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Influence of biochar on growth, yield and quality of summer organic sesame (*Sesamum indicum* L.) and soil properties

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Abstract
A field experiment was conducted on organically managed medium black calcareous clayey soil at Junagadh (Gujarat) during summer season of 2019-20 to study the effect of biochar on growth, yield and quality of summer sesame (*Sesamum indicum* L.) and soil properties. The experimental results revealed that significantly higher values of growth parameters *viz.*, plant height and number of branches per plant and yield attributes *viz.*, number of capsules per plant, length of capsule, seed weight per plant and test weight along with higher seed yield (1741 kg/ha) and stover yield (2123 kg/ha) were recorded with application of enriched biochar 0.25 t/ha + vermicompost 1 t/ha. However, significantly higher nutrient uptake by plant, organic carbon, available N, P, K in soil after harvest along with higher net return (₹ 99142/ha) and B:C ratio (2.69) were also realized with the application of enriched biochar 0.25 t/ha + vermicompost 1 t/ha. Based on the results, it could be concluded that higher production and net returns from sesame along with improved soil fertility can be obtained by the application of microbial consortium enriched biochar 0.25 t/ha + vermicompost 1 t/ha.

Keywords: *Sesamum indicum*, sesame, biochar, microbial consortium enrichment, soil properties

Introduction

Sesame is one of the world's oldest oil crop and has been cultivated in Asia from ancient times. India is the largest producer of sesame both in terms of area (19.50 lakh ha) and production (8.51 lakh tonnes) with an average productivity of 436 kg/ha. It is cultivated as commercial crop in Gujarat, West Bengal, Rajasthan, Tamil Nadu, Andhra Pradesh, Madhya Pradesh and Maharashtra. In Gujarat, sesame is the most important oilseed crop and cultivated in 1.23 lakh ha which produces 0.72 lakh tonnes with productivity of 586 kg/ha (Anon., 2018) [1]. The sesame seed has been considered as "Queen of Oilseed" by virtue of its excellent quality of oil content, flavour, taste and traditionally categorised as a health food. Since sesame is low water requiring, remunerative and short duration crop, farmers of Saurashtra region are attracted towards its cultivation in summer season.

Agricultural waste is generally handled as a liability, often because the means to transform it into an asset is lacking. Crop residue management is one of the emerging problems in agriculture sector. Crop residues in fields can cause considerable crop management problems as they accumulate in surplus. Most of the farmers do crop residue burning and hence in addition to loss of valuable biomass and nutrients, burning also release of toxic gases like CO_2, methane and nitrous oxide causing global warming. On the other hand, maintenance of a threshold level of organic matter in the soil is crucial for maintaining physical, chemical and biological integrity of the soil and also for the soil to perform its agricultural production. The low level of organic matter causes a strong reduction in soil fertility. Hence, conversion of organic waste to produce biochar using the pyrolysis process is one viable option that can enhance natural rates of carbon sequestration in the soil, reduce farm waste and improve the soil quality. The use of biochar as soil amendment is proposed as a new approach to mitigate man-induced climate change along with improving soil productivity.

The effect of biochar in increasing plant growth and soil quality has been well documented by many workers for many crops. Biochar may improve soil organic carbon, water holding capacity, cation exchange capacity, pH and nutrients availabilities. Compost can be enriched by N-fixing, P-solubilizing and K mobilizing cultures and biocontrol microbial cultures.

In addition to improving availability of plant nutrients, these additions help to reduce the composting time considerably and increase population of microorganisms.

Taking note of the facts highlighted above, a field experiment was conducted to study the effect of integration of various organic amendments along with microbial enrichment on growth and yield of sesame and post-harvest soil fertility.

Materials and Methods

A field experiment was conducted on a medium black clayey soil at Instructional Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh (Gujarat) in summer season of 2019-20. Geographically, Junagadh is situated at 21.50° N latitude and 70.50° E longitude with an altitude of 60 m above the mean sea level. The experimental soil was organically managed (since 8 years) and slightly alkaline in reaction with pH 8.18 and EC 0.52 dS/m, low in available nitrogen (246 kg/ha), medium in available phosphorus (27 kg/ha) and high in available potash (254 kg/ha). The mean maximum and minimum temperature during the crop period ranged from 29.2 to 42.2 °C and 12.1 to 27.4 °C, respectively. During the crop period, the relative humidity was in the range of 38 to 78%. Bright sun shine hours, wind velocity and daily evaporation was 7.4 to 11 h/day, 4 to 9.5 km/h and 5.5 to 11.7 mm/day, respectively.

