



Evaluation of Biofertilizers and Biochar on the Plant Growth and Productivity of Soybean (*Glycine max*)

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SA and DT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DB and NR managed the analyses of the study. Author DB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The field experiment was conducted in Organic farm of Amity university Noida, Uttar Pradesh, during the kharif season, to evaluate the sole and conjoint effect of biofertilizers and biochar on the yield, growth and productivity of Soybean (*Glycine max*). The five treatments viz. T₁ (Control), T₂ (Biochar), T₃ (Biochar + *Rhizobium*), T₄ (Biochar + *Azospirillum*) and T₅ (Biochar + *Rhizobium* + *Azospirillum*) were used. Plant growth parameters like shoot length, root length, number of leaves, pod length, pod girth, plant height, crop yield and soil parameters were observed for the effect of various treatments. Among the all treatments the treatment T₃ (Biochar with *Rhizobium*) maximum shoot length (52.30), root length (17.30) followed by T₄ (Biochar + *Azospirillum*) and plant productive are maximum mean of number of pods was recorded in T₃ (Biochar + *Rhizobium*) i.e. 32.6, whereas minimum (30.1) was recorded in T₁(control) followed by T₄(Biochar + *Azospirillum*) i.e.32.41, T₅(Biochar + *Rhizobium* + *Azospirillum*) i.e. 31.05 and T₂(Biochar) i.e.31.31 has shown significant effect on plant growth characters and plant yield. These results indicate that the conjoint use of biochar and *Rhizobium* have potential to enhance the crop performance and simultaneously improves the soil properties for sustainable farming without reliance on synthetic agrochemicals.

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1. INTRODUCTION

Modern agricultural farming traditions, beside the irrational use of chemical products over the past four decades have resulted in not only loss of natural habitat balance and soil health but have also caused many hazards like soil erosion, decreased groundwater level, soil salinization, pollution due to fertilizers and pesticides, genetic erosion, negative effects on environment, reduced food quality and increased the cost of cultivation, rendering the farmer poorer year by year [1,2]. The ill effects of modern agriculture practices have now provoked the need of the eco-friendly and healthy farming practices such as organic farming. Biofertilizers are the integral part of the organic farming whereas, Biochar is gaining its importance in the non-agrochemical agriculture practices.

Biochar is a porous and highly stable form of charcoal produced by slow pyrolysis of organic wastes such as crop residues. There is increasing interest in its potential particularly as a soil amendment and for carbon sequestration in the low-oxygen environment. Biochar is known to have positive effects on physico-chemical and biological properties of soil [3]. Compile which physico-chemical and biological properties of soil [4]. In addition, biochar can also be used to improve topsoil water retention in farmlands, reduce nitrous oxide emissions, and balance soil acidity and increase soil organic carbon. By enhancing soil organic matter, biochar also enhances soil nutrient levels and water availability, which in turn contribute to higher crop yields [5]. Subjected to various mentioned beneficial effects, biochar is used as a soil amendment to increase yields of rice, soybean, corn, and vegetables [6]. Biofertilizers, on the other hand, are the formulations of living microorganisms, which are capable of mobilizing nutritive elements from non-usable form to usable form through various biological processes [7]. The role and importance of different biofertilizers specifically of *Rhizobium* and *Azospirillum*, in sustainable crop production have been reported and reviewed by several authors [8,9,10].

Soybean (*Glycine max*) is also known as 'poor man's meat', due to its high nutritional value, is a pulse crop that initially gained importance as an oilseed crop, as it contains 20% cholesterol free oil [11]. Soybean played a key role in the

yellow revolution. Madhya Pradesh is the first largest producer in India with 81% area of land under cultivation [12]. *The total soybean production in 2019 is 83% in nation* [13]. Soybean has been playing an important role in the national economy by earning an average of Rs. 32,000 million per annum through export of soy meal and contributing about 18% to the edible oil production [14]. They are not only a quality source of protein for human beings, but also called as 'fertility restorer crops'. They are able to fix atmospheric nitrogen with the help of symbiotic nitrogen fixers. This helps in improving the nitrogen economy of the soil. The pulse farming is largely dependent on the use of chemical fertilizers, leading to environmental concerns.

Although there the wide and established research on role biofertilizers and biochar in cereals, there still lays the possibilities to unfold effect of biofertilizers and biochar on pulses. Taking this into the consideration, the present study was conducted with an objective to test the combined and individual effects of biofertilizers and biochar on plant growth and productivity of Soybean (*Glycine max*) in the field conditions.

2. MATERIALS AND METHODS

The experiment was conducted during Kharif season, 2018 at the research farm of Amity Institute of Organic Agriculture, Amity University, Noida (UP), situated at 28°53' N latitude and 77°39' E longitude and at an altitude of 200 m above mean sea level. Soybean (JS335) was used under Randomized Block Design (RBD), with five treatments and three replications. The plot size was 2.0 × 2.0 m with 30 cm × 15 cm spacing. *Treatment details are as:* T₁(Control); T₂(Biochar); T₃(Biochar +*Rhizobium*); T₄(Biochar + *Azospirillum*) and T₅ (Biochar + *Rhizobium* + *Azospirillum*). For determining the initial status, the soil samples were collected from experimental site, processed and physico-chemical properties of soils were measured with the prescribed standard procedure (Jackson 2005).

