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Growth and yield response of cowpea (*Vigna unguiculata* L.) in sodic soil amended with marine gypsum, biochar and bioinoculants

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ABSTRACT

Abiotic stresses adversely affect the global food security of a fast-growing populace. In order, to achieve global food security and increase agriculture production, there is a considerable need to restore barren and degraded lands. Salt affected soils are one such degraded lands, which can be brought into productive soils by applying gypsum. However, due to shortage of natural mined gypsum and phospogypsum, there is an opportunity for the other kind of gypsum from marine source from sea salt manufacturing industry as a byproduct. This form of gypsum is commonly available from the marine based salt industry, which is readily available in coastal areas. Prosopis wood biochar was processed and required quantity of biochar is calibrated and applied as band placement to the ridge of field. In addition, bioinoculants *viz.*, Rhizobium and PGPR enhances the growth and development of crops in sodic soils. Cowpea (*Vigna unguiculata* L.) variety Co (CP) 7, which is medium sensitivity to sodicity, is taken as a test plant. A field experiment was conducted during summer 2021 using Randomized block design with eight treatments and replicated thrice. Treatments include different combinations of organic sources, i.e., Biochar, PGPR, Rhizobium with Unamended, and marine gypsum reclaimed sodic soils. Plant biometric observations and growth parameters were recorded and analyzed at vegetative, flowering and maturity stages. Experimental results revealed that sodic soil amended with Marine Gypsum (50% GR) + Biochar+ PGPR+ Rhizobium (T_8) significantly enhanced the plant growth characters, i.e., plant height, dry matter production, yield and yield attributes of cowpea.

***Key words**: Marine Gypsum, Biochar, Rhizobium, PGPR, Cowpea*

Introduction

Globally to achieve food security, attempts need to focus on both to expand the area under agriculture as well as technology to increase the crop productivity. Currently, due to rapid urbanization and industrialization, the pressure on agricultural lands is ever increasing, resulting in the reduction of agricultural landholdings. The only possibility in expanding the area under agriculture exists in the form of restoration of degraded lands. In order to ensure food security for the people, India has fixed the target of restoring 26 M ha of degraded lands by the year 2030, including salt-affected soils. Globally about 1128 M ha of the area is affected by salinity and sodicity stresses (Mandal *et al.*, 2018). In India, salt-affected soils occupy 6.74 M ha area of which 56% are sodic soils (3.77 M ha) and 44% are saline

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(Kumar and Sharma, 2020). The sodic soil can be brought under cultivation, provided proper reclamation procedure is followed. Gypsum based reclamation is most commonly followed and cost-effective approach. Gypsum is the source of calcium and replaces the exchangeable sodium, reduces alkalinity and improves soil permeability (Murtaza *et al*., 2013).

During the past, natural mined mineral was used for reclamation of sodic soil. However, due to shortage of natural mined gypsum, farmers are using phosphogypsum which is a byproduct from phosphoric acid plant from the fertilizer industry. Currently, the availability of the phosphogypsum is also in scarce. There is an opportunity for the other kind of gypsum from marine source from sea salt manufacturing industry as a byproduct. This form of gypsum is readily available in coastal areas. After gypsum, biochar has emerged as the most preferred organic conditioner for sodic soils. Biochar can sustainably maintain or increase soil organic matter, crop yield and soil fertility by retaining soil nutrients in an available form for plant uptake (Trupiano *et al*., 2017). Biochar along with rhizobium in soil complex could enhance the availability of essential micronutrients such as molybdenum as required for the root nodule formation. PGPR also helps to withstand the increased concentration of salts by producing different organic and inorganic compounds, thus improving plant's growth and health under salt stress (Shahid *et al*., 2018). Legumes such as Cowpea (*Vigna unguiculata* L.) is medium sensitive to sodicity. It has long been known for its unique ability to enrich the soil through the biological nitrogen-fixing system in symbiotic association with rhizobial strains. Consequently, the current investigation was assumed to assess the growth and yield response of cowpea in unamended and amended sodic soil with marine gypsum, biochar, rhizobium and PGPR as alone and with combination respectively, using cowpea as a test plant.

