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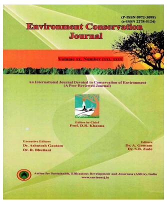

Synthesis and application of biochar in conjunction with various amendments to improve salt-affected soil and crop productivity

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ABSTRACT

Soil salinity is an important abiotic constraint that affects soil quality and crop productivity and has a direct impact on crop yields. Ensuring the sustainable use of saline soils while maintaining environmental integrity is of utmost importance. To achieve this, it is essential to explore and implement methods that can enhance productivity without causing harm to the ecosystem. In the current study, the effect of biochar, Simultaneous inoculation of biomes (Trichoderma harzanium and Pseudomonas fluorescence) and gypsum on soil properties and growth parameters of chickpea was investigated. Of all treatments, the combination of 75 percent GR + biochar@20t/ha and biome @2kg/ha had the greatest effect on lowering pH (9.32 to 7.61), EC (3.65 to 1.6 dSm^{-1}) and SAR (24.22 to 5.9 Cmolc (+) kg^{-1}). As a result, there was a notable improvement in the length of chickpea shoots and roots as well as the overall production of dry matter.

Introduction

A long-lived, self-pollinating, diploid, annual legume with the chromosome number 2N=16, the chickpea (*Cicer arietinum* Linn.) is a member of the Fabaceae family. It has been cultivated in different regions of the world since 7000 BC, as reported by (Tekeoglu *et al.* 2000). Despite its widespread cultivation, chickpea is mainly grown in semi-arid regions (Saxena, 1990). It grades third after the field bean and pea. World's largest producer country is India, accounting for 66% of total global production. Chickpea is cultivated on approximately 11.98 million hectares worldwide, with a yield of 10.91 million tonnes and a productivity rate of 911.2 kg/ha, according to the Food and Agriculture Organization FAO (2010). Salinity has a variety of effects on chickpea, Salinity can have detrimental effects on chickpea growth, including reduced and delayed seed germination, as well as suppression of vegetative plant growth (Yadav *et al.* 1989). Soil salinity is a significant abiotic stress factor that can negatively impact various physiological and metabolic processes in plants, resulting in lower growth and yield (Abbaspoor *et al.* 2009). Several factors, such as germination, survival, plant height, accumulation of suitable solutes in shoots or leaves, and the synthesis of particular metabolites, are typically considered when evaluating a plant's tolerance to salt. (Gamma *et al.* 2009). Salinity causes plants to accumulate sodium (Na^+) and chloride (Cl^-), which can cause critical nutrients like potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) to be displaced., as well as nitrate (NO^{3-}), which can adversely affect their uptake and utilization by the plant. (Sairam *et al.* 2004). Recently, some preliminary research results on the positive effect of biochar as an additive for remediation of sodic soils. An organic soil supplement called biochar

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can improve soil quality, nutritional content, and plant development., Glaser *et al.* (2002), Lehmann *et al.* (2006). As a result, the addition of Ca^{2+} and Mg^{2+} to calcareous soils via biochar improves aggregate stability, hydraulic conductivity and possibly increases Na^{+} leaching from the soil. Furthermore, biochar can enhance the colonization of beneficial microorganisms in the soil, promoting plant growth and overall soil health. (Mukherjee *et al.* 2011). The totaling of old biochar has been exposed to rise microbial activity (Wang *et al.* 2013). Biochar mineralizes faster in soils where it has been previously applied, suggesting that microorganisms play an active role in the mineralization process of biochar (Budai *et al.* 2016). PGPR are soil bacteria that are naturally present and aggressively invade plant roots, benefiting plants by encouraging growth. Early inoculation of crops with specific PGPR strains increases biomass production by directly affecting root and shoot growth (Hamdia *et al.* 1997). There are a variety of ways in which PGPR can affect nutrient uptake, yield and growth (Joseph *et al.* 2011). The application of biochar to soil has numerous benefits, includes enhanced legume nitrogen fixation, encouragement of naturally occurring nitrogen-fixing microorganisms, and improved availability of essential nutrients like iron, copper, phosphorus, and sulphur. PGPRs have attracted a lot of research interest and more are currently being marketed for use in other crops. Many researchers around the world have focused on the biotic strategy of "plant-microbe interaction" to solve salt and salinity problems. Some microorganisms are known for their capability to tolerate and recover the salt tolerance of plants (Ilanghumaran *et al.* 2017). with extremely positive results (Mastouri, 2010). Due to their high success rates, *Trichoderma harzanium* and *Pseudomonas fluorescence* species are extensively used in the experiment to reduce the negative effects of SAS. Trichoderma strains can increase a plant's resistance to biotic and abiotic stresses such as salt and drought (Shoresh *et al.* 2010). However, it has been economically unviable and challenging to implement appropriate management strategies and reclamation practices on a large scale in places affected by salt. This study aims to synthesis biochar and its application in conjunction with various amendments to improve salt-affected soil and crop productivity.