Initial physicochemical status of the soil recorded sandy loam texture with 62.20 % sand, 11.00 % silt and 24.20 % clay respectively. Organic carbon (0.60%), and total N (0.045%) status was low. The available P status was also low (19.70);

however available K was in medium range (263.30) Soil pH was slightly alkaline in nature.

The biochar was applied in the field plots 5 days before sowing and the seeds were inoculated with treatments comprising of Rhizobium, Azospirillum on the day before sowing. Cultural practices as per the package of practices were followed. The Neem oil was sprayed to control pest like aphids in three regular intervals. The crop was harvested at the time of maturity, pods are handpicked and stored. The threshing of the crop was done after sun drying.

Five tagged plants from each plot were used for periodical observations. These plants were separately harvested at maturity for assessing their growth and yield attributes. Plant parameters, viz. Seed germination, Shoot and Root length (cm), Number of leaves per plant, Number of branches per plant, Pod length (cm), Pod girth (cm), Number of pods per plant, Test weight (g), Grain yield (kg/ha), Straw yield (kg/ha), Total plant biomass, Final plant stand and Harvest index.

Soil physico-chemical parameters such as Bulk density (Core sampler method), pH, organic matter, available N, P and K status (Jackson 2005) were measured.

The data on various soil and plant parameters was subjected to statistical analysis using randomized block design as outlined by (Gomez

and Gomez 1984). The critical difference at 5% level was used for testing the significant differences among the treated means.

3. RESULTS

3.1 Effect on Plant Growth Parameters

3.1.1 Shoot length and root length (cm)

The shoot length recorded at 15, 30, 45, 60, 90 DAS and maturity stages were statistically computed and the data is presented in figure. The treatment T₃(Biochar + *Rhizobium*) attained significantly taller plants compared to all other treatments at all stages of crop growth. The maximum shoot length was recorded under treatment T₃ (Biochar + *Rhizobium*) i.e. 52.29 cm and the minimum was observed in T₁ (Control) i.e. 48.62, followed by T₄(Biochar + *Azospirillum*) i.e.50.23, T₅ (Biochar + *Rhizobium* +*Azospirillum*) i.e.48.62 and T₁ (Biochar) i.e. 47.44. The recorded data was shown in Fig. 1.

The maximum root length, was also recorded under treatment T₃ (Biochar + *Rhizobium*) i.e. 17.31 cm and the minimum root length (14.31 cm) was recorded under treatment T₁ (control) at the days 90, followed by T₄(Biochar + *Azospirillum*) i.e.16.81, T₅ (Biochar + *Rhizobium* +*Azospirillum*) i.e.15.91 and T₁ (Biochar) i.e. 15.11. The recorded data was shown in Fig. 2.

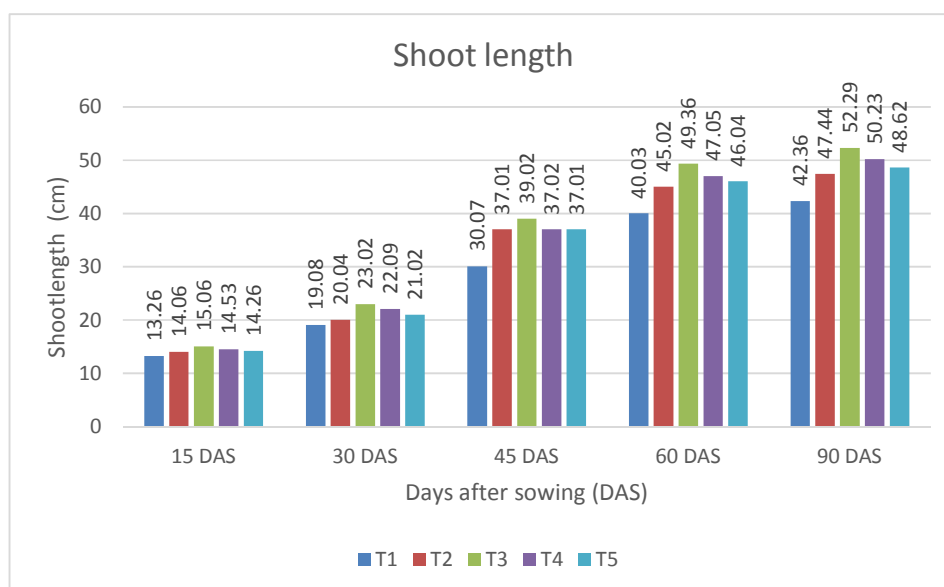


Fig. 1. Effect of different treatments on shoot length of Soybean (*Glycine max*) at different intervals

