with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1} (129.3 cm, 131.50 dm^2 $plant^{-1}$, 342.00 g), 100 per cent RDCF + press mud 5.0 t ha^{-1}+ biochar 0.5 t ha^{-1} (125.2 cm, 126.50 dm^2 $plant^{-1}$, 332.73 g), 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} (124.3 cm, 123.83 dm^2 $plant^{-1}$, 326.01 g) and 100 per cent RDCF + FYM @ 10 t ha^{-1} (122.5 cm, 121.83 dm^2 $plant^{-1}$, 320.71 g) for plant height, leaf area and total dry matter production.

In contrast, the application of 50 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} recorded the lower plant height (90.0 cm), leaf area (98.23 dm^2 $plant^{-1}$) and total dry matter production (227.20 g). Compared with application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} the treatment received 50 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} recorded reductions of 32.9 per cent in plant height, 28.1 per cent in leaf area and 35.5 per cent in total dry matter production. These results indicated that reducing RDCF to 50 per cent, even when combined with press mud and biochar, was insufficient to maintain growth comparable with the full-RDCF integrated nutrient management treatments under the experimental conditions.

Table 1: Plant height (cm), leaf area (dm^2 $plant^{-1}$) and total dry matter production (g) at harvest of *Bt* cotton as influenced by combined application of organic manures, varying levels of inorganic fertilizers and biochar

Treatment	Plant height (cm)	Leaf area (dm^2 $plant^{-1}$)	Total dry matter production (g)
T_1: 100% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	129.3	131.50	342.00
T_2: 75% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	113.0	110.17	265.67
T_3: 50% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	102.3	100.83	236.05
T_4: 100% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	134.1	136.63	352.05
T_5: 75% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	114.8	114.00	273.00
T_6: 50% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	105.6	103.93	244.19
T_7: 100% RDCF + Press mud @ 5.0 t ha^{-1}+ Biochar @ 0.5 t ha^{-1}	125.2	126.50	332.73
T_8: 75% RDCF + Press mud @ 5.0 t ha^{-1}+ Biochar @ 0.5 t ha^{-1}	110.2	108.43	258.27
T_9: 50% RDCF + Press mud @ 5.0 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	90.0	98.23	227.20

T_{10}: 100% RDCF + FYM @ 10 t ha^{-1}	122.5	121.83	320.71
T_{11}: 100% RDCF + Vermicompost @ 2.5 t ha^{-1}	124.3	123.83	326.01
T_{12}: 100% RDCF + Press mud @ 5.0 t ha^{-1}	117.8	115.67	295.29
T_{13}: 100% RDCF + Biochar @ 0.5 t ha^{-1}	116.1	114.80	279.22
S.Em. ±	5.5	6.88	10.87
C.D. (0.05)	16.1	20.07	31.73

RDCF – Recommended dose of chemical fertilizers; FYM – Farmyard manure.

