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Potential of Biochar and Silicon on Productivity and Profitability of Organic Fenugreek (*Trigonella frenum-graecum* L.) in Southern Rajasthan

Akshita Bhatt, Deepak Kumar[1*], M.K. Kaushik, Brijesh Kumar[1], P.S. Hindoriya[1] and Pooja Nain[2]

Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur-313 001, India
[1]ICAR- National Dairy Research Institute, Karnal-132 001, India.
[2]College of Agriculture, G.B. Pant University of Agriculture & Technology (GBPUAT), Pantnagar- 263 153, India
**E-mail: bhardwaj051238@gmail.com*

Abstract: The aim of the present study accessed the effects of the integrated use of organic inputs such as silicon and biochar on the growth, yield and profitability of fenugreek. The field experiment was conducted in *rabi,* 2020-21 at MPUAT, Udaipur (Rajasthan). The treatments consisted of four levels of soil-applied biochar (control, 2, 3 and 4 t/ha) and four foliar-applied silicon sprays at 45 and 90DAS (water spray, 1.5, 2.0 and 2.5 %). Significantly maximum plant height (53.30 and 90.14 cm), dry matter accumulation (5.00 and 20.43 g) at 60 DAS and harvest, respectively, total chlorophyll content with SPAD meter at flower initiation (56.55), and seed yield (1944 kg/ha) were recorded with the application of 4 t /ha biochar at par with 3 and 2 t/ha. Moreover, the maximum plant height (49.43 and 90.23 cm), dry matter accumulation (4.65 and 20.18 g/plant) at 60 DAS and harvest, and seed yield (1919 kg/ha) were with 2.5% foliar application of silicon. Maximum seed yield (2155 kg/ha), net return (150490₹/ha), and BC ratio (2.66) were obtained with the treatment's combination of 2 t/ha soil applied biochar and 2.5% foliar applied silicon.

Keywords: Biochar, Fenugreek, Organic farming, Silicon

Fenugreek (*Trigonella foenum-graecum* L.) is an annual crop and member of the family Fabaceae, the order Leguminosae. Since ancient civilizations, fenugreek has been renowned for its several culinary and medicinal purposes, from preserving carcasses and mummies in Egypt to acting as a traditional ameliorate in the medical system of several Southeast Asian countries. This plant is primarily used as a spice in India and countries of the Mediterranean region. India leads the fenugreek production in the world with an area of 120 thousand hectares, contributing to the production of 188.48 thousand tonnes with average productivity of 1007 kg/ha as per the advance estimate of 2019-20 (Spice Board of India, 2020). Rajasthan leads in fenugreek production, having 150 thousand hectares area under cultivation and alone contributing up to 77 percent production, *i.e.*, 160 thousand tonnes with average productivity of 1066 kg/ha in 2016-17 (Sachan et al 2020). The recognition and demand for organic products in the world market are rising. Still, production is deficient under organic cultivation because of limited land area and poor crop productivity, which needs to be supplemented with incorporating advanced inputs to increase crop production per unit area under organic farming. Several organic inputs are being studied to increase yield and productivity without sabotaging the agricultural ecosystem to improve the organic cultivation of crops. In a similar line of research, two potential inputs, biochar and silicon, are considered in the organic cultivation of fenugreek.

Biochar is a pyrolyzed product of the biomass formed after heating at the temperature of 300-600^0 C in the absence of oxygen. It is a carbon-rich, dark-colored powdery product with several unique properties. Biochar is preferred as an amendment because of its low density, high porosity and aeration, significant adsorption and cation exchange capacity, providing favorable conditions for living microbiology in the soil, capacity to increase the soil carbon pool and nutrient availability and thus to improve the overall fertility of the soil. With the upliftment in soil's physical, chemical and biological properties, biochar can be categorized as potential input to increase the yield under organic farming conditions. Adequate nutrient management is necessary to enhance the productivity of the organic fenugreek crop. The foliar application of silicon can play a crucial role by promoting several desirable physio-chemical processes in plants to increase crop productivity and quality besides mitigating the stresses (Jinger et al 2021). The need for proper Si management to increase yield and sustain crop productivity appears necessary where Si diminution in the

soil can occur due to intensive and continuous cultivation practices of high-yielding cultivars. As a result, these soils are generally low in plant-available Si (Korndorfer et al 2001). Keeping these facts, the present study was conducted to evaluate the effect of soil-applied biochar and foliar-applied silicon on fenugreek's growth, yield and economics.

