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RESEARCH ARTICLE

Boron and silicon fertilization impact on groundnut growth and soil properties of coastal saline soil

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Abstract

Boron and silicon nutrients play a crucial role in groundnut growth and productivity in coastal saline soil. However, farmers in coastal areas tend to prioritize macronutrients over their use of boron and silicon nutrients for groundnuts. In general, organic fertilizers promote growth of plants and maintain soil ecosystems, but their combination with boron and silicon is yet to be studied. So, this study aimed to (a) assess the impact of boron and silicon on nutrients content in coastal saline soil and (b) evaluate how boron, silicon and composted coir pith (CCP) improve soil properties in coastal soil. To meet the various objectives of study a two-season field experiment was conducted in a coastal farmer's field at Singarakuppam village, near Chidambaram in Cuddalore district, Tamil Nadu, during July-October 2021 and December-March 2022, using groundnut variety VRI 2. The study revealed that the soil application of borohumate (BH) + diatomaceous earth (DE) + CCP, along with foliar application of silixol plus (SP) and recommended dose of fertilizers (RDF), was the most effective in improving soil properties in coastal saline soil.

Keywords

borohumate; boron; diatomaceous earth; organics; silicon; soil properties

Introduction

Coastal saline soils are naturally endowed resources for agriculture; however, agricultural production remains challenging due to the adverse effects of salinity and related issues. Despite this, coastal farmers often cultivate these lands without adopting appropriate management practices, particularly in nutrient management. Implementing effective soil management strategies can significantly enhance productivity and ensure sustainable agricultural growth in these regions. By adopting appropriate techniques, these soils have the potential to become leading agricultural production areas in the future. Coastal soils are present in the Indian peninsular region, covering approximately 8129 km along the coastline. Of these, 6.75 million hectares (M ha) are salt-affected, with 2.96 M ha classified as saline and 3.79 M ha as sodic soils (1, 2). In Tamil Nadu, nearly 2.04 lakh hectares (L ha) are coastal saline soils with the coastal area of 680622 hectares, constituting 26.8% of the total area of coastal districts in India. The extent of salinity is increasing each year due to saline water inundation and the impact of fertilizers on soil (3).

Across these vast coastal areas, nearly 50% of farmers cultivate groundnut due to its adaptability to the favourable soil texture especially for groundnut crop. In India, groundnut is grown on 6.09 M ha, producing 10.21 million tonnes, with an average productivity of 1676 kg ha^{-1} (3). However, the global human population is expected to reach 9.7 billion by 2050 (4). To feed this enormous population, there will be an increased demand for production, and the current production levels will not be sufficient to meet the requirement in 2050. Groundnut serves as an essential source of calories, protein, healthy fats, dietary fiber, vitamins and essential nutrients for people worldwide. It is also a major crop next to rice in the nutrient-impoverished coastal saline sandy soils.

Several studies have revealed the essential role of boron in groundnut production, as it enhances seed quality, yield and growth. In addition to these functions, boron is also involved in the synthesis of carbohydrates and fats, prevents blossom drop, and is crucial for cell proliferation during nodule formation (5, 6). Silicon plays a key role in alleviating both biotic and abiotic stress in plants. While extensive research has been conducted on soil and foliar nutrition using silicon fertilizers, studies on coastal soils remain limited. The beneficial effects of silicon on various crops have clearly demonstrated its importance in agricultural production (7). However, studies on the combined effects of boron and silicon are lacking. Therefore, the present investigation aims to highlight boron's essential role in groundnut production and silicon's ability to ameliorate soil salinity effects.

In addition, utilization of organic materials in agriculture has garnered increasing attention in recent years due to its potential to positively influence soil properties and enhance overall soil health. Organic inputs, such as compost, manure, cover crops and biochar, are recognized for their ability to replenish soil organic matter, improve soil structure, foster beneficial microbial communities and promote nutrient cycling. Several earlier works have emphasized the need for application of organic manures for increasing the soil biological properties and productivity of groundnut (8). Considering the inherent poor soil fertility, poor yield and economic condition of the coastal farmers, it is an imperative need to recycle the locally available organic wastes to achieve sustainable yield at minimum cost. Composted coir pith (CCP) is one of the cheapest sources of organic manure has widely available in coastal regions of Tamil Nadu and CCP is most importance among the organic wastes because of their nutrient withholding capacity (9–11). Composted coir pith contains several plant nutrients, growth regulators and enzymes, which can sustain soil health and crop production.

