

Original Research Article

Use of Biochar as Soil Amendment for Improvement of Soil Properties and Yield of Spinach (*Spinacia oleracea*) Leafy Vegetable

Comment [c1]: Delete:
Suggested Title: Microbial enriched biochar levels and fertilizer doses on soil chemical properties under Spinach production

ABSTRACT

The present study was carried out at BAIF, Central Research Station, Urulikanchan near Pune to find out the Influence of Biochar as soil amendment on Spinach yield and soil properties during 2020-21. Biochar was used for the experiment with of different doses (5, 7.5, 10 and 15 tha^{-1}) along with recommended dose of NPK fertilizers (40:40:40 kg NPK ha^{-1}). Maximum growth parameters (plant height, leaf length, leaf width and petiole length) were recorded in (T4) with Biochar @ 10 tha^{-1} + 75% of RDF followed by in (T7) Biochar @ 7.5 tha^{-1} + 50% of RDF. Whereas, the highest Spinach yield (18.58 tha^{-1}) was recorded under (T4) Biochar @ 10 tha^{-1} + 75 % of RDF followed by (T3) Biochar @ 7.5 tha^{-1} + 75 % of RDF recorded (17.93 tha^{-1}). The treatment (T1) @ 100 % RDF has registered the superior from economic point of view. Furthermore, the minimum values of growth and yield were recorded under absolute control.

Key words: Spinach, Yield, Biochar, Growth

1. INTRODUCTION

Soil fertility degradation, caused by depletion or imbalance of organic matter/nutrients, is affecting world agricultural productivity (Foley *et.al*, 2005). Inorganic fertilizers have played a significant role in increasing crop production since the “green revolution” (Liu *et. al.*, 2010) however, they are not a sustainable solution for maintenance of crop yields (Vanlauwe *et. al.*, 2010). Long-term overuse of mineral fertilizers may accelerate soil acidification, affecting both the soil biota and biogeochemical processes, thus posing an environmental risk and decreasing crop production (Aciego Pietri *et. al.*, 2008). Organic amendments, such as biochar and compost could therefore be useful tools to sustainably maintain or increase soil organic matter, preserving and improving soil fertility and crop yield.

Comment [c2]: Delete and Rewrite
It must have all the components of manuscript Introduction. Methodology, Result and discussion and conclusion

Suggested

Intensive cultivation of vegetables and imbalanced fertilization depleted the soil nutrients and caused low yield with poor quality crops. A novel microbial enriched biochar and fertilizer combination could alleviate the soil and nutrient stress. Therefore, a field experiment was conducted with 14 treatments [4 levels of biochar (5, 7.5, 10, 15 t ha^{-1}), 3 doses of fertilizers (50, 75, 100% of recommended) along with without biochar and absolute control] in spinach production. This study was conducted with randomized block designed and replicated thrice at BAIF, Central Research Station, Pune during 2020-2021. Maximum growth parameters (plant height, leaf length, leaf width and petiole length) were recorded in (T4) with Biochar @ 10 tha^{-1} + 75% of RDF followed by in (T7) Biochar @ 7.5 tha^{-1} + 50% of RDF. Whereas, the highest Spinach yield (18.58 tha^{-1}) was recorded under (T4) Biochar @ 10 tha^{-1} + 75 % of RDF followed by (T3) Biochar @ 7.5 tha^{-1} + 75 % of RDF recorded (17.93 tha^{-1}). The treatment (T1) @ 100 % RDF has registered as superior from an economic point of view. Furthermore, the minimum values of growth and yield were recorded under absolute control. Based on the above results it is concluded that the combined application of biochar (10 t ha^{-1}) and fertilizers (75% of recommended dose) enhanced the nutrient availability to spinach.

Comment [c3]: Add few lines about spinach and their constraints on production.