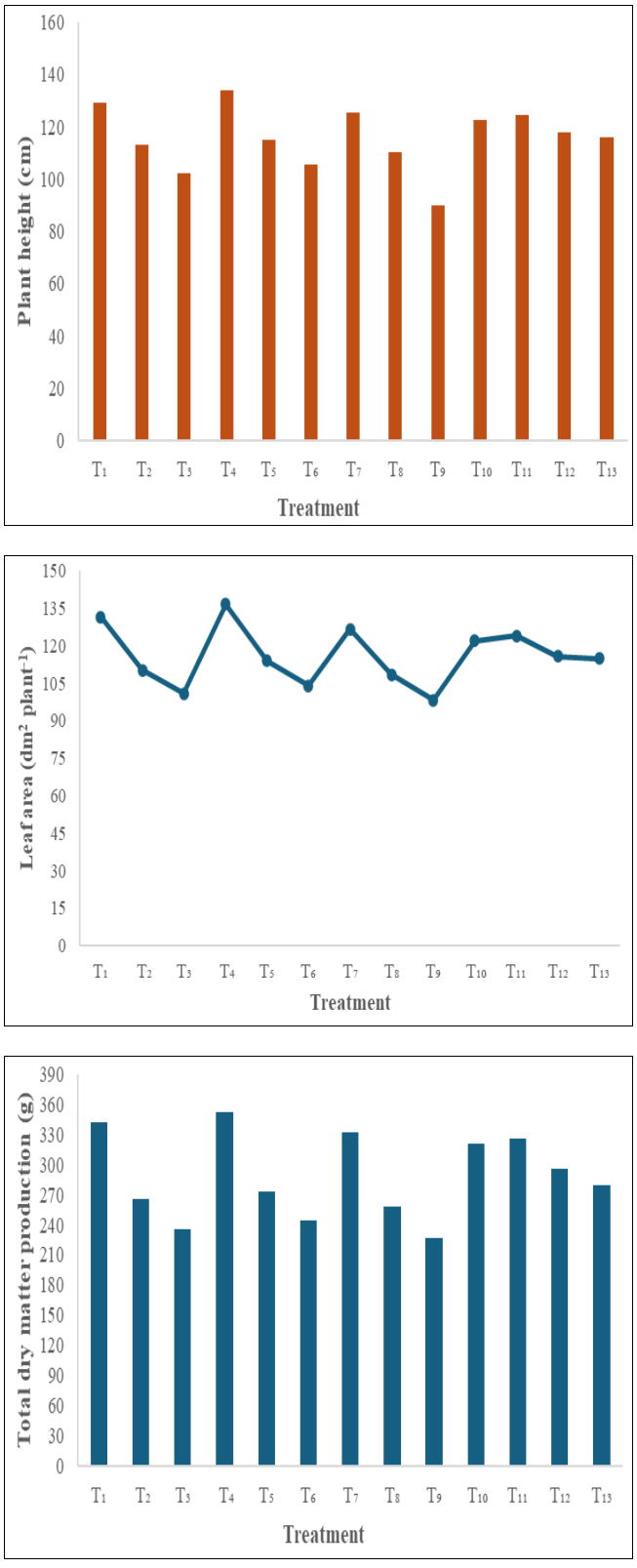


Fig 1: Plant height (cm), leaf area (dm^2 $plant^{-1}$) and total dry matter production (g) of *Bt* cotton as influenced by combined application of organic manures, varying levels of inorganic fertilizers and biochar

The higher growth, leaf area and total dry matter accumulation observed with application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} might be attributed to the combined effects of readily available nutrients from RDCF and the gradual nutrient release from vermicompost. The addition of biochar might have further contributed by improving nutrient retention, soil physical conditions and moisture availability, thereby supporting leaf expansion and biomass accumulation. Greater leaf area could have enhanced light interception and photosynthetic activity, contributing to increased dry matter production. Conversely, the lower growth, leaf area and total dry matter accumulation recorded in 50 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} might be associated with a relatively limited supply of readily available nutrients, restricting canopy development and biomass accumulation.

These findings were in agreement with Elangovan and Sekaran (2014b) [11], who reported improved plant height and other growth attributes of *Bt* cotton through the combined application of biochar, inorganic fertilizers and FYM. Ahmad *et al*. (2021) [1] also recorded higher plant height and leaf area index in cotton under integrated nutrient management involving organic manures and synthetic fertilizers. The improvement in dry matter accumulation observed in the present study was also consistent with the findings of Fltelib *et al.* (2006) [12], who reported increased dry matter yield with the combined application of biochar, FYM and recommended fertilizer. Thus, the combined application of recommended fertilizer, organic manure and biochar showed potential for improving the growth and biomass accumulation of *Bt* cotton under the experimental conditions.