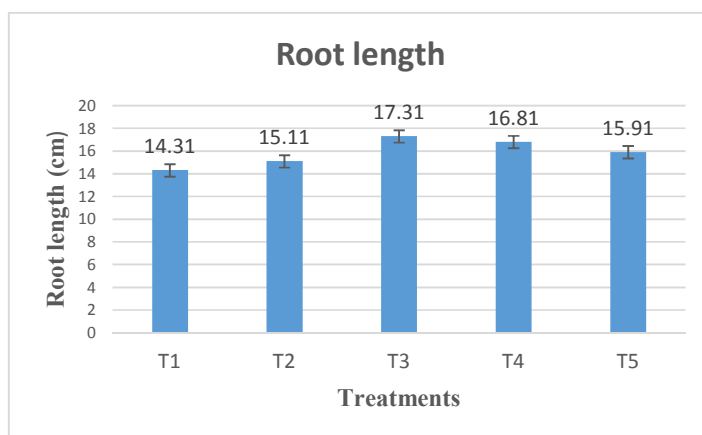


Fig. 2. Effect of different treatments on root length of Soybean (*Glycine max*) at 90 DAS

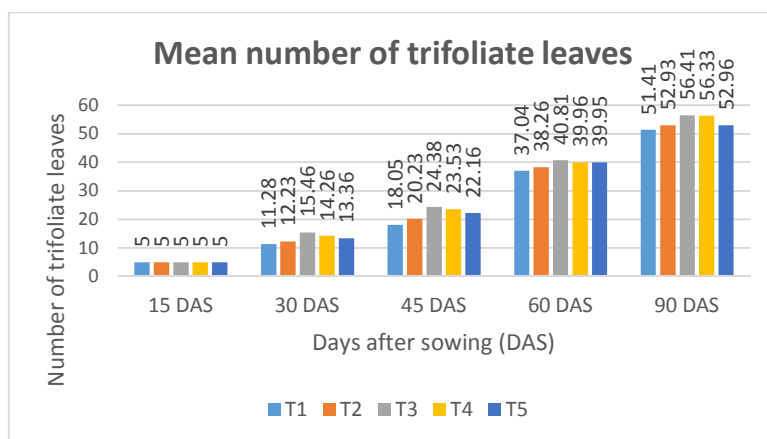


Fig. 3. Effect of different treatments on number of trifoliolate leaves of Soybean (*Glycine max*) at different intervals

3.1.2 Number of trifoliolate leaves per plant

The number of trifoliates were counted in the selected plants as per the treatment T₃ (Biochar + *Rhizobium*) i.e.56.41 recorded maximum number of trifoliolate leaves, whereas the minimum number (51.41) of trifoliolate leaves were recorded under T₁ (control) at 90 DAS followed by T₄ (Biochar + *Azospirillum*) i.e.56.33, T₅(Biochar + *Rhizobium* + *Azospirillum*) i.e. 52.96 and T₂(Biochar) i.e.52.93. The recorded data was shown in Fig. 3.

3.1.3 Number of branches per plant

Branching is one of the important character in Soybean, which has direct effect on seed yield. As per the data recorded on 90 DAS treatment the maximum number of branches (23.56) were

recorded in T₃ (Biochar + *Rhizobium*) whereas the minimum (19.63) were recorded in T₁ (Control) followed by T₄ (Biochar + *Azospirillum*) i.e.22.93, T₅(Biochar + *Rhizobium* + *Azospirillum*) i.e. 21.26 and T₂(Biochar) i.e.21.16. The recorded data was shown in Fig. 4.

3.1.4 Pod length

It is evident from the data presented in figure, that the treatment T₃ (Biochar + *Rhizobium*) was significantly superior (4.44) when compared to all other treatments followed by T₄ (Biochar + *Azospirillum*) at 90 DAS that maximum pod length was recorded under treatment T₃ (Biochar + *Rhizobium*) i.e. 4.44 cm, whereas, the minimum (3.46 cm) pod length was recorded under treatment T₁ (control) followed by T₄ (Biochar + *Azospirillum*) i.e.4.19, T₅ (Biochar +

Rhizobium + *Azospirillum*) i.e.3.77 and T₂ (Biochar) i.e.3.71. The data collected on pod length is presented in Fig. 5.

3.1.5 Pod girth

The application of *Rhizobium*, and *Azospirillum* along with biochar exerted a significant influence on pod girth. At 90 DAS the maximum pod girth (2.59 cm) was recorded under treatment T₃ (Biochar + *Rhizobium*), whereas the minimum (2.22 cm) pod girth was recorded under treatment T₁ (control). There was no significant difference among the pod girth under different treatments. The data collected on pod girth is presented in Fig. 5.