MATERIAL AND METHODS

Experimental site and soil status: The field experiment was carried out during *rabi* season of 2020-21 at the organic farm unit, MPUAT, Udaipur, which lies in Rajasthan's South-Eastern zone (IV a). The soil of the experimental site was clay loam in nature, with a slightly alkaline reaction (pH 7.8) having a bulk density of 1.35 g/cc and electrical conductivity of 0.75dS m^{-1}. The nutrient status of the soil showed 0.70 %, 283.44, 22.2 and 279.3 kg/ha of organic carbon, available nitrogen, phosphorus and potassium content, respectively, depicting the overall medium nutrient status of the soil.

Preparation of biochar: In the present experimental field, legume biochar was used through slow pyrolysis in the biochar production system (Pratap Kiln) prepared in the CTAE, Udaipur. Biochar was made by partial oxidation of the biomass at high temperatures to convert it into a carbon-rich porous substance. Haulms of legume were fed to the pyrolysis reactor in the oxygen-limiting condition, where the temperature went up to 450^0 C for 4 minutes. This process occurs in 3 stages, first where the moisture content of the biomass is reduced to <10% at the temperature of 180^0 C, second here the biochar production starts with the breakdown of hemicellulose and cellulose at the temperature range of 180-360^0 C and last stage where lignin breaks down at the temperature of 450^0 C. In slow pyrolysis, the final yield of the converted biochar goes up to 35 %, which is more in comparison to fast pyrolysis**.** The biochar was then applied in each plot as per the detail of the treatments before the crop sowing and incorporation in the soil was done with the help of a rake.

Preparation of suspension of silicon: The source used for the foliar spray of active silicon was diatomaceous earth. Silicon present in this compound is in the form of silicates. It is a smooth white sedimentary talc with 80-90 percent silica, forming a milky white suspension when it dissolves in water. To make a stable suspension and to prevent it from settling down, Na CMC (Carboxyl Methyl Cellulose) was used at the rate of 0.05 percent as it is a natural polymer and helps stabilize the suspension. The desired amount of suspension was made by adding diatomaceous earth in water with 0.05 percent of Na CMC and sprayed in each plot as per the treatments with the help of a knapsack sprayer. Two foliar sprays were done at 45 and 90 DAS.

Experimental design and treatments: The experiment consists of two input factors, each at four levels, represented symbolically such as soil application of biochar, i.e., B_1, B_2, B_3 and B_4 (control, 2, 3 and 4 t/ha, respectively) and foliar spray of silicon, i.e., S_1, S_2, S_3 and S_4 (water spray, 1.5, 2.0 and 2.5 %, respectively), respectively, was laid out in a factorial randomized block design and replicated thrice. The recommended dose of 20 N and 40 P_2O_5 kg/ha was applied as basal at the time of sowing through organic sources like vermicompost, NADEP and neem cake. The crop variety Pratap Rajasthan Methi-45 (PRM-45) was sown using 25 kg seed /ha and harvested after 137 days of sowing. Biochar was applied and incorporated into the soil before the crop sowing. At the same time, silicon was foliar applied two times at 45 and 90 DAS in silicate suspension through diatomaceous earth (80% Si) as per the treatment recommendation. To make a stable suspension of silicate in water, sodium carboxymethyl cellulose (Na-CMC) was used to increase the solubility with an organic origin.

Observations: Dry matter accumulation was calculated by weighing the oven-dried samples (65°C). Total relative chlorophyll content was measured at the flower initiation stage with the help of a SPAD meter. Yield attributes and yield were recorded from the net plot area at and before the crop harvest.