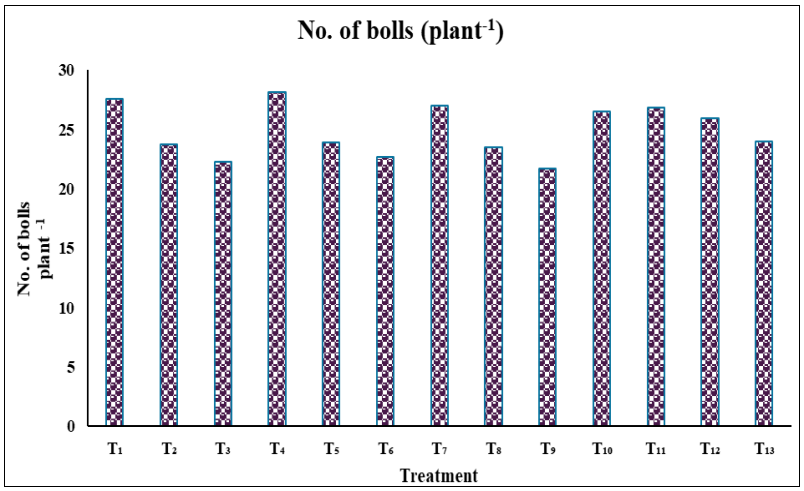
Yield attributes

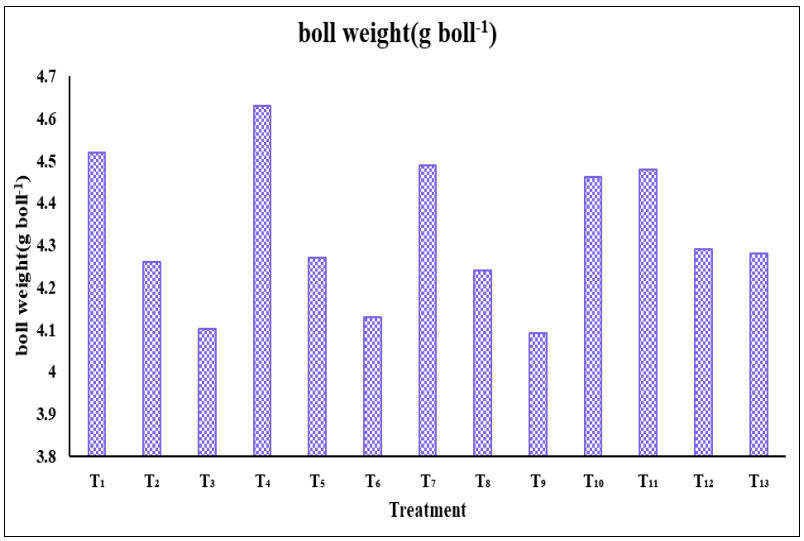
The number of bolls per plant, boll weight (g) per boll and seed cotton yield per plant (g) differed significantly among the treatments (Table 2; Fig. 2). The application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} recorded significantly higher number of bolls per plant (28.1), boll weight (4.63 g $boll^{-1}$) and seed cotton yield per plant (127.8 g) compare other treatments except 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar 0.5 t ha^{-1} (27.6 bolls $plant^{-1}$, 4.52 g $boll^{-1}$ and 124.8 g $plant^{-1}$), 100 per cent RDCF + press mud 5.0 t ha^{-1}+ biochar 0.5 t ha^{-1} (27.0 bolls $plant^{-1}$, 4.49 g $boll^{-1}$ and 121.1 g $plant^{-1}$), 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} (26.8 bolls $plant^{-1}$, 4.48 g $boll^{-1}$ and 120.1 g $plant^{-1}$) and 100 per cent RDCF + FYM @ 10 t ha^{-1} (26.5 bolls $plant^{-1}$, 4.46 g $boll^{-1}$ and 118.1 g $plant^{-1}$). The lower yield attributes (21.7 bolls $plant^{-1}$, 4.09 g $boll^{-1}$ and 88.6 g $plant^{-1}$) were recorded with 50 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar 0.5 t ha^{-1}, which gave 22.8 per cent fewer bolls per plant than 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1}.

Table 2: Number of bolls per plant, boll weight per boll, seed cotton yield per plant, seed cotton yield per hectare and stalk yield per hectare of *Bt* cotton as influenced by combined application of organic manures, varying levels of inorganic fertilizers and biochar

Treatment	No. of bolls (plant^{-1})	Boll weight (g boll^{-1})	Seed cotton yield (g plant^{-1})	Seed cotton yield (kg ha^{-1})	Stalk yield (kg ha^{-1})
T_1: 100% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	27.6	4.52	124.8	2312	4449
T_2: 75% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	23.7	4.26	100.8	1867	3905
T_3: 50% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	22.3	4.10	91.3	1690	3509
T_4: 100% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	28.1	4.63	127.8	2367	4593
T_5: 75% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	23.9	4.27	101.9	1887	3890
T_6: 50% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	22.7	4.13	93.6	1733	3621
T_7: 100% RDCF + Press mud @ 5.0 t ha^{-1}+ Biochar @ 0.5 t ha^{-1}	27.0	4.49	121.1	2243	4368
T_8: 75% RDCF + Press mud @ 5.0 t ha^{-1}+ Biochar @ 0.5 t ha^{-1}	23.5	4.24	99.6	1845	3673
T_9: 50% RDCF + Press mud @ 5.0 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	21.7	4.09	88.8	1645	2926
T_{10}: 100% RDCF + FYM @ 10 t ha^{-1}	26.5	4.46	118.1	2187	4203
T_{11}: 100% RDCF + Vermicompost @ 2.5 t ha^{-1}	26.8	4.48	120.1	2224	4242
T_{12}: 100% RDCF + Press mud @ 5.0 t ha^{-1}	25.9	4.29	112.6	2085	4146
T_{13}: 100% RDCF + Biochar @ 0.5 t ha^{-1}	24.0	4.28	102.6	1900	4089
S.Em. ±	0.7	0.11	3.4	62	179
C.D. (0.05)	2.0	0.33	9.8	181	524

RDCF – Recommended dose of chemical fertilizers; FYM – Farmyard manure.