Materials and Methods

A field experiment was conducted at Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli, India. Geographically, the research plot is located at 10.7556 º N latitude and 78.6024 º E longitude, at an altitude of 85 m above MSL during summer season, 2021. The experiment was conducted in Randomized Block Design with eight treatments and each treatment was replicated thrice. The treatment comprises of T_1 - Control (No Amendments), T_2 - Marine Gypsum (50% Gypsum Requirement), T_3 - Biochar alone, T_4 -Rhizobium+ PGPR, T_5 - Biochar + Rhizobium+ PGPR, T_6 - Marine Gypsum (50% GR) + Biochar, T_7 - Marine Gypsum (50% GR) + Rhizobium+ PGPR and T_8 - Marine Gypsum (50% GR) + Biochar+ Rhizobium+ PGPR. The soil in the field was clay loamy in nature. For correction of soil sodicity, marine gypsum was added for reclamation according to treatment plots. The gypsum requirement was calculated as per the procedure given by Schoonover (1952). The principle behind the reclamation of sodic soils with gypsum is to replace exchangeable sodium by another cation calcium (Ca^{+2}). In our current study, calcium (Ca^{+2}) which is solubilized from marine gypsum replaces sodium (Na^+), leaving soluble sodium sulphate (Na_2So_4) in the water, which is then leached out. Marine Gypsum applied plots are well bunded and good quality irrigation water was used and is allowed to stand up to 10 cm height and drained out after 10 days through provision of sufficient drainage. The leaching out process is repeated for three times. After the reclamation of sodic soil with marine gypsum, field was allowed to dry and prepared to a fine tilth. Ridges and furrows were formed with a spacing of 45x15 cm. Biochar used in the study was taken from the shrub, *Prosopis juliflora*. The biochar was crushed and powdered using wooden mallet and sieved through 2 mm sieve. Calculated quantity of biochar 0.88-ton ha^{-1} was applied to ridge of field by band placement about 5 cm below the sowing depth. The Cowpea seed variety CO(CP)7 having a duration of 75 days were seed treated with Rhizobium culture (COC 10) 200 g ha^{-1} using rice kanji as binder and soil application of PGPR 2 kg ha^{-1} as per the treatments. Seeds are sown to the side of the ridge 15 cm above from the furrow at the rate of 25 kg ha^{-1}. After band placement of biochar and sowing of seeds, the field was irrigated with good quality water. Life irrigation was given on 3rd day. Pendimethalin 0.75 litre ha^{-1} was applied on 3rd DAS as pre-emergence herbicide. Regular crop management practices are followed as per the Tamil Nadu Agricultural University, crop production guide 2020.

Five plants were tagged randomly in each plot for recording biometric observations. The plant height was measured at 20, 40 and 60 days after sowing (DAS) from the base of the main stem to the tip of the top most leaf using a measuring scale. The length and breadth of top most fully expanded leaves from tagged plants are measured with scale for leaf area index (LAI) at 20, 40 and 60 DAS. LAI was calculated using the procedure given by (Palanisamy and Gomez, 1974). Above ground biomass mass was collected at 25, 45, 65 DAS and oven dried at 70ºC in a hot air oven for 72 hrs till a constant weight was obtained. Dry weight of oven dried plants was recorded and the dry matter production per plant was obtained, which was expressed in kg ha^{-1}. The Crop growth rate (g m^{-2} day^{-1}) and Relative growth rate (g g^{-1} day^{-1}) was calculated at two stages, i.e., 25 to 45 DAS and 45 to 65 DAS, by the formulae suggested by Buttery (1970) and Enyi (1962) respectively. With respect to yield attributes, length of the pods was measured and the total number of pods, number of seeds per pod were counted. Pods were shelled, winnowed to separate the grains from chaff. Then the grains were weighed, for determining the yield (kg ha^{-1}). The experimental data on different parameters were statistically analyzed, using Agres software.