RESULTS AND DISCUSSION

Effect of biochar levels: The maximum plant height (53.30 and 90.14 cm), dry matter accumulation (5.00 and 20.43 g) at 60 DAS and harvest, respectively and total chlorophyll content with SPAD meter at flower initiation (56.55) of the crop were observed with the biochar addition of 4 t/ha which were at par with 3 and 2 t /ha biochar (Table 1). Moreover, all the biochar levels failed to show significant variations in days to flower initiation and days to maturity in fenugreek. All the yield attributes viz., the number of pods/plant (30.42), seed weight/plant (6.11 g) and test weight (12.01g) were significantly maximum at 4 t/ha over control and at par with 3 and 2 t/ha of biochar addition in the soil (Table 2). In contrast, the number of seeds/pods failed to increase significantly. Higher seed yield (1994 kg/ha) and haulm yield (4816 kg/ha) of fenugreek were soil application of 4 t/ha over control and at par with 3 and 2 t/ha. Similarly, biological yield (6810 kg/ha) was found to be maximum under 4 t/ha biochar at par with 3 t/ha. Harvest index (29.75%) was the maximum, with 2 t /ha biochar over control and the rest of the treatments. Economic analysis (Table 3) revealed that soil application of 2 t/ha biochar gave a maximum return (₹130409 /ha).

The increase in growth attributes like plant height and dry matter accumulation could be due to more nutrient

availability by improving the CEC of the soil, total organic carbon and total nitrogen content (Schulz et al 2013) and also by providing favorable conditions to the soil microbiota mainly when biochar is applied in combination with the organic manures (Arif et al 2021). The biochar incorporation in the soil leads to vigorous vegetative growth resulting in higher photosynthate production and translocation from source to the sink, which is apparent in reproductive growth, *viz.,* the number of pods/plant, the number of seeds/pod and seed weight/plant, which were the vital yield attributes having a significant positive effect on seed yield. Similar results were obtained by Hiama et al (2019) and Ye et al (2020) regarding seed yield and biological yield.

Effect of silicon levels: The varying levels of foliar-applied silicon positively improved the fenugreek's growth (Table 1). Foliar application of 2.5% silicon recorded maximum plant height (49.43 and 90.23 cm) and dry matter accumulation (4.65 and 20.18 g/plant) over control and other treatments at 60 days after sowing and harvest, respectively. Although, silicon application had no significant impact on total chlorophyll content, days to flower initiation and days to maturity. The foliar-applied silicon increased the number of pods/plant (30.50) and seed weight/plant (6.12g) with silicon concentration at 2.5%. In contrast, the number of seeds/pod and test weight did not affect significantly. Maximum seed yield (1919 kg/ha), haulm yield (4806 kg/ha) and biological yield (6725 kg/ha) were reported with 2.5% foliage applied silicon over control and the rest treatments. The harvest

Table 1. Effect of biochar and foliar applied silicon on the growth attributes of organic fenugreek

Treatments	Plant height(cm)		Dry matter accumulation (g/plant)		Chlorophyll content at flower initiation (SPAD meter)	Days to flower initiation	Days to maturity
	60 DAS	At harvest	60 DAS	At harvest			
Biochar levels (t /ha)							
Control	40.97	82.94	4.20	15.84	51.51	44.17	136.58
2	43.77	88.21	4.34	19.81	54.41	44.75	136.75
3	51.89	88.24	4.67	20.00	54.79	44.83	136.92
4	53.30	90.14	5.00	20.43	56.55	45.17	137.08
CD (p=0.05)	1.86	2.09	0.16	0.68	2.29	NS	NS
Silicon levels (%)							
Water spray	46.10	84.67	4.43	18.25	54.00	44.75	136.75
1.5	45.61	86.57	4.48	18.58	54.21	44.58	136.67
2.0	48.79	88.07	4.65	19.07	54.52	44.83	136.42
2.5	49.43	90.23	4.65	20.18	54.53	44.75	137.50
CD (p=0.05)	1.86	2.09	0.16	68	NS	NS	NS

Table 2. Effect of biochar and foliar applied silicon on the yield attributes and yield of fenugreek

Treatments	No. of pods/ plant	No. of seeds/pod	Seed weight /plant	Test weight (g)	Seed yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Biochar levels (t /ha)								
Control	26.58	15.83	4.85	11.53	1328	3953	5281	25.25
2	29.50	16.08	5.65	11.89	1935	4575	6510	29.75
3	29.67	16.42	5.82	11.93	1967	4698	6665	29.51
4	30.42	17.00	6.11	12.01	1994	4816	6810	29.35
CD (p=0.05)	1.59	NS	0.47	0.19	63.85	242.78	241.74	1.34
Silicon levels (%)								
Water spray	28.25	16.00	5.31	11.76	1712	4333	6044	28.25
1.5	28.58	16.25	5.48	11.78	1757	4383	6140	28.54
2.0	28.83	16.33	5.59	11.86	1837	4520	6357	28.72
2.5	30.50	16.75	6.12	11.97	1919	4806	6725	28.35
CD (p=0.05)	1.59	NS	0.47	NS	63.85	242.78	241.74	NS

index of fenugreek did not significantly affect by the silicon application as a foliar spray. Net return (₹127367 /ha) was obtained highest with 2.5% foliar application of silicon (Table 3).