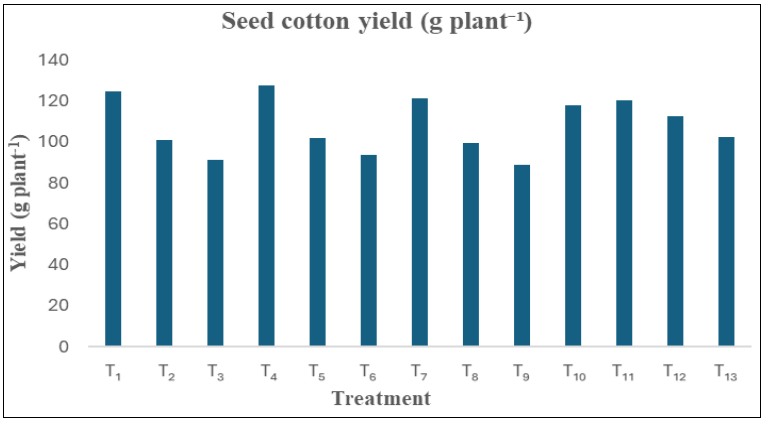


Fig 2: Number of bolls per plant, boll weight per boll (g) and seed cotton yield per plant (g) of *Bt* cotton as influenced by combined application of organic manures, varying levels of inorganic fertilizers and biochar.

The higher number of bolls, heavier boll weight and seed cotton yield per plant under 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} might be attributed to the balanced supply of nutrients during flowering and boll formation. Nitrogen from RDCF supports leaf development and photosynthesis, phosphorus supports root growth and energy metabolism and potassium facilitates translocation of photosynthates to the developing bolls. Vermicompost might have supplied nutrients through gradual mineralization, while biochar could have improved nutrient retention and moisture availability in the root zone, favouring retention of squares and young bolls and better boll filling. Further, it was found at par with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} and 100 per cent RDCF + FYM @ 10 t ha^{-1}. Thus, it clearly indicates that 100 per cent RDCF was itself sufficient to support boll development, with the organic sources and biochar adding a numerical advantage. Fewer bolls with 50 per cent RDCF reflect a restricted supply of readily available nutrients, which would have limited canopy development and the number of fruiting bodies retained. Improved boll number and yield attributes with integrated use of fertilizers and organic manures have been reported by Bhoite and Thombre (2006) [7] and Subramanian *et al.* (2020) [27], and with biochar by Wu *et al.* (2019), who recorded more buds, bolls and effective branches and Qayyum *et al.* (2020) [23], who recorded gains in boll number and boll weight with rice-straw biochar and potassium.

Seed cotton yield and stalk yield

Seed cotton yield and stalk yield were significantly influenced by the treatments (Table 2; Fig. 3). Significantly higher seed cotton yield recorded with 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} (2367 kg ha^{-1}), which was found *on par* with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1} (2312 kg ha^{-1}), 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} (2243 kg ha^{-1}), 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} (2224 kg ha^{-1}) and 100 per cent RDCF + FYM @ 10 t ha^{-1} (2187 kg ha^{-1}). The lower seed cotton yield (1645 kg ha^{-1}) was obtained with 50 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1}, so that application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} out-yielded with 50 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} by 43.9 per cent. Stalk yield followed a similar trend, the higher yield (4593 kg ha^{-1}) being recorded with 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1}, which found *on par* with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1} (4449 kg ha^{-1}), 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} (4368 kg ha^{-1}), 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} (4242 kg ha^{-1}), 100 per cent RDCF + FYM @ 10 t ha^{-1} (4203 kg ha^{-1}), 100 per cent RDCF + press mud @ 5.0 t ha^{-1} (4146 kg ha^{-1}) and 100 per cent RDCF + biochar @ 0.5 t ha^{-1} (4089 kg ha^{-1}), while the lower stalk yield (2926 kg ha^{-1}) was recorded with 50 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1}.