Material and Methods

Experimental Site Information:

A pot experiment was conducted in the year 2021-2022 at Rajmata Vijayaraje Scindia Krishi Viswa Vidyalaya, College of Agriculture in Gwalior (Madhya Pradesh).

Soil sample collection and preparation:

In the Bhind district of Madhya Pradesh's Malanpur, soil sample was taken at depths ranging from 0 to 15 cm. A composite sample was created by combining the samples. The larger aggregates were gently crushed with a wooden hammer after being air dried, and they were then put through a 2 mm filter. Incubation of the sieved soils for the column and pot studies was done in a plastic bag.

Analytical procedure:

The methodologies listed below were used to analyze different physical and chemical characteristics of soil. EC and pH were analyzed using method given by (Jackson 1967), (Jackson1962) respectively, the organic carbon content of soil samples was ascertained using wet digestion method (Walkley and Black1934). The CEC was estimated using Neutral ammonium acetate solution (Jackson,1962). Micro-Kjeldahl method was used to assess the soil's total nitrogen content. (Piper,1950). Ca^{2+} and Mg^{2+} were extracted from a 1 N NH4OAc solution (pH 7.0), as described by Piper and Jackson,1973. the sodium (Na^{+}) content of soil samples was determined separately using a flame emission spectro photometer (Model: Jenway, PEP-7) and a sodium filter (Jackson,1962). The equation $SAR = [Na]/(([Ca]+Mg])/2)^{1/2}$, used to calculate the sodium adsorption ratio, (Bohn *et al.* 2001). These standard methods were used with advanced technologies as followed, (Zeinab *et al.*2016).

Leaching Experiment:

The soil column experiment observed the deterioration of particular salt components and assessed the remediation of saline soils to monitor alterations in soil characteristics for the purpose of leaching trails (Roy *et al.* 2020b). incubating them with diverse combinations of amendments for 30 days., and leaching was carried out in 10 steps (0.5-5 pv) with amounts of water of the desired pore volumes (pv). The amount of water that a saturated soil contains in its pores is known as the pore volume. After leaching, soil samples from different columns were analyzed.

Pot Experiment:

A greenhouse experiment was carried out, using several treatment combinations to obtain the best possible results. Three Kgs of air-dried soil in various additive combinations were placed inside every container so that the bulk density of the soil was maintained to 1.5 Mgm^{-3} as the volume of the pot was 200 cm^3. To complete the leaching study 30 days period was found sufficient to leach out the salts at room temperature (the average room temperature was arounds 30) For 30 days, these pots were incubated at the necessary temperature in a net house. The chickpea seeds were planted in each pot and grown under different combinations of treatments and recommended dose of fertilizer (RDF). Irrigation and other measures to prevent pests and diseases were taken regularly.

Treatment Details:

T1-Control, T2-100%GR, T-3 75%GR, T4-Biochar, T5-Biomes, T6- 75%GR + Biochar, T7-75%GR +Biochar+ Biomes

* GR-Gypsum Requirement, Biomes (*Trichoderma harzanium* and *Pseudomonas fluorescence* *Rate of application of biochar-20 t/ha and biomes-2.5kg/ha.

Morphological and growth parameters:

Using a metre scale, the height of four identified plants was measured from the base of the plant to the tip of the main stem, and the data were expressed in centimetres (cm). One morphological measure used to assess plant growth is this one. By averaging the heights of four different plants, each plant's height was determined. Four plants were weighed both fresh and dried, and the average root length of each plant was measured in cm from the tip of the root to the base of the root, including all plant parts (root, shoot and leaves), was recorded. The remaining plants were kept until harvest for additional observations and post-harvest analysis.