3.2 Effect on Plant Productive Parameters

3.2.1 Number of pods per plant

The perusal of data embedded in Fig. 6 revealed that the number of pods per plant were significantly influenced by various combination of biofertilizers and biochar. The data on number of pods per plant was collected after 75 DAS. The treatment T₃ (Biochar + *Rhizobium*) was significantly higher when compared to all other treatments). The maximum mean of number of pods was recorded in T₃ (Biochar + *Rhizobium*) i.e. 32.6, whereas minimum (30.1) was recorded in T₁(control) followed by T₄(Biochar + *Azospirillum*) i.e.32.41, T₅ (Biochar + *Rhizobium*

+ *Azospirillum*) i.e. 31.05 and T₂ (Biochar) i.e.31.31. The recorded data was shown in Fig. 6.

3.2.2 Test weight (g) (1000 seed weight)

The thousand seeds from each treatment were weighed on measuring scale and the average was recorded. At 90 DAS the maximum test weight (424 g) was observed in T₃ (Biochar +*Rhizobium*), whereas the minimum (408 g) was recorded in T₁ (Control). The treatment T₃ (Biochar + *Rhizobium*) was significantly higher when compared to all other treatments followed by T₄ (Biochar + *Azospirillum*) i.e. 423, T₅ (Biochar + *Rhizobium* + *Azospirillum*) i.e. 422 and T₂ (Biochar) i.e. 421. The data collected on test weight is presented in Fig. 7.

3.2.3 Grain yield (kg ha⁻¹)

The plants after harvesting were collected and grains of different treatments were separated and sundried. At 90DAS the grains were weighed and it was recorded that T₃ (Biochar + *Rhizobium*) i.e., 743.18 kg/ha⁻¹, significantly higher, whereas the minimum (600.22 kg/ha⁻¹) was recorded under T₁ (Control) followed by T₄ (Biochar + *Azospirillum*)i.e. 728.16, T₅ (Biochar + *Rhizobium* + *Azospirillum*) i.e. 700.12 and T₂ (Biochar) i.e.677.89. The data collected on grain yield is presented in Fig. 7.

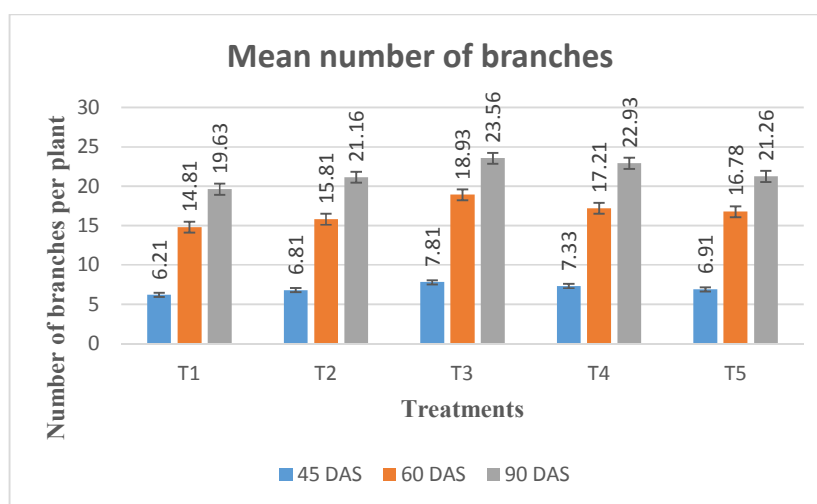


Fig. 4. Effect of different treatments on Number of branches of Soybean (*Glycine max*) at different intervals

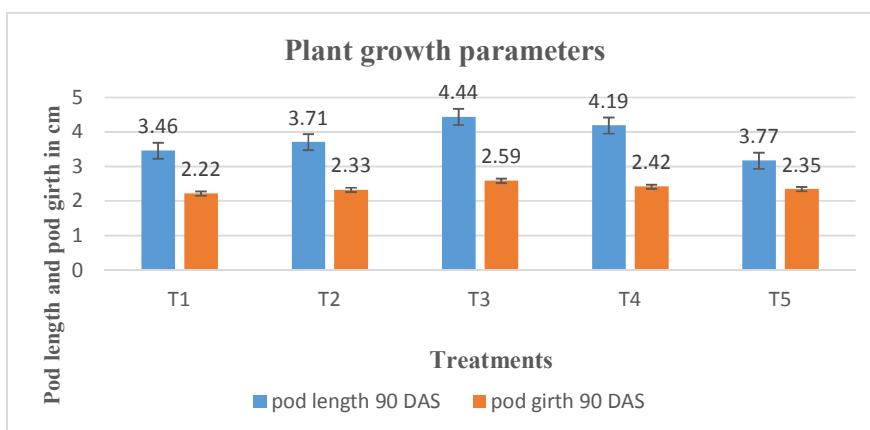


Fig. 5. Effect of different treatments on Pod length and Pod girth of Soybean (*Glycine max*) at 90 DAS