Results and Discussion

Plant height and Dry matter production

The data on plant height and dry matter production of cowpea as influenced by various treatments were recorded in Table 1. The highest mean plant height was recorded at 20, 40, 60 days after sowing were 25.2, 31.3 and 51.5 cm respectively. Similarly, high dry matter production was recorded at 25, 45 and 65 DAS were 536, 2360 and 2640 kg ha^{-1} (Fig.1) respectively, by the application of Marine Gypsum (50% Gypsum requirement) + Biochar+ PGPR+ Rhizobium (T_8), followed by Marine Gypsum (50% GR) + Biochar (T_6) and Marine Gypsum (50% GR) + PGPR+ Rhizobium (T_7). However, ameliorated sodic soil with biochar alone and ameliorated sodic soil with bioinoculants alone are statistically on par with each other. Biochar has improved nutrient and moisture retention capacity at the root zone hence, resulted in increased plant height and dry matter production. Rhizobium and PGPR enhanced the plant growth by supplying nitrogen. These results were in

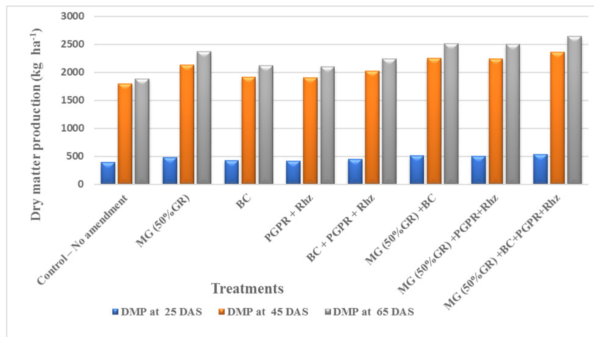

Fig. 1. Dry matter production of cowpea (*Vigna unguiculata* L.) at different growth stages under sodic soil amended with marine gypsum, biochar, rhizobium and PGPR.
MG (50%GR) – Marine gypsum (50% Gypsum requirement), BC- Biochar,
Rhz-Rhizobium, DAS-Days after sowing.

Table 1. Effect of Marine Gypsum, Biochar, Rhizobium and PGPR on plant growth parameters of cowpea (*Vigna unguiculata* L.).

Treatments	Plant height (cm)			Leaf Area Index		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Control – No amendment	14.2	17.0	29.0	1.88	1.43	0.98
MG (50%GR)	20.2	25.0	42.0	1.90	2.60	1.40
BC	16.6	20.0	34.0	1.89	2.00	1.20
PGPR + Rhz	16.0	19.5	33.0	1.88	1.71	1.15
BC + PGPR + Rhz	18.4	22.5	38.0	1.89	2.30	1.30
MG (50%GR) +BC	22.5	28.9	47.5	1.90	3.21	1.50
MG (50%GR) +PGPR+Rhz	22.0	27.5	46.0	1.90	2.90	1.49
MG (50%GR) +BC+PGPR+Rhz	25.2	31.3	51.5	1.91	3.50	1.70
SEd (±)	0.82	1.10	1.68	0.09	0.11	1.34
CD (p=0.05)	1.75	2.36	3.61	NS	0.23	0.07

MG (50%GR) – Marine gypsum (50% Gypsum requirement), BC- Biochar,
Rhz-Rhizobium, DAS-Days after sowing.

accordance with Taiwo *et al.* (2018) for plant height in cowpea. Increased dry matter production with biochar application has been reported by Liang *et al.* (2014) and Tammeorg *et al.* (2014) for the spot and ring methods of biochar application.

Leaf Area Index (LAI)

With respect to leaf area index (Table 1) amended and unamended sodic soils showed statistically non-significant difference at 20 DAS. In contrast, the highest LAI was recorded with the soil application of marine Gypsum (50% GR) + Biochar+ PGPR+ Rhizobium at 40 DAS (3.50) and 60 DAS (1.70) was due to increased number of leaves per unit area. Leaf area index depends on the total number of leaves and the leaf area expansion. Amelioration of sodic soil with biochar and bioinoculants *viz.*, Rhizobium and PGPR have improved the plant biomass, greater number of leaves and leaf area by the nutrient uptake and biological nitrogen fixation. The lowest LAI was recorded in unamended sodic soil at three stages i.e., 20, 40, 60 DAS due to high concentration of Na^+ ions, which has negative effect on uptake of nutrients. Adediran *et al.* (2005) reported that application of organic sources increases leaf area in cowpea.