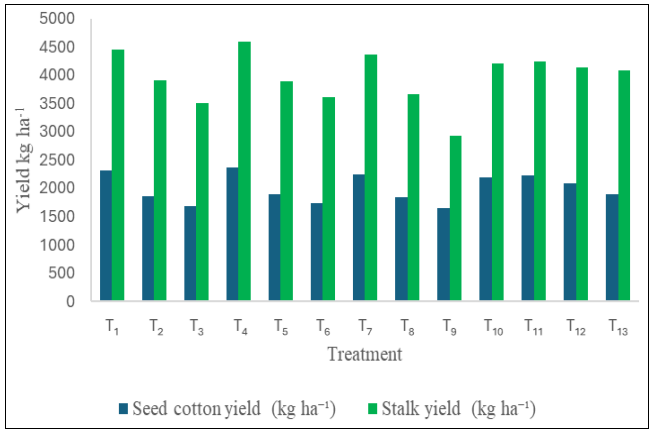


Fig 3: Seed cotton yield (kg ha^{-1}) and stalk yield (kg ha^{-1}) of *Bt* cotton as influenced by combined application of organic manures varying levels of inorganic fertilizers and biochar.

The higher seed cotton yield under 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} is the cumulative result of more bolls per plant, heavier boll weight leads to higher seed cotton yield per plant. Full RDCF ensured adequate availability of nitrogen, phosphorus and potassium, vermicompost added nutrients and organic matter through mineralization, and biochar, because of its porous structure, could have reduced nutrient losses and improved nutrient and moisture availability in the rhizosphere, thereby increasing root activity, nutrient uptake and translocation of assimilates to the bolls. The beneficial effect of organic manure combined with biochar on cotton root growth and yield was observed by Zhang *et al.* (2020) [31], and higher yields with biochar, poultry and farmyard

manures combined with synthetic fertilizers reported by Ahmad *et al.* (2021) [1]. Similar gains in seed cotton and stalk yield with vermicompost-based integrated nutrient management were reported by Ramesh *et al.* (2017) [24] and Naeem *et al*. (2017) [20] reported, in maize, better crop response to the combined use of biochar, compost and recommended fertilizers.

The yields obtained with application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} and 100 per cent RDCF + biochar @ 0.5 t ha^{-1} did not differ significantly, so the choice among them is governed largely by cost. The yield of 75 and 50 per cent RDCF treatments was lower than that of the corresponding 100 per cent RDCF treatments even with manure and biochar. Biochar @ 0.5 t ha^{-1} along with the organic manures therefore did not compensate for a reduction in chemical fertilizer. Fltelib *et al.* (2006) [12] similarly found in forage maize that biochar and FYM together with the recommended fertilizer gave a much higher dry matter yield than biochar and FYM without it.

Economics

The cost of cultivation (Table 3; Fig. 4) ranged from Rs 67,340 ha^{-1} with 100 per cent RDCF + biochar @ 0.5 t ha^{-1} to Rs 87,340 ha^{-1} with 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1}, reflecting the quantity and price of fertilizers and organic inputs. Gross returns were highest with 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} (Rs 1,83,653 ha^{-1}) followed by application of 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1} (Rs 1,79,385 ha^{-1}), 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} (Rs 1,74,083 ha^{-1}), 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} (Rs 1,72,608 ha^{-1}) and 100 per cent RDCF + FYM @ 10 t ha^{-1} (Rs 1,69,685 ha^{-1}), whereas the lower gross return recorded with 100 per cent RDCF + biochar @ 0.5 t ha^{-1} (Rs 1,27,652 ha^{-1}).

Net returns were highest with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar 0.5 ha^{-1} (Rs 1,01,045 ha^{-1}), which found *on par* with 100 per cent RDCF + FYM @ 10 t ha^{-1} (Rs 97,345 ha^{-1}), 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} (Rs 96,313 ha^{-1}), 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} (Rs 96,243 ha^{-1}), 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} (Rs 91,268 ha^{-1}) and 100 per cent RDCF + press mud @ 5.0 t ha^{-1} (Rs 89,956 ha^{-1}). The lowest net returns (Rs 53,297 ha^{-1}) were obtained with 50 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar 0.5 t ha^{-1}. Although 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} recorded the higher seed cotton yield and gross returns, its net returns were Rs 4,732 ha^{-1} lower than those of 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar 0.5 ha^{-1} because vermicompost @ 2.5 t ha^{-1} cost Rs 9,000 ha^{-1} more than FYM @ 10 t ha^{-1}, whereas 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} compared with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, and 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} with 100 per cent RDCF + FYM @ 10 t ha^{-1}. The higher net returns with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar 0.5 ha^{-1} therefore resulted from a favourable balance between yield and expenditure rather than from the maximum yield alone.