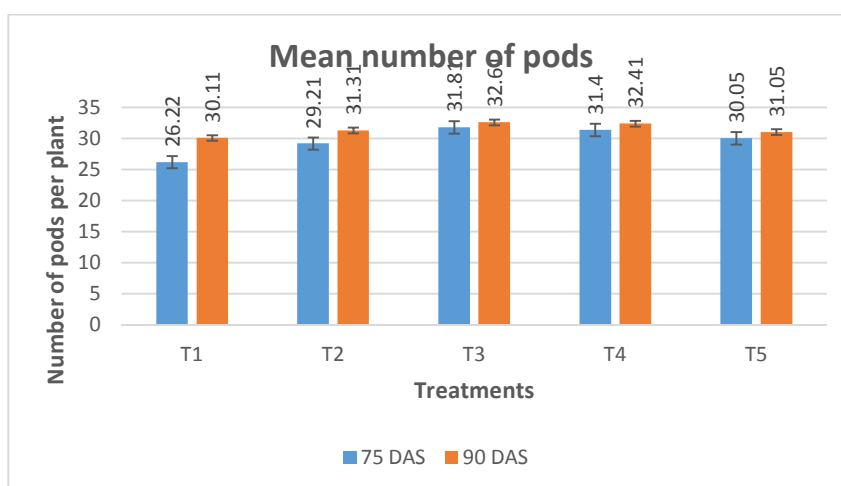


Fig. 6. Effect of different treatments on mean number of pods of Soybean (*Glycine max*) at different intervals

3.2.4 Straw yield (kg ha⁻¹)

The straw yield per hectare was calculated based on the total bundle weight per plot and the data so obtained was subjected to statistical analysis. The average straw yield is presented in the same Fig. 7. The different treatments were found to deviate the straw yield significantly. At 90 DAS the maximum straw yield was recorded under the treatment T₃ (Biochar + *Rhizobium*) i.e., 1321.4 kg ha⁻¹, whereas lowest straw yield was produced in T₁ Control (1201.11 kg ha⁻¹) followed by T₄ (Biochar + *Azospirillum*) i.e. 1281.21, T₅ (Biochar + *Rhizobium* + *Azospirillum*) i.e. 1279.11 and T₂ (Biochar) i.e. 1211.61. The data collected on straw yield is presented in Fig. 7.

3.2.5 Total plant biomass

The application of biochar alone as well in conjunction with biofertilizers exerted a significant influence on plant biomass production. At 90 DAS the maximum (42.04 kg ha⁻¹) biomass was produced by the treatment T₃ (Biochar + *Rhizobium*) whereas the minimum (30.23 kg ha⁻¹) total plant biomass was recorded in T₁ (Control) followed by T₄ (Biochar + *Azospirillum*) i.e. 33.43, T₅ (Biochar + *Rhizobium* + *Azospirillum*) i.e. 32.77 and T₂ (Biochar) i.e. 32.63. The data collected on plant biomass is presented in Fig. 8.

3.2.6 Final plant stand

The final plant stand was recorded at the time of harvesting. At 90 DAS The maximum number of

standing plants per plot were recorded in the treatment T₃ (Biochar + *Rhizobium*) i.e., 65.19, whereas the minimum was recorded in T₁ (Control) followed T₄ (Biochar + *Azospirillum*) i.e. 64.21, T₅ (Biochar + *Rhizobium* + *Azospirillum*) i.e. 63.11 and T₂ (Biochar) i.e. 63.08. There was no significant change observed. The data collected on final plant stand is presented in Fig. 8.

3.2.7 Harvest index

In each treatment, the harvest index was calculated in accordance with the prescribed formula and the values were then analyzed statistically. The average data shown in Fig. 8.

The different treatments were found to exert significant changes in this parameter. At 90 DAS the treatment T₃ (Biochar + *Rhizobium*) resulted

in significantly higher harvest index (36.24) as compared to the other treatments. The significantly lowest values (31.23) of harvest index were observed in T₁ (Control) followed by T₄ (Biochar + *Azospirillum*), T₅ (Biochar + *Rhizobium* + *Azospirillum*) and T₂ (Biochar).

3.3 Effect on Soil Parameters

3.3.1 Organic carbon and organic matter

At 90 DAS the maximum Organic carbon and Organic matter was recorded significantly under T₂ (Biochar) i.e. 12.22 and 21.16 followed by T₃ (Biochar + *Rhizobium*) whereas the minimum (10.00, 17.32) was recorded under treatment T₁ (Control). The collected sample is shown under Fig. 9.

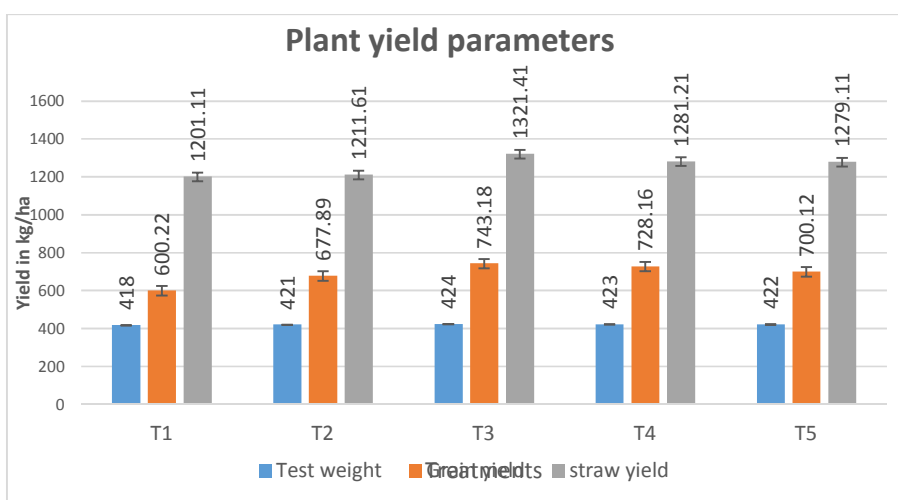


Fig. 7. Effect of different treatments on yield parameters of Soybean (*Glycine max*) at 90 DAS