Biochar is a carbon-rich material obtained from thermochemical conversion (slow, intermediate, and fast pyrolysis or gasification) of biomass in an oxygen-limited environment. It can be produced from a range of feedstock, including fire wood of forest trees and agriculture residues, such as straw, nut shells, rice hulls, cotton talk pellets, tree bark, and switch grass (Sohi *et. al.*, 2009). Biochar has been described as a possible tool for soil fertility improvement, potential toxic element adsorption, and climate change mitigation (Ennis *et. al.*, 2012).

Indeed, several studies have shown that Biochar application to soil can improve soil physical and chemical properties (Mukherjee *et. al.*, 2013), enhance plant nutrient availability and correlated growth and yield (Biederman *et.al.*, 2013) and reduce greenhouse gas emissions through C sequestration (Crombie *et. al.*, 2015). Therefore, experiment was conducted on use of Biochar for amendment of soil and with an aim to study the influence of Biochar on soil properties and yield of Spinach (*Spinacia oleracea*) Leafy Vegetable.

2. MATERIALS AND METHODS

The study was conducted at BAIF, Central Research Station, Urulikanchan, Ta Haveli Dist. Pune Maharashtra, India. The land having clay type of soil with properly managed cultivable land was selected for conducting the field experiment. The analysis of soil carried out to understand the chemical properties of soil before conducting the experiment. Initially, land was prepared with deep plough and laid out the plot adapting the RBD design. The plot size of 4 x 3 m² were prepared and spread equally the farmyard manure @ 10 tons per ha. The fourteen treatments were designed for this study is given in table 1 below;

Table 1: Treatment details:

Sr #	Treatments Details
T 1	100 % Recommended dose of fertilizer (RDF)
T 2	Biochar @ 5 t ha ⁻¹ + 75 % RDF
T 3	Biochar @ 7.5 t ha ⁻¹ + 75 % RDF
T 4	Biochar @ 10 t ha ⁻¹ + 75 % RDF
T 5	Biochar @ 15 t ha ⁻¹ + 75 % RDF
T 6	Biochar @ 5 t ha ⁻¹ + 50 % RDF
T 7	Biochar @ 7.5 t ha ⁻¹ + 50 % RDF
T 8	Biochar @ 10 t ha ⁻¹ + 50 % RDF

Comment [c4]: Add- Nutrient enrichment by impregnation and intercalation with biochar have improved their use efficiency (Manikandan and Subramanian 2013; 2015). Reference also provided

Comment [c5]: microbial enriched biochar for amendment of soil with fertilizer combinations and specific to understand the soil chemical properties spinach production.

Comment [c6]: Provide Initial soil characteristics in words or table

Comment [c7]: Give details of Spinach variety, duration, sowing date, spacing, fertilizer recommendation, irrigation schedule and harvesting.

T 9	Biochar @ 15 t ha ⁻¹ + 50 % RDF
T 10	Biochar @ 5 t ha ⁻¹ + 100 % RDF
T 11	Biochar @ 7.5 t ha ⁻¹ + 100 % RDF
T 12	Biochar @ 10 t ha ⁻¹ + 100 % RDF
T 13	Biochar @ 15 t ha ⁻¹ + 100 % RDF
T 14	Control (No fertilization)

Different levels of Biochar application in combination with chemical fertilizers (RDF) were applied in the experimental plot with an objective to understand the change in the chemical properties of soil, growth and yield of spinach. Each treatment was replicated into three times under randomized block design. The Biochar was produced from subabul wood (*Leucaena leucocephala*) using a kiln and the coarse powder prepared using pounding machine.

Comment [c8]: Why did you select subabul? Brief about production efficiency and cost of biochar

The powdered Biochar was treated with 20% concentration of pure microbial cultures like *Rhizobium*, *Phosphate Solubilizing Bacteria (PSB)* and *Tricoderma*. The treated biochar was dried under shade for a day and applied to the field as per the doses 5, 7.5, 10 and 15 t ha⁻¹ separately. At the same time chemical fertilizers applied before sowing of the crop as per the dose mentioned in the Table-1. Before two days of the harvest of crop, the plant growth observations like Plant height, leaf length, width and petiole length were recorded and then spinach leaves were harvested from each treated plot separately.