Crop growth rate (CGR) and Relative growth rate (RGR)

The synergistic effect of sodic soil amended with Marine Gypsum (50% GR), Biochar, PGPR and Rhizobium, showed significant effect on crop growth rate and relative growth rate. The maximum CGR and RGR recorded at 25-45 DAS were 12.88 g m^{-2} day^{-1} and 0.0364 g g^{-1} day^{-1} respectively, with the application of Marine Gypsum (50% GR) + Biochar+ PGPR+ Rhizobium (T_8), followed by Marine Gypsum (50% GR) + Biochar (T_6) and Marine Gypsum (50% GR) + PGPR+ Rhizobium (T_7) (Fig.2 and 3). With the increase in the leaf area from vegetative stage to pod formation stage, light is efficiently absorbed by photosynthetic pigments, which resulted in maximum crop growth rate. Whereas, the relative growth rate always decreases over the period of time as the plant biomass increases. Likewise, at 25-45 DAS, the lowest rate of crop growth and relative crop growth was recorded in unamended sodic soil due to salt stress on crop growth and lack of bioinoculants *viz.*, PGPR and rhizobium. These results are in accordance with Dutta *et al.*

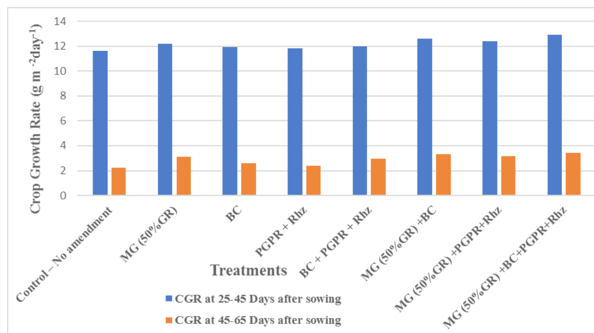

Fig. 2. Crop growth rate (g m^{-2} day^{-1}) of cowpea (*Vigna unguiculata* L.) at different growth stages under sodic soil amended with marine gypsum, biochar, rhizobium and PGPR.
MG (50%GR) – Marine gypsum (50% Gypsum requirement), BC- Biochar,
Rhz-Rhizobium, DAS-Days after sowing.

Table 2. Effect of Marine Gypsum, Biochar, Rhizobium and PGPR on yield parameters of cowpea (*Vigna unguiculata* L.).

Treatments	No. of pods/plant	No. of seeds/pod	Pod length (cm)
Control – No amendment	14.4	4.8	9.5
MG (50%GR)	19.5	8.5	12
BC	16.3	6.0	10.9
PGPR + Rhz	16.0	6.0	10.4
BC + PGPR + Rhz	18.6	7.3	11.8
MG (50%GR) +BC	21.5	10.0	13
MG (50%GR) +PGPR+Rhz	20.9	9.8	13
MG (50%GR) +BC+PGPR+Rhz	23.2	12.0	14
SEd (±)	0.63	0.48	0.41
CD (p=0.05)	1.35	1.03	0.86

MG (50%GR) – Marine gypsum (50% Gypsum requirement), BC- Biochar,
Rhz-Rhizobium.

(2019) and Olusegun (2014).

Yield parameters and Grain yield

Data presented in the Table. 2 and 3, revealed that the maximum number of pods $plant^{-1}$ (23.2), seeds pod^{-1} (12.0), pod length (14 cm) and grain yield (1106 kg ha^{-1}) was recorded significantly highest in the sodic soil ameliorated with marine gypsum (50% GR) + biochar+ PGPR+ Rhizobium (T_8). Similarly, 39.1 % yield increase over the control was observed in the sodic soil amended with marine gypsum (50% GR) +biochar+ rhizobium + PGPR (T_8). Biochar pore spaces act as an anchorage for holding of nutrients and resulted in uptake of more nutrients, vegetative growth and high dry matter accumulation, which leads to production of more number of seeds and pods. Whereas, PGPR and rhizobium enables nitrogen fixation which results in increased plant growth and grain yield. These results were in accordance with Agboola *et al*. (2015) and Taiwo *et al.* (2018) for the increased number of pods per plant, seeds per pod and grain yield with application of biochar and PGPR in pea. Similar results were also reported in radish by Chan *et al.* (2008).