The experiment comprising 10 treatments *viz*., T_1: RDF (50-25-0 kg N-P_2O_5-K_2O/ha, outside of organic plot), T_2: FYM 5 t/ha, T_3: Vermicompost 2 t/ha, T_4: FYM 2.5 t/ha + Vermicompost 1 t/ha, T_5: Biochar 1 t/ha, T_6: Biochar 0.5 t/ha + FYM 2.5 t/ha, T_7: Biochar 0.5 t/ha + Vermicompost 1 t/ha, T_8: Enriched Biochar 0.25 t/ha + FYM 2.5 t/ha, T_9: Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha and T_{10}: Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha, was laid out in randomized block design with three replications.

As per the treatments entire dose of nitrogen and phosphorus was applied in form of urea and diammonium phosphate, respectively at sowing in outside of organic plot. Liquid formulation of *Azotobacter* (*Azotobacter chroococcum*), phosphate solubilizing bacteria (*Bacillus subtilis*) and potash mobilizing bacteria (*Frateuria aurantia*) and powder formulation of biocontrol microbial cultures *viz*., *Trichoderma harzianum*, *Pseudomonas fluorescencs* and *Beauveria bassiana* were used for microbial enrichment of biochar. Biochar was obtained from Greenfield Eco Solution Pvt. Ltd. The biochar containing 715-725, 1.6-1.9, 1.9- 2.1 and 24-26 g/kg organic carbon, N, P and K respectively. *Azotobacter*, PSB and KMB each @ 2 L/ha and biocontrol microbial cultures @ 2 kg/ha were applied to biochar and thoroughly incorporated in to biochar and incubated for 10 days before application. The organic inputs like biochar, enriched biochar, FYM and vermicompost were applied in furrows as basal in respective treatments just before sowing. After that sesame seeds were sown in open furrow and cover with soil gently. The sesame variety ‘GJT-5’ was sown on February 21, 2019 at row spacing of 30 cm using seed rate of 5 kg/ha. The gross and net plot size was 5.0 m x 1.8 m and 4.0 m x 1.2 m, respectively. The crop was raised as per the recommended package of practices. The crop was harvested at physiological maturity on May 16, 2019. The growth and yield attributes were recorded from the five tagged plants in each plot. Seed and stover yield were recorded from the net plot area and converted into kilogram per hectare base. Soil and plant analysis was carried out adopting standard methods (Jackson, 1974) [9].

The expenses incurred for all the cultivation operations from preparatory tillage to harvesting including the cost of inputs *viz*., seeds, manures, biochar, enrichment materials, irrigation, *etc*. applied to each treatment was calculated on the basis of prevailing local charges. The gross realization in terms of rupees per hectare was worked out taking into consideration the seed and stover yields from each treatment and local market prices. Net return of each treatment was calculated by deducting the total cost of cultivation from the gross returns. The benefit: cost ratio (B:C) was calculated by dividing gross return with cost of cultivation.

Results and Discussion

Growth and yield

The results revealed that different treatments manifested significant influence on growth and yield of sesame (Table 1). The treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha) recorded significantly the highest plant height (70.00 cm) and number of branches per plant (3.10) at harvest, but it remained statistically equivalent to the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha). This might be due to adequate supply of nutrients in sufficient amount required by the plant throughout the growing season and improved soil physico-chemical and biological properties of soil through microbial enriched biochar along with vermicompost and FYM lead to improving root proliferation and promoting crop growth. These results are in conformity with the findings of Elangovan and Sekaran (2014) [6], Lal *et al*. (2018) [11] and Mansour *et al.* (2019) [12].

An appraisal of data (Table 1) indicated that significantly the most number of capsules per plant (58.00), length of capsule (2.86 cm), seed weight per plant (5.55 g) and test weight (4.22 g) were recorded with the treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha), which remained statistically at par with the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha). A scrutiny of data (Table 1) further revealed that application of enriched biochar 0.25 t/ha + vermicompost 1 t/ha (T_9) established its superiority by producing significantly the highest seed yield (1741 kg/ha), however it was found statistically at par with the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha). The magnitude of increase in seed yield with treatments T_9, T_{10} and T_7 was 58.90, 52.72 and 40.65 per cent, respectively over the treatment T_1 (RDF).