The B:C ratio was highest with 100 per cent RDCF + FYM @ 10 t ha^{-1} (2.35), which was followed by 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar 0.5 ha^{-1} (2.29), 100 per cent RDCF + press mud @ 5.0 t ha^{-1} (2.25), 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1} (2.24) and 100 per cent RDCF + biochar @ 0.5 t ha^{-1} (2.19), and lowest with 50 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} (1.66). 100 per cent RDCF + FYM @ 10 t ha^{-1} (T_{10}) combined a seed cotton yield on par with the best treatment with a low cost of cultivation (Rs 72,340 ha^{-1}), whereas the higher cost was application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} reduced its B:C ratio to (2.10). Reducing RDCF lowered the cost of cultivation by only about Rs 3,065 ha^{-1} for each 25 per cent reduction, but the associated yield loss was far larger, net returns of 75 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1} (T_2) (Rs 69,578 ha^{-1}) were Rs 31,467 ha^{-1} below those of 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, so that lowering the fertilizer dose was not economical.

Table 3: Economics of *Bt* cotton as influenced by organic manures, varying levels of inorganic fertilizers and biochar

Treatment	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
T_1: 100% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	78,340	1,79,385	**1,01,045**	2.29
T_2: 75% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	75,275	1,44,853	69,578	1.92
T_3: 50% RDCF + FYM @ 10 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	72,210	1,31,144	58,934	1.82
T_4: 100% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	87,340	1,83,653	96,313	2.10
T_5: 75% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	84,275	1,46,431	62,156	1.74
T_6: 50% RDCF + Vermicompost @ 2.5 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	81,210	1,34,507	53,297	1.66
T_7: 100% RDCF + Press mud @ 5.0 t ha^{-1}+ Biochar @ 0.5 t ha^{-1}	77,840	1,74,083	96,243	2.24
T_8: 75% RDCF + Press mud @ 5.0 t ha^{-1}+ Biochar @ 0.5 t ha^{-1}	74,775	1,43,146	68,371	1.91
T_9: 50% RDCF + Press mud @ 5.0 t ha^{-1} + Biochar @ 0.5 t ha^{-1}	71,710	1,27,652	55,942	1.78
T_{10}: 100% RDCF + FYM @ 10 t ha^{-1}	72,340	1,69,685	97,345	**2.35**

T_{11}: 100% RDCF + Vermicompost @ 2.5 t ha^{-1}	81,340	1,72,608	91,268	2.12
T_{12}: 100% RDCF + Press mud @ 5.0 t ha^{-1}	71,840	1,61,796	89,956	2.25
T_{13}: 100% RDCF + Biochar @ 0.5 t ha^{-1}	67,340	1,47,440	80,100	2.19
S.Em. ±	–	4816	4816	0.07
C.D. (0.05)	–	14059	14059	0.19

RDCF - Recommended dose of chemical fertilizers; FYM - Farmyard manure.

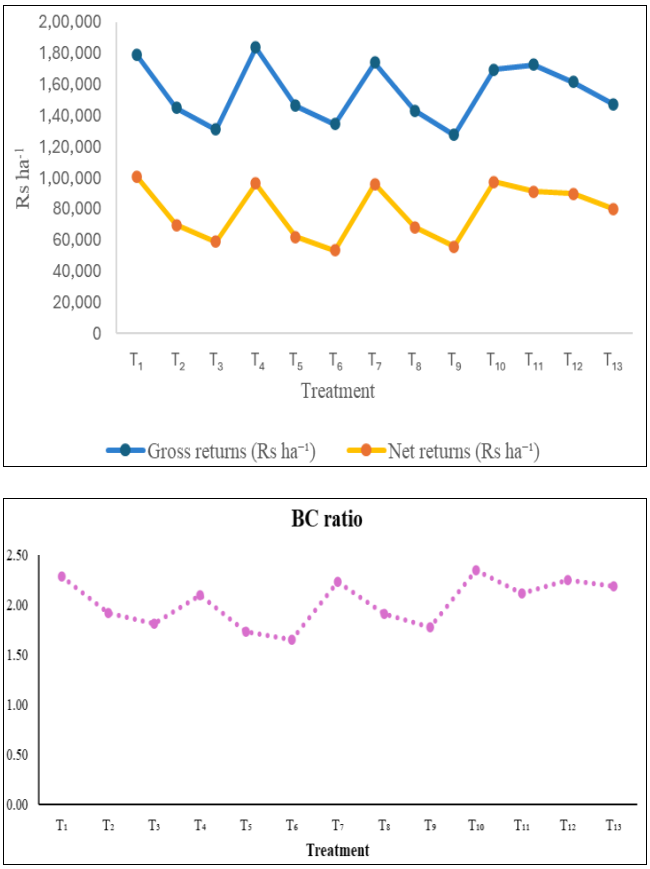


Fig 4: Economics of *Bt* cotton as influenced by organic manures, varying levels of inorganic fertilizers and biochar

