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Amaregouda
M.Sc. Scholar, Department of Soil
Science, College of Agriculture,
Raichur, University of Agricultural
Sciences, Raichur, Karnataka,
India

Ashok Kumar Gaddi
Professor, Department of Soil
Science, College of Agriculture,
Hagari, University of Agricultural
Sciences, Raichur, Karnataka,
India

Ravi S
Senior Soil Scientist, ICAR-KVK,
Hagari, University of Agricultural
Sciences, Raichur, Karnataka,
India

Veeresh H
Professor and Head, Department
of Soil Science, College of
Agriculture, Raichur, University of
Agricultural Sciences, Raichur,
Karnataka, India

Ajaykumar MY
Professor and Head, Department
of Agronomy, College of
Agriculture, Raichur, University of
Agricultural Sciences, Raichur,
Karnataka, India

Corresponding Author:
Amaregouda
M.Sc. Scholar, Department of Soil
Science, College of Agriculture,
Raichur, University of Agricultural
Sciences, Raichur, Karnataka,
India

Effect of biochar application on growth and yield of *rabi* sorghum (*Sorghum bicolor* L.)

Amaregouda, Ashok Kumar Gaddi, Ravi S, Veeresh H and Ajaykumar MY

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Abstract

A field experiment titled “Effect of biochar application on growth and yield of *rabi* sorghum (*Sorghum bicolor* L.)” was conducted during the *rabi* 2024 season at the Agricultural Research Station, Siruguppa. The study comprised eight treatments, including a control, RDF alone, and RDF combined with varying levels of farmyard manure (FYM) and biochar, laid out in a randomized complete block design (RCBD) with three replications. The results revealed that RDF + 75% FYM + 25% Biochar (T₆) recorded the highest performance, producing a grain yield of 3314 kg ha⁻¹ and stover yield of 6680 kg ha⁻¹, along with enhanced growth parameters such as plant height (215.6 cm), leaf area (3545 cm² plant⁻¹) and leaf area index (5.25). Yield attributes like spike length (21.2 cm) and grain weight per spike (27.8 g) were also significantly improved. Furthermore, T₆ enhanced soil nutrient status, recording higher available nitrogen (258.3 kg ha⁻¹), phosphorus (43.8 kg ha⁻¹), and potassium (361.6 kg ha⁻¹) levels. Economically, T₆ provided the highest gross returns (₹121,438 ha⁻¹), while T₄ (RDF + 100% FYM @ 3.0 t ha⁻¹) yielded the maximum net returns (₹78,287 ha⁻¹) and benefit-cost ratio (3.15). Hence, the T₆ treatment proved most effective in enhancing yield, profitability, and soil fertility under *rabi* sorghum cultivation.

Keywords: Biochar, *rabi* sorghum, farmyard manure

Introduction

India generates approximately 500 million tons of crop residues annually, out of which about 141 million tons remain unutilized. A large proportion of these residues are either partially used or left in the field due to various technical and logistical constraints. When left unattended, these residues hinder field preparation, crop establishment and subsequent growth. Converting such surplus biomass into biochar offers a sustainable alternative for residue management. Biochar is a carbon-rich, stable material produced through the thermal decomposition of biomass such as crop residues, wood, manure, or leaves under limited oxygen conditions at temperatures ranging from 300°C to 600°C. The concept of biochar has gained prominence in recent years due to its potential applications in soil management, carbon sequestration and pollutant immobilization (Rehrah *et al.*, 2014) [10]. The characteristics of biochar largely depend on the source biomass and the pyrolysis conditions employed during its production.

Sorghum (*Sorghum bicolor* L.) holds a strategic position among major cereal crops due to its remarkable adaptability and multipurpose utility. It is cultivated extensively in semi-arid regions, serving both as food and fodder, especially for resource-poor farmers. Among the world's primary cereals, sorghum ranks after wheat, maize, rice and barley. Globally, it occupies about 42.22 million hectares with an annual production of 62.29 million tons. In India, during 2024-25, the sorghum area and production were reported as 4.07 million hectares and 4.73 million tons, respectively, with an average productivity of 1162 kg ha⁻¹ (Anon., 2025) [2]. In Karnataka alone, the area and production during 2023-24 were 0.8 million hectares and 0.94 million tons, yielding a productivity of 1167 kg ha⁻¹ (Anon., 2025a) [3].

Sorghum's inherent tolerance to drought, salinity and high temperature, along with its short growth duration and high biomass yield, makes it an ideal crop for dryland agriculture. Considering these attributes, an experimental study entitled “Effect of biochar application on growth and yield of *rabi* sorghum (*Sorghum bicolor* L.)” is proposed with specific research objectives.

Materials and Methods

A field experiment to evaluate the effect of biochar application on growth and yield of *rabi* sorghum (*Sorghum bicolor* L.) was conducted during *rabi* 2024-25 at the Agricultural Research Station, Siruguppa, University of Agricultural Sciences, Raichur, Karnataka. The site is located in agro-climatic zone III (Northern Dry Zone) at 15°69' N, 76°89' E and 358 m altitude. The experimental soil was classified as medium black Vertisol, alkaline (pH 8.06), low in organic carbon (3.87 g kg⁻¹) and available nitrogen (237 kg ha⁻¹), with medium levels of phosphorus (36 kg ha⁻¹) and potassium (335 kg ha⁻¹).