Culture collection and Inoculum Preparation:

A potent isolate of Biome was used in this experiment. The pure strain of *Trichoderma harzianum* (NAIMCC-F-1744) and Pseudomonas fluorescence (NAIMCC-B-762) was obtained from ICAR-National Bureau of Agriculturally Important Microorganism (NBAIM) (NAIMCC) Kushmaur, Mau Nath Bhanjan (U.P). Mass propagation of *Trichoderma harzianum* was carried out in PDA media incubated at 250°C for 7-10 days. A similar method of mass propagation was used for the propagation of *Pseudomonas fluorescence* by simply changing the culture medium PDB from PDA. The spore suspension was prepared by harvesting the biomass of a 10–15-day old culture and then adjusting the concentration using a suitable diluent. Then the soil was soaked with the spore suspension and mixed thoroughly.

Biochar preparation:

Freshly harvested stalks of pigeon pea (*Cajanas cajan*) were collected from a field and stalks from a local farm. They were carefully cut into small pieces. The stalks were dried separately in the sun to reduce the moisture content to less than 10-12% to ensure uniform loading of biomass from pigeon pea crop residues and uniform heat transfer between crop residues during the thermal conversion process. The biomass samples were cleaned to eliminate dirt and dust using distilled water, then dried at 105°C for 10-12 hours in a hot air oven. After proper drying In, order to characterise some of the dried raw materials for physical, chemical, and morphological analyses, they were crushed and ground into powder form. The muffle furnace with a digital temperature controller was used to pyrolyze the dried stems at a slow rate. The experiment was conducted at a temperature of 400 degrees Celsius. The experiment was conducted at a heating rate of 13 degrees Celsius per minute for 1 hour to ensure uniform pyrolysis conditions (Lehmann *et al.* 2009). An initial nitrogen purge was performed to create a low oxygen environment. After the biomass remained in the muffle furnace for 10 minutes, the biochar was crushed and passed through a 2-mm sieve to obtain homogenised material for further analytical studies. To get the exact amount of biochar yield from raw material the mathematical calculation was done from given equation: Yield of biochar (%) = (Mass of biochar)/ (Mass of the raw materials) × 100 (Antal and Groni, 2003).

Results and Discussion

The characterization of synthesised biochar was done and yield was also calculated. The results of changes on soil various physico-chemical parameters are represented in various figures from 1-8 and morphological changes are tabulated in table 1.

Table 1: Effect of gypsum and other amendments on the growth of chickpea plants under salinity condition

Treatments	Yield (Kg/ha)	Cost of Cultivation (Rs.)	Gross Return (Rs.)	Net Return(Rs.)	B:C
T1	780	21000	40794	19794	0.943
T2	1430	22500	74789	52289	2.324
T3	1190	21980	62237	40257	1.832
T4	992	21000	51881	30881	1.471
T5	884	21300	46233	24933	1.171
T6	1400	22789	73220	50431	2.213
T7	1570	23000	82111	59111	2.570

Characterization:
The biochar sample was characterized for various composition which are given below:
The (%) Ash and moisture content (%) 4.0 ± 0.05, 6.45 ± 0.09 respectively, the pH- value ranges 6.71 ± 0.16 and the EC was around 2.12 ± 0.04 (dS/m), the percentage elemental composition of biochar was Carbon - 74 %, Nitrogen - 0.49, % Phosphorus 0.41%, Potassium- 0.65% and the resulted biochar yield from pigeon-pea stalks was 28.7 % .