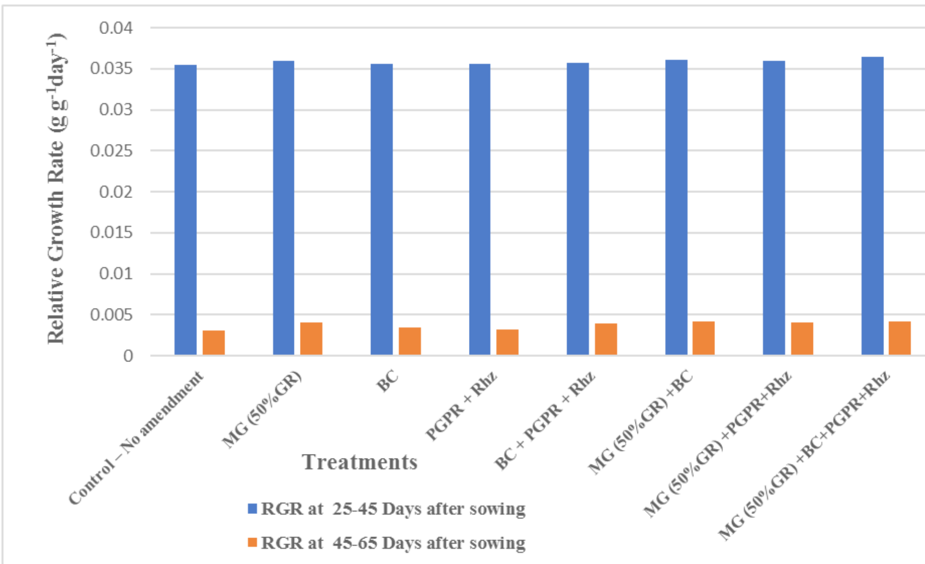

Fig. 3. Relative growth rate (g g^{-1} day^{-1}) of cowpea (*Vigna unguiculata* L.) at different growth stages under sodic soil amended with marine gypsum, biochar, rhizobium and PGPR. MG (50%GR) – Marine gypsum (50% Gypsum requirement), BC- Biochar, Rhz-Rhizobium, DAS-Days after sowing.

Table 3. Effect of Marine Gypsum, Biochar, Rhizobium and PGPR on Grain yield and % yield increase of cowpea (*Vigna unguiculata* L.).

Treatments	Grain Yield (kg ha^{-1})	% Yield increase over control (No amendment)
Control – No amendment	795	-
MG (50%GR)	986	24.0 %
BC	888	11.7 %
PGPR + Rhz	875	10.1 %
BC + PGPR + Rhz	937	17.9 %
MG (50%GR) +BC	1056	32.8 %
MG (50%GR) +PGPR+Rhz	1035	30.2 %
MG (50%GR) +BC+PGPR+Rhz	1106	39.1 %
SEd (±)	21.9	
CD (p=0.05)	47	

MG (50%GR) – Marine gypsum (50% Gypsum requirement), BC- Biochar, Rhz - Rhizobium.

Conclusion

This study has shown that reclamation of sodic soil with marine gypsum (50 % GR) removed the excess exchangeable sodium ions by leaching process. Biochar improved soil porosity and acts as an anchorage for retention of nutrients. Rhizobium and PGPR also contributed significantly for increased growth, yield attributes and yield of cowpea in contrast to unamended sodic soil. Sodic soil amended with marine gypsum (50% GR), biochar, rhizobium and PGPR (T_8) showed a yield increase of 39.1 % over unamended sodic soil. Similarly, 32.8 % and 30.2 % yield increase over the unamended soil was observed by the application of marine gypsum (50 % GR) + biochar (T_6) and marine gypsum (50 % GR) + rhizobium + PGPR (T_7) respectively. So, this approach could be a novel management strategy to ameliorate sodic soil with marine gypsum (50% Gypsum requirement), prosopis wood biochar, rhizobium and PGPR to strengthen soil health and its fertility to enhance the crop growth and productivity of cowpea.

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Conflict of interest

The authors declare that there is no conflict of interest

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