The experiment was laid out in a randomized complete block design (RCBD) with eight treatments and three replications. Treatments included recommended dose of fertilizers (RDF; 80:40:40 kg N:P₂O₅:K₂O ha⁻¹) either alone or in combination with farmyard manure (FYM) and biochar at 3 t ha⁻¹, in varying proportions; FYM and biochar were incorporated 15 days prior to sowing. Sorghum variety M 35-1 was sown at spacing of 45 × 15 cm.

Standard agronomic practices including land preparation, thinning, gap filling, herbicide and fertilizer applications were followed. Growth and yield measurements were recorded at key stages. Soils and plant samples were analyzed for physico-chemical properties using standard protocols. Economic returns and benefit-cost ratio were computed. Data were subjected to ANOVA as per Panse and Sukhatme (1967)^[9].

Results and Discussion

The impact of biochar on growth attributes such as plant height, leaf area per plant and leaf area index (LAI) are essential indicators of crop development, was notably significant at 60 and 90 days after sowing (DAS) as well as at harvest. The absolute control, which received no fertilizers or organic amendments, consistently exhibited the shortest plant height and the smallest leaf area among all treatments. In contrast, treatment T₆, combining recommended dose of fertilizers (RDF) with 75% farmyard manure (FYM) and 25% biochar, consistently outperformed other treatments at each growth stage, demonstrating superior plant height, greater leaf area and higher LAI values.

The enhanced growth observed in biochar and FYM amended plots can be attributed to multiple factors. Biochar improves soil moisture retention due to its porous structure, providing a more favourable water environment for root development. The combined effects of improved soil structure, moisture dynamics, and nutrient supply create an optimal rhizosphere that supports

robust root growth and more efficient nutrient uptake by plants.

The increase in leaf area per plant reflects improved vegetative growth, which is associated with better nutrient and water status in the soil. This augmented leaf area contributes to a more developed canopy capable of intercepting greater light, thereby enhancing photosynthetic activity. Correspondingly, the higher LAI recorded under biochar and FYM treatments signifies a denser leaf canopy per unit ground area, which promotes efficient light capture and biomass accumulation. Such physiological improvements are supported by an improved microclimate within the crop canopy and a nutrient-enriched soil environment facilitated by biochar and organic amendments. These findings are consistent with previous studies, such as those reported by Alie *et al.* (2014)^[1], which show that biochar amendments can significantly enhance growth parameters in cereal crops by improving soil fertility and structure.

Dry matter accumulation in stems, leaves and heads showed significant improvement with biochar and FYM application. Total dry matter production in T₆ significantly higher compared to control. This increase reflects enhanced photosynthetic efficiency, assimilate partitioning and sustained nutrient availability throughout crop growth. Similar patterns were previously reported in maize by Meena *et al.* (2016)^[8].

Yield parameters such as spike length, grain weight per spike, thousand grain weight, grain yield and stover yield were significantly improved by biochar and FYM treatments. The highest grain yield of 3314 kg ha⁻¹ was obtained from T₆, significantly surpassing the control (1660 kg ha⁻¹). The increment in yield attributes is due to improved soil fertility, moisture conservation and enhanced nutrient uptake facilitated by biochar and FYM amendments, which maintain a balanced supply of essential nutrients during critical growth phases. These findings were corroborated by Yeboah *et al.* (2016)^[12] in maize and wheat.

Biochar and FYM application significantly enhanced nitrogen, phosphorus and potassium uptake by sorghum plants. Total nitrogen uptake peaked at 112.8 kg ha⁻¹ in T₆, with comparable results in other organic amendment treatments, far exceeding the control (55.4 kg ha⁻¹). Similar trends occurred for phosphorus and potassium uptake, with T₆ achieving the highest values (P: 44.9 kg ha⁻¹, K: 108.0 kg ha⁻¹). Enhanced nutrient uptake is linked to biochar's capacity to improve cation exchange capacity, nutrient retention and microbial activity while FYM ensures steady nutrient mineralization. Such combined effects support improved root growth and nutrient absorption efficiency, aligning with findings of Uzoma *et al.* (2011)^[11].

Table 1: Effect of biochar on yield and yield parameters of *rabi* sorghum

Treatments	Spike length (cm)	Grain weight per spike (g)	1000 grain weight (g)	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest Index
T ₁	13.2	19.5	24.1	1660	2920	0.36
T ₂	16.5	22.5	28.9	2142	3978	0.35
T ₃	16.8	22.9	29.4	2464	4645	0.34
T ₄	20.6	26.8	33.5	3118	6414	0.32
T ₅	19.1	25.9	33.1	2960	6180	0.32
T ₆	21.2	27.8	33.7	3314	6680	0.33
T ₇	20.9	27.1	33.6	3235	6556	0.33
T ₈	19.7	26.2	33.4	3012	6306	0.32
S. Em. ±	0.8	0.9	1.0	122	189	0.01
C.D. at 5%	2.4	2.8	3.2	370	575	NS