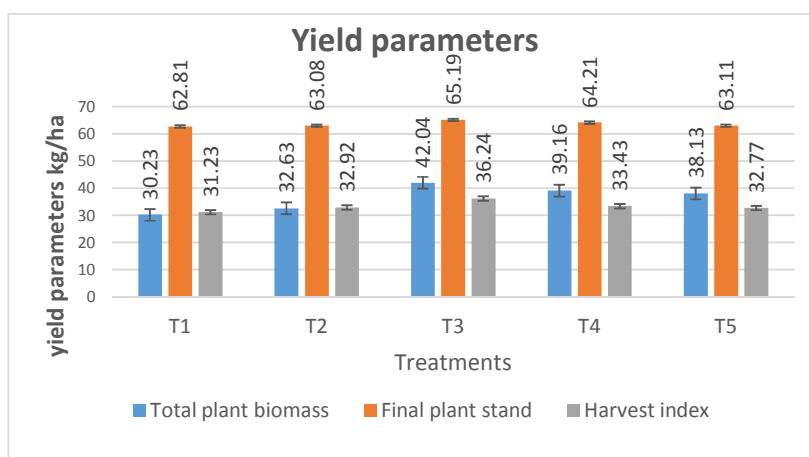


Fig. 8. Effect of different treatments on various plant parameters of Soybean (*Glycine max*) at 90 DAS

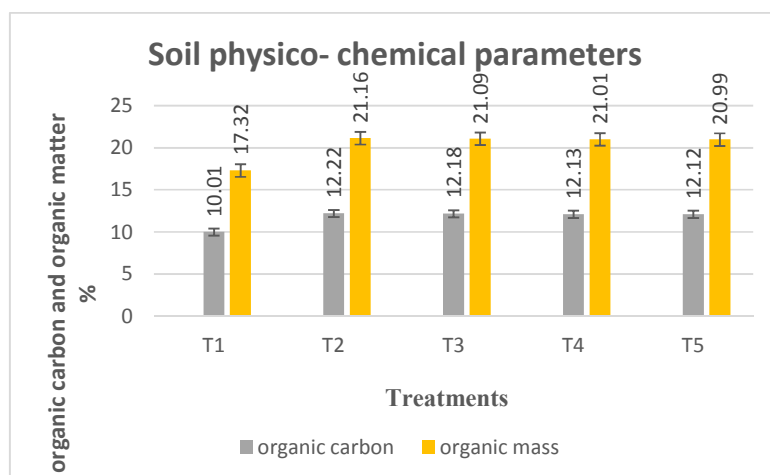


Fig. 9. Effect of different treatments on organic carbon and organic matter at 90 DAS

3.3.2 Available N, P and K

Nitrogen

The available N content was increased significantly by conjoint application of biochar along with biofertilizers over control. At 90 DAS the maximum available N content was recorded under the treatment T₃ (Biochar + *Rhizobium*) i.e. 178.77 kg ha⁻¹ whereas the minimum (178.40 kg ha⁻¹) was recorded under T₁ (Control) followed by T₄ (Biochar + *Azospirillum*) 178.72, T₅ (Biochar + *Rhizobium* + *Azospirillum*) i.e. 178.41 and T₂ (Biochar) 178.41.

The N uptake was also significantly influenced by application of different combinations of biochar and Biofertilizers. The treatment T₃ (Biochar + *Rhizobium*) was significantly higher compared to other treatment. The collected on soil sample is presented in Fig.10.

Phosphorous

The N content like that of available P content was increased significantly by conjoint application of biochar along with biofertilizers over control. At 90 DAS the maximum available P content was recorded under the treatment T₃(Biochar + *Rhizobium*) i.e. 21.80 kg ha⁻¹ however it was statistically at par with T₄ (Biochar + *Azospirillum*) i.e.21.22 whereas the minimum (20.71) was recorded under T₁ (Control).

The P uptake was also significantly influenced by application of different combinations of biochar and biofertilizers. The treatment T₃ (Biochar +

Rhizobium) was significantly higher compared to other treatment. The data collected on soil sample was presented in Fig. 10.