Significantly the highest stover yield (2123 kg/ha) was registered under the treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha), and it was found statistically comparable to the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha). The extent of increase in stover yield with the treatments T_9, T_{10} and T_7 was 47.34, 41.32 and 29.82 per cent, respectively over the treatment T_1 (RDF). The beneficial effects of enriched biochar and manures on yield and yield attributes seems to be due to co-application of organics could have maintained high regime of soil fertility and moisture by means of better utilization of nutrients and moisture available in the soil by the crop leading to production of more photosynthates leads to higher plant growth and development, which ultimately depicted in increased yield attributes.

The increase in seed yield was attributed to remarkable improvement in almost all the growth and yield attributes under these treatments. Positive response of sesame crop in terms of yield attributes and yield to biochar, enriched biochar, FYM and vermicompost have also been reported by Bhattacharya *et al*. (2015) [3], Gokila (2017) [8] and Garamu (2019) [7].

Nutrients uptake and post-harvest soil fertility

The data given in Table 2 showed that application of enriched biochar 0.25 t/ha + vermicompost 1 t/ha (T_9) recorded significantly the highest uptake of nitrogen (122.65 kg/ha), phosphorus (24.18 kg/ha) and potassium (35.26 kg/ha), but remained statistically at par with the treatment T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha). Higher content of N, P and K in sesame with application of enriched biochar and other organics might be due to increased nutrients availability owing to better physical, chemical and biological properties of soil under these treatments. Furthermore, higher yield with these treatments ultimately resulted in higher uptake of nutrients. The present findings are within the close vicinity of those reported by Coumaravel *et al*. (2015) [4], Arunkumar *et al*. (2019) [2] and Jatav and Singh (2019) [17].

The data furnished in Table 2 indicated that significantly the highest organic carbon content (0.96%) was recorded under the treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha), but it was statistically at par with the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha), T_7 (Biochar 0.5 t/ha + vermicompost 1 t/ha), T_8 (Enriched Biochar 0.25 t/ha + FYM 2.5 t/ha) and T_6 (Biochar 0.5 t/ha + FYM 2.5 t/ha). The treatment T_1 (RDF) recorded significantly the lowest organic carbon content (0.72%). Ample supply organic matter through enriched biochar, FYM and vermicompost to the soil provides a favourable environment for mineralization of the carbon in organics by enriched microbial consortium this might have increased the organic carbon content. Similar findings were also reported by Pal (2019) [13-14] and Sindhu *et al*. (2019) [15].

Significantly the highest available N (248.42 kg/ha) was recorded under the treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha), but it was statistically at par with treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha). The treatment T_5 (Biochar 1 t/ha) recorded significantly the lowest available N (202.20 kg/ha).

Significantly the highest available P_2O_5 (47.79 kg/ha) was noted with the treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha), which was remained statistically comparable with the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha). While, the lowest available P_2O_5 (20.25 kg/ha) was analysed with the treatment T_5 (Biochar 1 t/ha).

Application of enriched biochar 0.25 t/ha + vermicompost 1 t/ha (T_9) resulted in significantly the highest available K_2O (271.72 kg/ha) and it was found statistically similar to the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha). Conversely, the treatment T_5 (Biochar 1 t/ha) registered significantly the lowest available K_2O (236.95 kg/ha). Influence of biochar along with enrichment, FYM and vermicompost might have supplied the balanced nutrients timely and slowly for growth and development of plant. Enrichments of microbial consortia as supplements might have enhanced the nutrient availability by releasing or solubilizing the soil nutrients which are in fixed and unavailable forms. Hence, after harvest, higher amount of soil nutrients might have been observed due to rapid decomposition and mineralization of organics. These results are in conformity with those reported by Devika *et al*. (2018) [5], Palansooriya *et al*. (2019) [13-14] and Singh *et al*. (2019) [17].