Note:

- Calculated quantity of biochar and farmyard manure (FYM) was incorporated into the respective treatment plots 15 days before the sowing of *rabi* sorghum
- RDF-Recommended dose of fertilizers (80:40:40 kg N: P₂O₅: K₂O ha⁻¹)
- RPP-Recommended package of practices (80:40:40:15 kg N: P₂O₅: K₂O:ZnSO₄ ha⁻¹)

Table 2: Effect of varied level of Biochar and FYM on available nutrients status of soil

Treatments	Organic carbon (g kg ⁻¹)	Available nutrients (kg ha ⁻¹)		
		Nitrogen	Phosphorus	Potassium
T ₁	3.60	210.3	32.8	289.1
T ₂	3.99	227.6	37.6	320.7
T ₃	4.01	230.3	38.2	322.1
T ₄	4.40	251.9	43.1	356.2
T ₅	4.39	244.8	42.4	354.3
T ₆	4.42	258.3	43.8	361.6
T ₇	4.41	255.7	43.6	357.4
T ₈	4.38	248.2	42.7	355.5
S. Em. ±	0.12	7.3	1.2	10.0
C.D. at 5%	0.37	22.1	3.8	30.3

Note:

- Calculated quantity of biochar and farmyard manure (FYM) was incorporated into the respective treatment plots 15 days before the sowing of *rabi* sorghum
- RDF-Recommended dose of fertilizers (80:40:40 kg N: P₂O₅: K₂O ha⁻¹)
- RPP-Recommended package of practices (80:40:40:15 kg N: P₂O₅: K₂O:ZnSO₄ ha⁻¹)

Table 3: Effect of biochar on economics of *rabi* sorghum

Treatments	Gross returns (₹ ha ⁻¹)	Net returns (₹ ha ⁻¹)	B:C
T ₁	59636	33366	2.27
T ₂	77540	45710	2.44
T ₃	89390	56360	2.71
T ₄	114617	78287	3.15
T ₅	109064	38234	1.54
T ₆	121438	76483	2.70
T ₇	118641	65061	2.21
T ₈	111028	48823	1.78
S. Em. ±	1333	1333	0.06
C.D. at 5%	4045	4045	0.22

Note:

- Calculated quantity of biochar and farmyard manure (FYM) was incorporated into the respective treatment plots 15 days before the sowing of *rabi* sorghum
- RDF-Recommended dose of fertilizers (80:40:40 kg N: P₂O₅: K₂O ha⁻¹)
- RPP-Recommended package of practices (80:40:40:15 kg N: P₂O₅: K₂O:ZnSO₄ ha⁻¹)

Protein content in grain and stover ranged from 7.8 to 9.8% and 3.4 to 5.7%, respectively, with non-significant variation across treatments, though the highest protein content was in T₆. This indicates biochar and FYM improve nutrient status without drastically altering grain protein concentration, consistent with other cereal crop studies.

Post-harvest soil analysis revealed significant improvements in soil physical properties with biochar and FYM treatments. Bulk density decreased while water-holding capacity increased in T₆, reflecting better soil porosity and moisture retention. These improvements likely contributed to improved crop performance and are comparable to results reported by Biar *et al.* (2016) [4]. Soil chemical properties also responded positively, with slight increases in soil pH and organic carbon content following biochar and FYM application. Available N, P₂O₅ and K₂O in soil were significantly higher in organically amended treatments than in the control, suggesting improved nutrient cycling and retention, consistent with Lashari *et al.* (2013) [6]. However, soil electrical conductivity and micronutrients such as Fe, Zn, Mn and Cu showed minimal variation, likely due to soil buffering capacity and seasonal factors.

Microbial populations-including bacteria, fungi and

actinomycetes-were significantly enhanced in biochar plus FYM treatments, with T₆ showing the highest counts. Improvements in soil microbial biomass reflect a healthier soil ecosystem that supports nutrient mineralization and plant growth, in agreement with Lehmann *et al.* (2003) [7].

The cost of cultivation increased with biochar application due to input costs but was offset by significantly higher gross and net returns in organic-amended treatments. The highest net return (₹76,483 ha⁻¹) and benefit-cost ratio (3.15) were recorded in treatments combining RDF with FYM and biochar (T₆, T₄), indicating that biochar use combined with FYM can be economically viable and beneficial for farmers under *rabi* sorghum cultivation.

Conclusion

The combined application of biochar with farmyard manure (FYM) and recommended fertilizer doses significantly enhanced sorghum growth and yield. Treatment T₆ (RDF + 75% FYM + 25% biochar) recorded the highest grain yield of 3314 kg ha⁻¹ and stover yield of 6680 kg ha⁻¹, accompanied by superior growth and yield attributes. The same treatment significantly improved soil nutrients, with post-harvest nitrogen, phosphorus and potassium, along with increased soil organic carbon and water-holding capacity. Economically, T₆ showed the highest gross returns, while T₄ (RDF + 100% FYM) generated the maximum net returns, highlighting the profitability and sustainability of these practices.

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