These results are confirmed with earlier reports that RDF with FYM gave higher net returns in cotton reported by Shivalingaiah (2007) [25] and Hosmath *et al*., 2011 [14] and that costly organic inputs can reduce net returns and the B:C ratio unless the extra yield offsets their cost (Aruna and Reddy, 2010) [5]. Channagouda *et al*. (2014) [9], on the other hand, recorded higher net returns and B:C ratio with crop residue and vermicompost in cotton, showing that the outcome depends on the relative price and yield effect of the organic input. Hussain *et al*. (2025) [16] likewise reported the highest net return and B:C ratio with biochar combined with FYM in cotton.

Contribution of biochar to yield and profitability

Application of 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar 0.5 ha^{-1}, 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar 0.5 ha^{-1} and 100 per cent RDCF + press mud @ 5 t ha^{-1} + biochar 0.5 ha^{-1} differ from 100 per cent RDCF + FYM @ 10 t ha^{-1}, 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} and 100 per cent RDCF + press mud @ 5 t ha^{-1} respectively. The contribution of addition of biochar @ 0.5 t ha^{-1} to 100 per cent RDCF with different organic manures on yield and economics was shown in (Table 4; Fig. 5). Biochar increased seed cotton yield by 125 kg ha^{-1} (5.7 per cent) with FYM, 143 kg ha^{-1} (6.4 per cent) with vermicompost and 158 kg ha^{-1} (7.6 per cent) with press mud, an average gain of 142 kg ha^{-1} (6.6 per cent). None of the individual yield differences exceeded the C.D. of 181 kg ha^{-1}, so the benefit of biochar at this rate is best regarded as a consistent but modest positive trend rather than a statistically established effect.

Table 4: Effect of adding biochar @ 0.5 t ha^{-1} to 100 per cent RDCF with different organic manures on yield and economics of *Bt* cotton

Organic source (with 100% RDCF)	SCY without biochar (kg ha^{-1})	SCY with biochar (kg ha^{-1})	Increase in SCY	Added cost (Rs ha^{-1})	Added gross returns (Rs ha^{-1})	Added net returns (Rs ha^{-1})	Marginal return per Rs 1
FYM @ 10 t ha^{-1}	2187	2312	+125 (5.7%)	6,000	9,700	3,700	1.62
Vermicompost @ 2.5 t ha^{-1}	2224	2367	+143 (6.4%)	6,000	11,045	5,045	1.84
Press mud @ 5.0 t ha^{-1}	2085	2243	+158 (7.6%)	6,000	12,287	6,287	2.05

SCY - Seed cotton yield. Calculated from the means of T_1 with T_{10}, T_4 with T_{11} and T_7 with T_{12}. C.D. (0.05) for seed cotton yield = 181 kg ha^{-1} and for net returns = Rs 14,059 ha^{-1}.

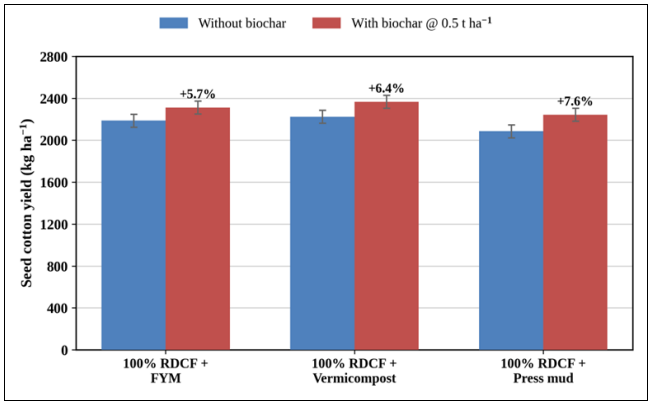


Fig 5: Seed cotton yield of Bt cotton with and without biochar @ 0.5 t ha^{-1} at 100 per cent RDCF along with FYM, vermicompost and press mud. Vertical bars indicate S.Em. ±; values above the bars show the per cent increase due to biochar.