Effect on soil reaction and soluble salt:
Physico-chemical properties of the intial soil samples:
pH-9.32, EC (dS/m)-3.65, OC (%)-0.451, N(kg/ha)-180, P(kg/ha)-13.87, K(kg/ha)-218.4, Ca (Cmolc (+) kg^{-1}) 27, Mg (Cmolc (+) kg^{-1}) - 10 Na (Cmolc (+) kg^{-1})- 247 SAR 24.22

Soil pH:
Soil reaction is considered the most significant physico-chemical property of soil as it determines the availability of nutrients and their uptake by plants. In the current study, soil pH was significantly reduced compared to the early soil pH (9.32) in all treatments that received biochar alone or in combination with the biomes shown in (Figure. 1). Application of 75 per cent GR + biomes + biochar @ 20 t/ha resulted in significantly lower soil pH. The reduction in soil pH caused by the addition of biochar could be due to the replacement of exchangeable Na^+ by Ca^{2+} (Luo *et al.* 2017). noted a similar reduction in the pH of surface and sub-surface horizons of salt-affected soils by the addition of biochar. (Wang *et al.* 2013) found that the addition of biochar lowered soil pH by releasing H^+ ions from exchange complexes through the addition of Ca^{2+} or Mg^{2+}. Another possible explanation for the low pH is the increased CEC of the soil due to the application of biochar, (Hinsinger *et al.* 2003).

Soil EC:
When biochar, biome and gypsum were used alone or in combination, there was a significant difference in EC compared to the control, as shown in (Figure 2). When biochar was used with 75 per cent GR and biome, the EC decreased (from 3.65 to 1.6 dSm^{-1}). Salt leaching may be responsible for the decrease in electrical conductivity (EC), which is subsequently followed by the addition of organic additives. The leaching of salts is caused by the release of organic acids during the breakdown process. The addition of various organic additives (Shoresh *et al.* 2010) significantly reduced the EC of saline soils. By enhancing the physical characteristics of the soil, leaching by organic matter led to a decrease in EC and an increase in the responsiveness of biomes.
Cation exchange capacity of soil:
The use of biochar or gypsum, either alone or in combination, enhanced the soil's ability to exchange cations, as shown in (Figure 3). The CEC was significantly higher (27.73 Cmolc (+) $kg^{-1}$to 35.97 Cmolc (+) kg^{-1}) in the treatments with 75 per cent GR plus biochar @ 20 t ha^{-1} and 2.5 kg/ha. This could be due to the inherent properties of biochar, particularly its large surface area, which may boost soil fertility CEC (Glaser *et al.* 2002). Some studies have consistently found that biochar has a higher intrinsic CEC than total soil, clay or soil organic matter, (Chan *et al.* 2008) likewise reported increases in soil CEC.
Exchangeable Cations in Soil:
Compared to the control, application of biochar or gypsum or their combination had a significant effect on exchangeable cations. The amounts are exchangeable Ca^{2+} and Mg^{2+} were significantly higher in the treatments 75% GR plus biochar @ 20 t/ha and 2.5 kg/ha, respectively. Application of gypsum increased exchangeable calcium and magnesium, while exchangeable Na^+ in the soils decreased (Figure 4, 5 and 6, respectively).

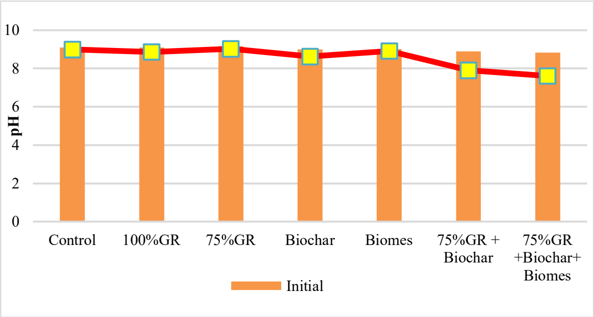

Figure 1: Soil pH for different treatments before and after leaching

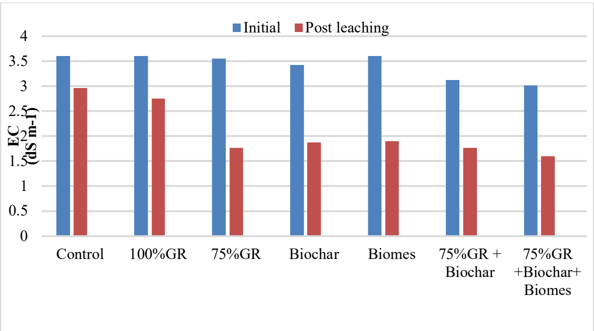

Figure 2: Electrical conductivity of saturation paste extracts of soils before and after leaching for different treatments