Comment [c9]: How did you fix 20% for microbial enrichment. If any reference is available mention it.

The change in the soil chemical properties before and after harvest of the crop was analyzed in the laboratory from the collected soil samples. At the end of the study statistical analysis was carried out for each observed characters under the study using MS-Excel (2010) and OPSTAT software (Sheoran *et al.*, 1998).

3. RESULTS AND DISCUSSION

Influence of Biochar on growth parameters of spinach

The data presented in Table 2. Clearly indicates that, except petiole length, there is a non-significant variation in other growth parameters due to application of different doses of Biochar and fertilizers. However, the study shows that, a higher plant growth was recorded in treatment T₉ (Biochar @ 15 t ha⁻¹ + 50 % RDF) in plant height (38.4 cm), Leaf length (16.3 cm), Leaf width (11.8 cm), was recorded in and average number of leaves per plant was same in (12 leaves plant⁻¹) in treatment T₈ (Biochar @ 10 t ha⁻¹ + 50 % RDF) and T₉ (Biochar @ 15 t ha⁻¹ + 50 % RDF). Whereas, minimum plant height (22.8 cm), Leaf length (8.8 cm), Leaf width (7.7 cm), Petiole length (12.7 cm) was recorded in treatment T₁₄ Control (No fertilization) over all the treatments. The observation made on leaf: petiole ratio shows that there was non-significant effect due to different level of treatments which might be attributed to slow release of nutrients through Biochar, this might have affected the growth of spinach. The growth parameters recorded were near to the results of Chat *et al.*, (2005) and Roy *et al.*, (2009) in spinach.

Comment [c10]: Optional: For better understanding of the results, data may be compared with either RDF or control. In another way group them as per level or dose (5,7.5,10 and 15 t ha⁻¹ or 50,75,100% fertilizer dose)

Table.2: Effects of different levels of Biochar in combination with NPK on growth of Spinach

Tr #	Treatment Details	Plant Height (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf: petiole (Length basis)	Average no. of leaves/plant
1	100 % Recommended dose of fertilizer (RDF)	32.7	13.4	10.2	18.5	0.72	11
2	Biochar @ 5 t ha ⁻¹ + 75 % RDF	36.4	14.7	10.4	21.6	0.68	11
3	Biochar @ 7.5 t ha ⁻¹ + 75 % RDF	30.0	13.2	9.3	17.3	0.77	11
4	Biochar @ 10 t ha ⁻¹ + 75 % RDF	34.6	13.7	9.3	20.0	0.69	11
5	Biochar @ 15 t ha ⁻¹ + 75 % RDF	30.1	13.4	8.6	17.6	0.76	11
6	Biochar @ 5 t ha ⁻¹ + 50 % RDF	35.7	14.4	9.7	21.1	0.69	10
7	Biochar @ 7.5 t ha ⁻¹ + 50 % RDF	37.9	15.0	9.7	21.6	0.70	11
8	Biochar @ 10 t ha ⁻¹ + 50 % RDF	34.2	13.6	8.9	20.3	0.67	12
9	Biochar @ 15 t ha ⁻¹ + 50 % RDF	38.4	16.3	11.8	24.0	0.68	12
10	Biochar @ 5 t ha ⁻¹ + 100 % RDF	34.2	14.2	9.3	22.4	0.63	10
11	Biochar @ 7.5 t ha ⁻¹ + 100 % RDF	33.9	14.0	9.5	20.4	0.69	11
12	Biochar @ 10 t ha ⁻¹ + 100 % RDF	31.5	12.5	8.8	22.9	0.55	10
13	Biochar @ 15 t ha ⁻¹ + 100 % RDF	30.1	13.6	9.4	19.6	0.69	10
14	Control (No fertilization)	22.8	8.8	7.7	12.7	0.69	7
	SE(m) _±	3.099	1.037	0.721	0.865	0.048	0.661
	CD at 5 %	N.S.	N.S.	N.S.	2.528	N.S.	N.S.