Biochar @ 0.5 t ha^{-1} added Rs 6,000 ha^{-1} to the cost of cultivation in each pair. It raised gross returns by Rs 9,700 to 12,287 ha^{-1} and net returns by Rs 3,700 (3.8 per cent) with FYM, Rs 5,045 (5.5 per cent) with vermicompost and Rs 6,287 (7.0 per cent) with press mud, so every rupee spent on biochar returned between Rs 1.62 and Rs 2.05 of additional gross income. The B:C ratio nevertheless changed little or fell slightly (2.35 to 2.29 with FYM, 2.12 to 2.10 with vermicompost and 2.25 to 2.24 with press mud) because the marginal return on biochar was below the average return of the cropping system. The additional net returns were also within the C.D. of Rs 14,059 ha^{-1}. The economic case for biochar at this rate and price is therefore positive but small, and it depends on the price of biochar, as noted by Galinato *et al.* (2011) [13].

The size of the yield response is of the same order as, though somewhat smaller than, the 8.0 to 21.9 per cent increase in lint yield reported by Tian *et al.* (2018) [28] with 5 to 20 t ha^{-1} of corn-straw biochar, and the 14.48 per cent increase in seed cotton yield with rice-straw biochar and potassium reported by Qayyum *et al.* (2020) [23]. It is notable that the present gains were obtained with only 0.5 t ha^{-1}, whereas Pinnamaneni *et al.* (2023) [22] used 10 to 40 t ha^{-1} and found a significant yield effect only in the third year, Karthik *et al.* (2019) [18] used 4 t ha^{-1} and Kannan *et al.* (2019) [17] 5 t ha^{-1}. Ahmad *et al.* (2021) [1] ranked biochar below poultry and farmyard manures when each was combined with fertilizers and Hussain *et al.* (2025) [16] and Huang *et al.* (2025) [15] found the largest benefit when biochar was combined with FYM or cow manure. In line with these reports, the best treatments here were those in which biochar supplemented both full RDCF and an organic manure. Biochar with RDCF alone (T_{13}) (1900 kg ha^{-1}) yielded 185 to 324 kg ha^{-1} less than 100 per cent RDCF with any of the three organic manures i.e. 100 per cent RDCF + FYM @ 10 t ha^{-1}, 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} and 100 per cent RDCF + press mud @ 5.0 t ha^{-1} (T_{12}), but its low cost of cultivation (Rs 67,340 ha^{-1}) recorded a B:C ratio of 2.19, *on par* with the highest. In rice and wheat, Wang *et al.* (2018) [29] observed much larger increases (34 to 77.8 per cent) in net returns over six years after a biochar amendment than were observed here.

Two limitations should be noted. The experiment did not include a treatment of 100 per cent RDCF alone, so the effect of biochar relative to fertilizer alone could not be separated and only one rate of biochar (0.5 t ha^{-1}) was tested in a single season. The yield advantage of biochar may increase with repeated application, as indicated by Pinnamaneni *et al.* (2023) [22], and should be verified in multi-season trials.

Conclusion

On the basis of present investigation, it can be concluded that application of 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} + biochar @ 0.5 t ha^{-1} recorded the higher plant height (134.1 cm), leaf area (136.63 dm^2 plant^{-1}), total dry matter production (352.05 g), producing highest number of bolls per plant (28.1), boll weight (4.63 g boll^{-1}), seed cotton yield (2367 kg ha^{-1}) and stalk yield (4593 kg ha^{-1}) of *Bt* cotton, although it found *on par* for seed cotton yield with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + press mud @ 5.0 t ha^{-1} + biochar @ 0.5 t ha^{-1}, 100 per cent RDCF + vermicompost @ 2.5 t ha^{-1} or FYM @ 10 t ha^{-1}. The highest net returns (Rs 1,01,045 ha^{-1}) were obtained with 100 per cent RDCF + FYM @ 10 t ha^{-1} + biochar @ 0.5 t ha^{-1} and the highest B:C ratio (2.35) with 100 per cent RDCF + FYM @ 10 t ha^{-1}, because of their lower cost of cultivation than the vermicompost treatments. At 100 per cent RDCF, adding biochar @ 0.5 t ha^{-1} to FYM, vermicompost or press mud raised seed cotton yield by 5.7 to 7.6 per cent and net returns by Rs 3,700 to 6,287 ha^{-1}, with each rupee spent on biochar returning Rs 1.62 to 2.05, but these gains were within the critical difference. Reducing RDCF to 75 or 50 per cent reduced yield and returns even with biochar. Biochar @ 0.5 t ha^{-1} can therefore be used as a supplement to full RDCF and organic manures for a modest gain in yield and returns, but not as a substitute for chemical fertilizer. These findings are based on a single season and a single rate of biochar, and multi-season trials are suggested before firm recommendations are made.

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