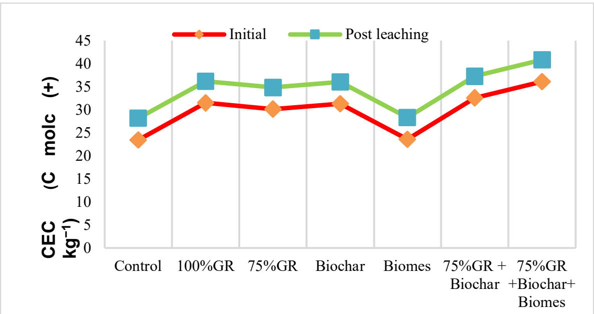

Figure 3: Soil cation exchange capacity for different treatments before and after leaching

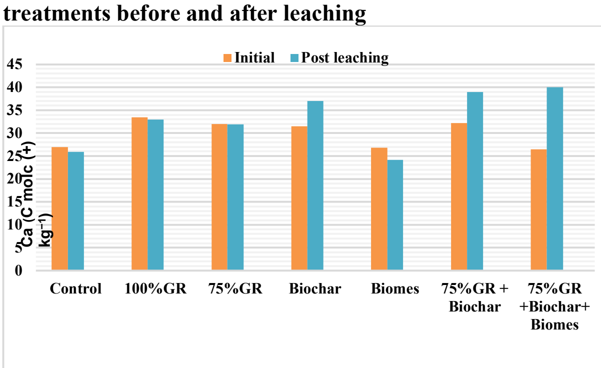

Figure 4: Soil exchangeable, Ca^{2+}concentrations (cmolc/kg) for different treatments, before and after leaching

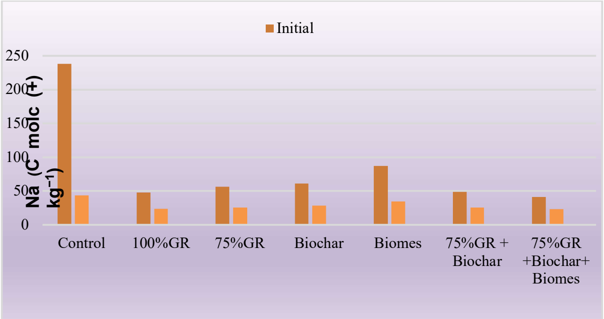

Figure 5: Soil exchangeable Na+ concentrations (cmolc/kg) for different treatments, before and after leaching

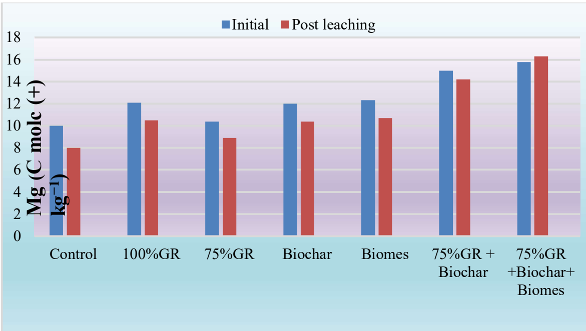

Figure 6: Soil exchangeable Mg^{2+} concentrations (cmolc/kg) for different treatments, before and after leaching

(Major *et al.* 2010) learned that the addition of 20 t ha^{-1} of biochar to a Colombian savanna oxisol increased Ca^{2+} and Mg^{2+} availability. The exchangeable sodium content, on the other hand, decreased with the combination of biochar and 75 per cent GR. This could be due to the higher concentrations of exchangeable Ca^{2+} and Mg^{2+} provided by biochar and gypsum, and their sorption over biochar, replacing Na+ from the soil exchange complex. It should be highlighted that the highest decrease in exchangeable Na+ was seen with the addition of 75% GR plus biochar at 20 t ha^{-1}. Increased Ca^{2+} and Mg^{2+} concentrations due to biochar addition may have reduced the exchangeable Na^{+} concentrations at these sites by enriching the soil profile exchange sites with Ca^{2+} and Mg^{2+}. (Kim *et al.* 2007) discovered a similar decrease in exchangeable Na^{+} concentration (35%) when 5% biochar was applied compared to the control soil and attributed this to the adsorption of Na^{+} on the biochar surface. The findings of (Laird *et al.* 2009) demonstrate that adding biochar raises the concentration of divalent cations and that adding biochar to salt-loaded soils can reduce salt stress because of the high Na^+ adsorption potential of biochar (Novak *et al.* 2009), (Akhtar *et al.* 2015).