Effects of different levels of Biochar on Spinach yield

The data pertaining to leaf yield and economics of experiment are presented in Table 3. The effect of Biochar dose on Spinach yield is indicated positively showed that, combined application of different levels of Biochar and chemical fertilizers. However, the application of Biochar @ 10 tha^{-1} + 75 % of RDF (T_4) has given significantly higher yield (18.58 tha^{-1}) and is also at par with T_1 (100 % RDF), in T_2 (Biochar @ 5 tha^{-1} + 75 % of RDF), T_3 (Biochar @ 7.5 tha^{-1} + 75 % of RDF), in T_8 (Biochar @ 10 tha^{-1} + 50 % of RDF) and in T_9 (Biochar @ 15 tha^{-1} + 50 % of RDF), were found superior for improving spinach yield. From this study indicates that, as the Biochar doses increases the Spinach leafy yield was not improved. However, the needs to continue at least for three seasons to come out with confined conclusion. The above findings are in conformity with Ansari (2008), Canali *et al.*, (2008) and Patel *et al.*, (2008) who observed higher yield in spinach by application of Farmyard manure with inorganic fertilizers.

Comment [c11]: Same as above

Benefit cost ratio of the study:

The data pertaining to economics of each treatment viz., cost of cultivation, gross income, net income and benefit: cost ratio has shown in Table 3. The maximum yield 18.58 tha^{-1} was recorded in T_4 and also the highest gross monetary return of Rs. 278625/- ha^{-1} was calculated. But cost of cultivation of Rs. 250641/- was higher in treatment T_{13} (Biochar @ 15 tha^{-1} + 100 % RDF) followed by T_5 (Biochar @ 15 tha^{-1} + 75 % RDF) Rs. 240500/- ha^{-1} , in T_9 (Biochar @ 15 tha^{-1} + 50 % RDF) Rs. 234668/- ha^{-1} , whereas, in treatment T_{14} lowest gross income Rs. 52500/- ha^{-1} was recorded. By considering all inputs, the benefit: cost ratio was calculated, higher in T_1 (3.75) followed by T_2 (2.15), T_3 (1.78), T_4 (1.73), T_8 (1.55) under, T_{10} (1.79). The highest benefit cost ratio was recorded in treatment T_1 (100 % RDF) i.e. 3.75, this is due to no cost of application of Biochar which has increased the net income.

Table.3 Effects of different levels of Biochar in combination with NPK Fertilization on yield and economics of Spinach

Tr #	Treatment Details	Yield (tha ⁻¹)	Gross Monetary Returns (Rsha ⁻¹)	Cost of cultivation (Rsha ⁻¹)	Net Monetary Returns (Rsha ⁻¹)	Benefit : cost ratio
1	100 % Recommended dose of fertilizer (RDF)	16.81	252083	67274	184809	3.75
2	Biochar @ 5 t ha ⁻¹ + 75 % RDF	17.22	258333	120411	137923	2.15
3	Biochar @ 7.5 t ha ⁻¹ + 75 % RDF	17.93	268958	150973	117985	1.78
4	Biochar @ 10 t ha ⁻¹ + 75 % RDF	18.58	278625	181536	97089	1.53
5	Biochar @ 15 t ha ⁻¹ + 75 % RDF	16.03	240500	242661	-2161	0.99
6	Biochar @ 5 t ha ⁻¹ + 50 % RDF	15.53	232917	112418	120499	2.07
7	Biochar @ 7.5 t ha ⁻¹ + 50 % RDF	16.25	243792	142981	100811	1.71
8	Biochar @ 10 t ha ⁻¹ + 50 % RDF	17.89	268292	173543	94749	1.55
9	Biochar @ 15 t ha ⁻¹ + 50 % RDF	16.74	251167	234668	16499	1.07
10	Biochar @ 5 t ha ⁻¹ + 100 % RDF	15.20	228042	127491	100551	1.79
11	Biochar @ 7.5 t ha ⁻¹ + 100 % RDF	15.46	231833	158954	72880	1.46
12	Biochar @ 10 t ha ⁻¹ + 100 % RDF	16.10	241458	189516	51942	1.27
13	Biochar @ 15 t ha ⁻¹ + 100 % RDF	15.27	229083	250641	-21558	0.91
14	Control (No fertilization)	3.50	52500	35320	17180	1.49
	SE(m)±	0.75	11,379.49		12,383.66	0.09
	CD at 5 %	2.21	33,262.61		36,197.84	0.263