The effect of silicon could explain the increase in plant height and dry matter accumulation in enhancing the plant-water relationship, which modifies the cell division and elongation process. The silicon in the plant system acts as an immuno-booster and regulates anti-oxidant properties, which can positively increase plant growth. Diwan et al (2019) and Hussain et al (2021) reported similar results on increased plant height and dry matter accumulation. The increase in yield attributes and yield of fenugreek could be due to the role of silicon in stomatal activity by hindering sodium flux and enhancing intracellular CO_2 concentration, which further increases photosynthesis and water use efficiency (Ahmad et al 2013). Moreover, silicon plays a significant role in plant stress resistance and disease prevention, leading to better plant yield and quality. Silicon modifies the source-sink relationship and thus increases the mobilization of photosynthates and amino acids from the vegetative parts to the reproductive organs. The increase in net return could be due to the increased seed yield (1780 kg /ha) and haulm yield (4089 kg /ha) obtained under the foliar application of 2.5% silicon. Similar findings were also reported by Rao et al (2018).

Interaction effect of biochar and foliar applied silicon: Biochar and foliar-applied silicon positively interacted with parameters like seed yield (Table 4), net return and BC ratio (Table 5). The highest seed yield (2155 kg /ha) was obtained with the treatment combination of 2 t /ha biochar and 2.5% foliar applied silicon, which was at par with 3 t/ha biochar and 2.5% foliar applied silicon (2115 kg /ha) and 3 t/ha biochar and 2.0% foliar applied silicon (2113 kg /ha). While the maximum net return (₹150490 /ha) was found with the treatment combination (B_2S_4) of 2 t/ha biochar with 2.5%, foliar applied silicon over control and other treatment combinations.

The positive coupling action of biochar could explain the interaction effect on the seed yield on below-ground modifications to increase the nutrient availability and active silicon on the above-ground control on the stomatal activities and enhanced photosynthesis through higher light use efficiency (Maghsoudi et al 2016), synergetic effects on the plant growth and development (Sattar et al 2020), improved the crop productivity (Seleiman et al 2019). Due to the increased seed yield of fenugreek significantly by the combined application of biochar and active silicon, the

Table 3. Effect of biochar and foliar applied silicon on net return (₹/ha) and BC ratio

Treatments	Total cost (₹/ha)	Net return (₹/ha)	BC ratio
Biochar levels (t/ha)			
Control	36367	93834	2.58
2	56454	130409	2.31
3	66370	123448	1.86
4	76131	117242	1.54
CD (p=0.05)		614.90	0.01
Silicon levels (%)			
Water spray	55150	107560	1.95
1.5	55876	111194	1.99
2.0	56578	118813	2.10
2.5	56607	127367	2.25
CD (p=0.05)		614.90	0.01

Table 4. Interaction effect of biochar and foliar applied silicon on seed yield (kg /ha)

Biochar levels (t/ha)	Silicon levels (%)			
	Water spray	1.5	2.0	2.5
Control	1297	1339	1336	1341
2	1845	1858	1883	2155
3	1815	1826	2113	2115
4	1889	2006	2015	2066
CD (p=0.05)	127.69			

Table 5. Interaction effect of biochar and foliar applied silicon on net return (₹/ha) and BC ratio

Biochar levels (t /ha)	Silicon levels (%)							
	Net return (₹/ha)				BC ratio			
	Water spray	1.5	2.0	2.5	Water spray	1.5	2.0	2.5
Control	90690	94333	94340	95973	2.54	2.59	2.58	2.62
2	122027	123291	125830	150490	2.19	2.18	2.23	2.66
3	109694	110940	136548	136613	1.67	1.67	2.05	2.05
4	107831	116212	118536	126391	1.42	1.52	1.55	1.65
CD (p=0.05)	319.48				0.02			

interaction effect of both factors is also visible on the economic parameter resulting in a higher net return from the treatment combination of B_2S_4.

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