Exchangeable Sodium Percentage in soil:

Compared to the control soil, applying biochar at various rates, either by itself or in conjunction with 75 per cent GR, significantly reduced ESP, shown in (Figure 7). Application of 75 per cent GR plus biochar at a rate of 20 t/ha reduced soil ESP more effectively than biochar alone. The increase in CEC or soil organic matter content was attributed to the significant reduction of ESP by biochar application in sodic soils (Luo *et al.* 2017), that was supported by the negative and significant correlation (0.875*) between soil CEC and ESP in the current study. The decrease in ESP seen with the addition of either gypsum or biochar may also be due to increased Ca^{2+}in the soil solution brought on by the addition of gypsum and/or varying rates of biochar that facilitated Na^+ displacement and subsequent removal during leaching to deeper soil layers., either alone or in combination (Gharaibeh *et al.* 2011). This was also confirmed in the current study where a negative and significant correlation (0.910**) was found between exchangeable Ca^{2+}content and soil ESP.

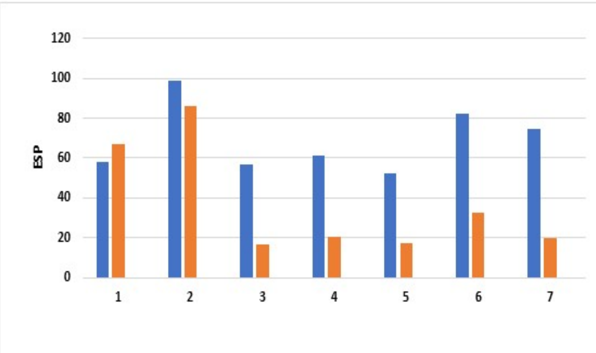

Figure 7: Exchangeable sodium percentage of soils before and after leaching

Soil sodium adsorption ratio:

Application of different amounts of biochar, either alone or in combination, had a significant effect on SAR of post-harvest soils. Significantly less soil SAR was produced by the treatment that got 75% GR along with biochar at a rate of 20 t/ha and various biomes represented in (Figure 8). This could be due to increased Na^+ displacement from the exchange complex as a result of increased Ca^{2+}availability from the combined application of biochar and gypsum. The increase in soil porosity caused by the addition of biochar may also have promoted the leaching of Na^+ from the soil profile and a decrease in SAR (Yue *et al.* 2016). Several studies have confirmed the positive effect of biochar as an additive for saline soils by lowering soil SAR (Amini *et al.* 2016), (Luo *et al.* 2017).

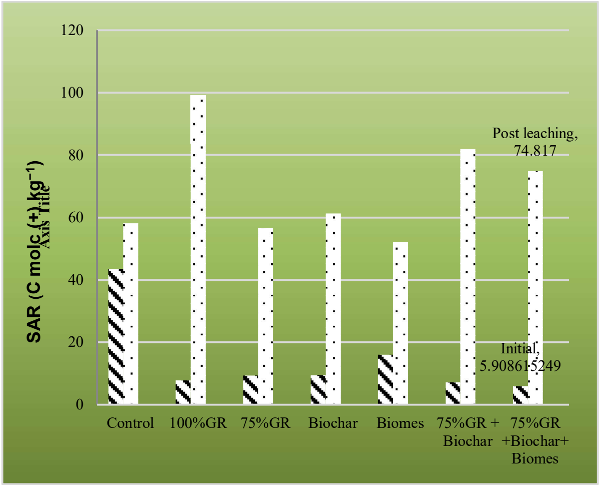

Figure 8: Sodium adsorption ratio of soils before and after leaching for different treatments

Growth and morphological parameters:

The height of each plant was calculated in centimetres from the plant's base to the growing tip of the main branch and represented in centimetres using a metre scale and four marked plants. (cm). To determine the height of each plant, the heights of four plants were averaged. The length of a plant's roots, from root tip to root base, was measured in centimetres Four different plants' roots were measured on average. Using the dry weight formula, the area of the leaf was determined. Salt stress affected the length of chickpea shoots and roots in the current study. The application of the salt-tolerant PGPR strains *P. fluorescens* and *T. harzanium* in combination with nano-gypsum significantly increased the growth and production of chickpea grown under salt stress, according to our results, which are in agreement with previously published studies. All morphological parameters increased statistically significantly compared to the control in biomes with 75 per cent GR + 20 t/ha biochar. Table 1 lists the possible results. In this study, the production of shoot length, root length, leaf area, and dry matter of the chickpea plant was greatly boosted by the addition of biochar and gypsum. At application of biomes with 75 per cent GR + 20 t/ha biochar the shoot length of plant was 24.9 cm, root length of plant 31.8 cm, shoot dry weight was 2330 mg/plant and root dry weight of plant was 1086 mg/plant. According to the root to shoot length ratio, the shoot was more impacted by salinity than the root (Moud *et al.* 2008). This value was considerably lowered by high salt stress (Akbarimoghaddam *et al.* 2011).

Effect on chickpea output in terms of grain and straw:

Increasing the amount of biochar and gypsum significantly increased grain production from chickpeas. The data range for mean grain yield from chickpeas was 7.39 to 8.52 g/plant. Treatment with 75% GR and biochar at 20 t/ha gave the highest grain yield (8.52 g/plant). How crops respond to biochar application depends on plant species, soil conditions, climate, and the biochar's chemical and physical properties (van Zwieten *et al.* 2010, (Haefele *et al.* 2011). After various treatments, chickpea straw yields showed the same pattern as grain yields. Compared to the other treatments, the 75% GR + 20 t/ha biochar and biome treatments had the highest average straw yields. This may be related to higher biomass yields made possible by biochar additives that mitigate the effects of salt stress on plants. The results are consistent with those of (Drake *et al.* 2016), where biochar application to soils in salinity conditions dramatically greater biomass of both plants that salt-tolerate and salinity-sensitive seedlings.

Economic analysis:

Economic feasibility in financial terms of any innovation or technique has primary importance in deciding its wider adoption among farming community represented in, accordingly, the maximum net benefit was obtained by treatment 7 was applied. Net benefit for the treatment 7 the (75% GR + 20 t/ha biochar) is higher i.e., 59111 Rs. as compared with the rest of the treatments, as it showed an increasing trend compared to other treatments. The benefit cost ratio also showed an increasing trend (2.570), presented in Table 2. Any breakthrough or technology must be economically viable in order for the agricultural sector to adopt it widely. In order to create goods that farmers can easily obtain, an economic analysis was done at the conclusion of the study, and the most effective and economical treatment levels were selected.

Table 2: Effect of gypsum and other amendments on the yield and economic analysis of chickpea plants under salinity condition

Treatment	Shoot length (cm)	Root length (cm)	Shoot dry weight (mg/plant)	Root dry weight (mg/plant)
T1	13	18	1470	486
T2	19.8	30.5	2130	920
T3	18.6	24.7	1690	230
T4	17	20.6	1460	163.4
T5	14	18	1465	490
T6	21	27	2180	586
T7	24.9	31.8	2330	1086

Conclusion

The findings of this investigation suggest that combination of 20 t/ha of biochar along with 75% GR as a supplement to soda ash can effectively reduce soil pH, ESP and SAR, compared to using either gypsum or biochar as a single application. This combination can significantly increase chickpea production, demonstrating the benefits of using biochar as an adjunct to soda soil remediation. Additionally, the pH of the biochar feedstock greatly influences its effectiveness in rehabilitating salinity-degraded soils. Using PGPR as an inoculant and biofertilizer is an effective way to replace chemical fertilizers and pesticides, and is beneficial for plant growth and development, promoting sustainable chickpea agriculture in India and other developing countries. Further studies, including field efficiency trials, are necessary to determine the functionality of PGPR as a viable biofertilizer. Environmental pressures are global variables that negatively impact agricultural productivity, preventing the introduction of crops into uncultivable areas and reducing yields.

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Conflict of interest

The authors declare that they have no conflict of interest.

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