Table 1: Growth and yield of summer sesame under organic amendment treatments

Treatments	Plant height (cm)	Number of branches/plant	Number of capsules per plant	Length of capsule (cm)	Seed weight per plant (g)	Test weight (g)	Seed Yield (kg/ha)	Stover yield (kg/ha)
T_1: RDF	60.0	2.13	47.1	2.45	3.51	3.67	1095	1441
T_2: FYM 5 t/ha	58.1	1.70	44.0	2.39	2.84	3.51	885	1165
T_3: Vermicompost 2 t/ha	58.6	1.75	45.2	2.41	3.02	3.56	951	1203
T_4: FYM 2.5 t/ha + Vermicompost 1 t/ha	59.4	1.90	46.4	2.44	3.44	3.64	1074	1417
T_5: Biochar 1 t/ha	55.4	1.33	41.6	2.29	2.23	3.00	682	889
T_6: Biochar 0.5 t/ha + FYM 2.5 t/ha	57.7	1.53	42.6	2.34	2.50	3.27	792	994
T_7: Biochar 0.5 t/ha + Vermicompost 1 t/ha	64.8	2.77	51.7	2.62	4.87	3.83	1541	1870
T_8: EBC 0.25 t/ha + FYM 2.5 t/ha	61.2	2.40	47.8	2.50	4.23	3.70	1323	1642
T_9: EBC 0.25 t/ha + Vermicompost 1 t/ha	70.0	3.10	58.0	2.86	5.55	4.22	1741	2123
T_{10}: EBC 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha	67.7	2.90	55.3	2.74	5.27	3.91	1673	2036
S.Em.±	2.92	0.13	3.06	0.12	0.27	0.17	88	99
C.D. at 5%	8.69	0.38	9.09	0.34	0.80	0.51	261	293
C.V. %	8.26	10.23	11.05	8.01	12.47	8.20	12.93	11.55

Table 2: Nutrients uptake, post-harvest soil fertility and economics under organic amendment treatments

Treatments	N uptake (kg/ha)	P uptake (kg/ha)	K uptake (kg/ha)	OC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Net return (≠/ha)	B:C ratio
T_1: RDF	69.01	13.14	20.44	0.72	220.65	27.85	251.45	61046	2.60
T_2: FYM 5 t/ha	50.37	10.39	15.83	0.76	210.46	25.57	244.51	38721	1.93
T_3: Vermicompost 2 t/ha	56.61	11.67	16.89	0.81	213.61	38.05	247.18	39023	1.83
T_4: FYM 2.5 t/ha + Vermicompost 1 t/ha	66.69	12.88	19.85	0.78	219.27	29.17	250.14	53053	2.20
T_5: Biochar 1 t/ha	29.67	6.59	11.37	0.79	202.20	20.25	236.95	3342	1.06
T_6: Biochar 0.5 t/ha + FYM 2.5 t/ha	39.36	8.32	13.55	0.82	206.77	22.42	241.25	21776	1.44

T_7: Biochar 0.5 t/ha + Vermicompost 1 t/ha	104.90	16.79	29.76	0.88	231.20	24.44	260.06	86805	2.64
T_8: EBC 0.25 t/ha + FYM 2.5 t/ha	82.92	16.95	24.09	0.85	222.03	43.76	253.01	64122	2.15
T_9: EBC 0.25 t/ha + Vermicompost 1 t/ha	122.65	24.18	35.26	0.96	248.42	47.79	271.72	99142	2.69
T_{10}: EBC 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha	115.52	21.89	32.89	0.94	235.39	46.03	265.17	94424	2.65
S.Em.±	5.74	1.15	1.74	0.05	8.11	1.50	6.21		
C.D. at 5%	17.07	3.42	5.18	0.14	24.09	4.44	18.45		
C.V. %	13.49	13.98	13.73	9.89	6.35	7.96	4.27		

Economics

The data on economics (Table 2) revealed that the maximum net returns of ≠ 99142/ha was realized with treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha), followed by the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) and T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha) having net return of ≠ 94424/ha and ≠ 86805/ha, respectively. Whereas, the lowest net realization of Rs. 3342/ha was accrued under T_5 (Biochar 1 t/ha). The data (Table 2) further indicated that the highest B:C (2.69) was obtained with the treatment T_9 (Enriched Biochar 0.25 t/ha + Vermicompost 1 t/ha), followed by the treatments T_{10} (Enriched Biochar 0.25 t/ha + FYM 1.25 t/ha + Vermicompost 0.5 t/ha) with B:C ratio of 2.65, T_7 (Biochar 0.5 t/ha + Vermicompost 1 t/ha) with B:C ratio of 2.64 and T_1 (RDF) with B:C ratio of 2.60. While, the lowest B:C ratio (1.06) was accrued with the treatment T_5 (Biochar 1 t/ha). The highest net return and B:C ratio gained in the treatment T_9 is mainly due to increased seed and stover yield over other treatments.

Based on the experimental results, it seems quite logical to conclude that higher production along with improved soil fertility and higher net return from sesame (Gujarat Junagadh Til 5) can be obtained by the application of microbial consortia enriched biochar 0.25 t/ha + vermicompost 1 t/ha on medium black calcareous clayey soil under South Saurashtra Agro-Climatic Zone.

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