Effects of different levels of Biochar application on soil properties

It has been reported that the application of biochar to soil improves nutrient availability, though the effects vary with biochar types/doses and soil types (Khodadad *et al.* 2011). The effects of biochar on soil nutrients can have high adsorption capacity and can reduce nutrient loss and increase soil fertility (Gul *et al.* 2015). The results in our research showed that soil organic carbon content was increased by 0.15 % after application of Biochar @ 10 t ha⁻¹ + 50% of RDF. Similar findings reported by (Laird *et al.* 2010) and (Wang *et al.* 2014) also reported that addition of Biochar at the rate of (5 t ha⁻¹) significantly increased soil organic carbon content. Primary reason for these observations could be due to presence of stable carbon in the Biochar that is difficult to decompose in soil environments, thus contributing to the soil carbon improvement.

Comment [c12]: Is there any change compared to initial soil chemical properties? Highlight it.

Table 4: Soil chemical analysis

Tr #	Treatment Details	pH	EC	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
	Base line	7.34	0.48	0.61	134	30	215
After harvesting							
T 1	100 % Recommended dose of fertilizer (RDF)	7.52	0.42	0.58	139	36	231
T 2	Biochar @ 5 t ha ⁻¹ + 75 % RDF	7.26	0.44	0.66	125	31	230
T 3	Biochar @ 7.5 t ha ⁻¹ + 75 % RDF	7.49	0.39	0.64	130	32	225
T 4	Biochar @ 10 t ha ⁻¹ + 75 % RDF	7.37	0.48	0.68	125	34	223
T 5	Biochar @ 15 t ha ⁻¹ + 75 % RDF	7.48	0.47	0.65	138	38	238
T 6	Biochar @ 5 t ha ⁻¹ + 50 % RDF	7.3	0.47	0.52	140	28	225
T 7	Biochar @ 7.5 t ha ⁻¹ + 50 % RDF	7.48	0.44	0.57	126	25	215
T 8	Biochar @ 10 t ha ⁻¹ + 50 % RDF	7.45	0.4	0.76	128	29	235
T 9	Biochar @ 15 t ha ⁻¹ + 50 % RDF	7.41	0.48	0.6	127	34	230
T 10	Biochar @ 5 t ha ⁻¹ + 100 % RDF	7.36	0.39	0.52	130	43	240
T 11	Biochar @ 7.5 t ha ⁻¹ + 100 % RDF	7.48	0.47	0.58	132	31	231
T 12	Biochar @ 10 t ha ⁻¹ + 100 % RDF	7.42	0.42	0.69	134	33	237
T 13	Biochar @ 15 t ha ⁻¹ + 100 % RDF	7.44	0.47	0.6	135	29	230
T 14	Control (No fertilization)	7.57	0.35	0.5	136	27	230

4. CONCLUSION

It can be concluded that spinach is highly responsive to combined application of different levels of Biochar and inorganic source of nutrition. Application of Biochar @ 10 tha^{-1} + 75 % of RDF (T₄) gives highest yield (18.58 tha^{-1})

Comment [c13]: Application of microbial enriched biochar with 75% of RDF (T₄) given maximum yield.

Considering the soil health, the consistent use of chemical fertilizer alone will not be recommended. Using chemical fertilizer along with the Biochar will be the more benefit in terms of moisture holding, increased soil organic carbon. However, the study need to be continued for at least for the three seasons to draw a precise conclusion related to yield and soil properties.

Comment [c14]: Microbial enriched biochar

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