Potassium

The N content like that of available K content was increased significantly by conjoint application of biochar along with biofertilizers over control. At 90 DAS the maximum available K content was recorded under the treatment T₃(Biochar + *Rhizobium*) i.e. 267.89 kg ha⁻¹ however it was statistically at par with T₄ (Biochar + *Azospirillum*) i.e. 267.65 kg ha⁻¹ whereas the minimum (265.90 kg ha⁻¹) was recorded under T₁ (Control).

The K uptake was also significantly influenced by application of different combinations of biochar and biofertilizers. The treatment T₃ (Biochar + *Rhizobium*) was significantly higher compared to other treatment. The data collected on soil sample was presented in Fig. 10.

4. DISCUSSION

4.1 Shoot Length and Root Length

With the progression of all treatment in age, a liner increase in plant height was observed. After sowing, the height of all soybean plants rapidly increased up to 60 days. The rapid increase in plant height in the early stage of plant growth can be attributed to the higher number of leaves producing higher growth food, more and larger leaves for preparing more food, which increased cell division and led to rapid plant growth [15].

The plant height was slow to maturity after 60 days, which may be due to the fact that the plant began to enter the reproductive phase of growth and development from vegetative to reproductive [16]. Thus it was also observed from the data that the increase in plant height continued up to maturity stage. Amongst all the treatments, the treatment with Biochar + *Rhizobium* produced significantly higher plant height at every stage whereas, control (no added biochar or biofertilizers) recorded lowest plant height than other treatments. These results are in close conformity with the findings of [17] who reported the increase of plant height in cowpea due to the inoculation of *Rhizobium*. Yusif et al., [18] has also concluded in his study that biochar improved shoot length and root length as inoculation with rhizobia may be more effective in the presence of biochar due to the habitat offered by the biochar. [19] reported the finding that biochar and *Rhizobium* inoculant positively affected plant growth metrics, root characteristics, and the chemical composition of plants supplied with N-free nutrient solution. In another study reported by [20], the establishment of the symbiotic interactions also induced changes in root morphology in particular, the degree of branching increased and the number of lateral roots was greater in plants inoculated with the *Rhizobium* strain.

4.2 Number of Branches and Trifoliolate Leaves per Plant

The number of branches and trifoliolate leaves per plant progressively increased up to 60 days' stage of crop with the advancement in growth stage. The increase may be probably due to

simultaneous increase in the growth period of the crop [21]. The different varieties exerted significant impact on the formation of leaves at every stage of observation. The treatment T₃ (Biochar + *Rhizobium*) produced higher number of leaves at every stage and were significantly superior than the remaining varieties. The treatment T₁(Control) produced the lowest leaves per plant. Saxena et al. [22] reported in her study that by the application of *Rhizobium* increases the number of branches in legume plants. Ahmad et al., [23] also found the increase of plant growth rate by application of biochar and seed inoculation with *Rhizobium*. Muhammad et al. [24] showed in his experiment the *Rhizobium* inoculation significantly enhanced the growth and yield parameters of groundnut cultivars. However, the maximum, number of leaves (173.27 per plant), was observed in synthetic *Rhizobium* inoculated seeds.

4.3 Number of Pods per Plant

Soybean yield per unit area is more influenced by the number of pods per plant. More pods per plant lead to higher seed yield, revealing the significant effect of different treatments. The treatment T₃ (Biochar + *Rhizobium*) gave the significantly higher number of pods (32.6 per plant) than most of the remaining treatments whereas, the treatment T₁(Control) showed comparatively low pod bearing capacity. The results are in close association with the findings of Taiwo et al. [25], who reported that by the application of biochar and biofertilizers there is an increase of number of pods per plant compared to control.

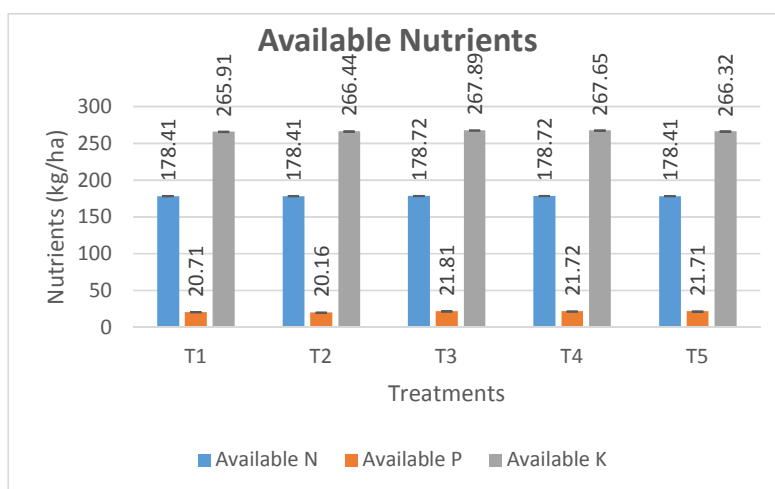


Fig. 10. Effect of different treatments on available N, P and K at 90 DAS

4.4 Pod Length and Pod Girth

The productivity of Soybean also depends on the pod yield like pod length and pod girth. Good pod length and pod girth, shows a good yield of Soybean. In the present study, the influence of different treatments was found to be significant in case of pod length and pod girth. The treatment T₃ (Biochar + *Rhizobium*) shown the significantly higher pod length and pod girth i.e. 4.44, 2.59 compared to all other treatments. The similar study conducted by Mensah et al. [26], who reported 62% increase in fresh fruit yield over other treatments in groundnut through combination of HYT biofertilizers and application of biochar. The same study also reported 55% yield better than inorganic fertilizer amended with biochar. Biochar also enhanced HYT biofertilizers efficiency by 8%. yooyen et al. [27] reported in his study that biochar application also improves the size of pods in Soybean.

4.5 Grain Yield

Grain yield per hectare is determined by the number of pods per plant and number of seeds per pod. Yield is a complex trait and exhibits continuous variation. Most of the yield contribution characters also exhibit continuous variation, such continuous variation being generally attributed to polygenic control. Yield is governed not only by polygenes but also highly influenced by environmental fluctuations. It is evident that the (Biochar + *Rhizobium*) i.e. Treatment T₃ effect on grain yield was significant. The treatment T₃(Biochar + *Rhizobium*) produced significantly higher grain yield (730.14 kg/ha⁻¹) than that of other treatments Rondon et al., [28] reported that bean yield increased by 46% and biomass production by 39% over the control at 60g biochar per kg soil. Agegnehu et al. [29] studied that application of biochar and compost increased seed yield by 23% and 24%, respectively in peanuts.

4.6 Straw Yield

The increase in straw yield is directly associated with an increase in vegetative growth and the increase in the reproductive portion of plants to a negligible extent. It reveals that effect of different treatments on straw yield was found to be significant. The treatment T₃ (Biochar + *Rhizobium*) produced significantly higher straw yield (1321 kg/ha⁻¹) than the remaining treatments. The treatment T₁ (Control) were

recorded as lowest straw yield. This result was similar with the findings of Shamim et al. [30] who reported that applications of biochar and N fertilizer when applied in combination, the increased the straw yield by 391% and 367%, respectively. Similar results were obtained by Hazarika et al., [31] who inoculated *V. radiata* with *Glomus mosseae*, *G. fasciculatum* or *Rhizobium*, or *Rhizobium* combined with either of the two *Glomus spp.*, before sowing, all treatments significantly stimulated the growth and straw yield of *V. radiata*.

4.7 Harvest Index (%)

Analysis of variance for harvest index shows that effects on T₃ (Biochar + *Rhizobium*) were substantially higher harvest index (36.42 percent) compared to the remaining soybean treatments. In T₁ (Control) the significantly lowest harvest index values were observed. The increased harvest index of Biochar and *Rhizobium* could be attributed to a better division of dry matter into grain portion. Indeed, the harvest index depends on the treatment's ability to produce more yield than the accumulation of straw. As such, higher the grain yield than the straw would account for the higher harvest index. Qin et al. [32] who reported that the application of different rates of biochar in the field the long term effect shows the positive change in Harvest index. Malik et al. [33] conducted experiment on corn fields and observed the increase of harvest index in the corn.

4.8 Soil Physico-Chemical Properties

4.8.1 pH and EC

There was no significant change observed in the pH and EC after the completion of experiment in all treatments. These results were similar with the findings of Quilliam et al. [34] who reported in his study that no significant change in short term effects of biochar on pH and EC of soil.

4.8.2 Organic carbon and organic matter

The increase of Organic carbon and Organic matter was observed in all treatments. The significant improvement was mainly observed in all treatments. Lehmann et al. [35] reported that applications of biochar into soil can, potentially improve soil fertility by improving its physico-chemical properties such as increasing organic C (OC) content and organic matter. Agee [36] were reported in his study that biochar can rapidly

increase the C content in the soil. Nguyen et al. [37] conducted an experiment in field with application of biochar and observed the increase of carbon in soil.

4.8.3 Available N, P and K

Biochar and biofertilizers significantly improve the available N, P and K in the soil. In the present study, it was observed that there was a significant increase of N, P and K in treatment T₃ (Biochar + *Rhizobium*). Pang et al. [38] conducted an experiment on application of different rates of biochar in soil and observed the improvement in N percentage and slight improvement in P and K. Yusif et al. [18] has also reported in his study that biochar improved the N and P as inoculation with *Rhizobia* may be more effective in presence of biochar due to habitat offered by biochar. Chan et al. [39] reported that *Rhizobium* inoculation improved the available N and also available P and K of the experiment soil.

5. CONCLUSION

Based on the observations of the conducted experimental study, it was concluded that the although all the treatments have shown positive effect on plant growth and yield of Soybean (*Glycine max*), as compared to control, the treatment T₃ (Biochar + *Rhizobium*) has shown significantly higher effect on the plant and soil parameters as compared to rest of the treatments. So it can be concluded that biochar in combination with the biofertilizers can be an answer to the hurdles faced by today's agriculture, and can be useful in improving the soil health along with its positive effect on the crop growth and yield, especially in legumes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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