Previous research on groundnut has extensively explored the individual effects of boron, silicon and organics, highlighting their crucial roles in enhancing crop yield, nutrient uptake, stress tolerance and overall plant health. However, limited research has investigated their combined effects on groundnut growth and productivity. The present investigation aims to assess the synergistic impact of boron, silicon and organics, providing insights into their potential to enhance crop production more effectively with following objectives (a) To assess the impact of boron and silicon on nutrients content in coastal saline soil and (b) To evaluate how boron, silicon and CCP improve nutrients content, microbial population and enzymatic activities in coastal soil.

Materials and Methods

A field experiment with a groundnut crop was carried out in a coastal village during the Kharif and Rabi seasons to meet the study's objectives. The details of the experiment and initial soil parameters are given below.

Kharif groundnut

To investigate the impact of boron and silicon on augmenting the nutrient content in coastal saline soil, a field experiment was conducted at a coastal farmer's field during July-October 2021 in Singarakuppam coastal village. The experimental soil was sandy in texture and taxonomically classified as *Typic Ustipsamments* with pH-8.21, EC-4.05 dSm^{-1} and represented low status of organic carbon (2.32 g kg^{-1}). Regarding available nutrient status, it was low in alkaline $KMnO_4$-N (139.26 kg ha^{-1}), low in Olsen-P (9.22 kg ha^{-1}) and medium in NH_4OAc-K (164.63 kg ha^{-1}). The available B and Si content were 0.22 and 30.03 mg kg^{-1}, respectively. The treatments included were different levels of B as borohumate *viz*., control, 0.5, 1.0 and 1.5 kg B ha^{-1} as factor B and different levels of Si as diatomaceous earth like control, 20, 40 and 60 kg Si ha^{-1} as factor S. The experiment was studied in a Factorial Randomized Block Design (FRBD) with three replications, using groundnut variety VRI 2 as test crop.

Rabi groundnut

To fulfil the objectives of present study a field experiment was carried out in a farmer's field during December-March, 2022 at Singarakuppam coastal village, near Chidambaram in Cuddalore district of Tamil Nadu. The experimental soil was sandy in texture and taxonomically classified as *Typic Ustipsamments* with Ph-8.25, EC-4.11 dSm^{-1} and represented low status of organic carbon (2.36 g kg^{-1}). Regarding available nutrient status, it was low in alkaline $KMnO_4$-N (139.91 kg ha^{-1}), low in Olsen-P (9.48 kg ha^{-1}) and medium in NH_4OAc-K (165.67 kg ha^{-1}).

The available B and Si content were 0.24 and 32.46 mg kg^{-1}, respectively. The initial biological properties of soil *viz*., enzyme activities of urease, dehydrogenase and phosphatase are 10.15 μg NH_4-N/g soil/24 h, 4.42 μg *p*-nitrophenol/g soil/h and 37.44 μg TTF/g soil/24 h, respectively and the microbial counts of bacteria, fungi and actinomycetes were 9.12 ´ 10^6 g^{-1} soil, 7.44 ´ 10^5 g^{-1} soil and 5.01 ´ 10^4 g^{-1} soil, respectively.

The various treatments included were, T_1-Control (RDF alone), T_2-RDF + CCP @ 12.5 t ha^{-1}, T_3-RDF + borohumate (BH) @ 1.5 kg B ha^{-1} + diatomaceous earth (DE) @ 60 kg Si ha^{-1} as soil application (SA), T_4-RDF + BH (SA) + silixol plus (SP) as foliar application (FA) @ 1.0% twice, T_5-RDF + DE (SA) + BH as foliar application (FA) @ 0.5% twice, T_6-RDF + (BH + SP) FA, T_7-RDF + (BH + DE) SA + (BH + SP) FA, T_8-RDF + CCP + (BH + DE) SA, T_9-RDF + CCP + BH (SA) + SP (FA), T_{10}-RDF + CCP + DE (SA) + BH (FA), T_{11}-RDF + CCP + (BH + SP) FA, T_{12}-RDF + CCP + soil application of borohumate @ 1.5 kg B ha^{-1} with diatomaceous earth @ 60 kg Si ha^{-1}+ foliar spray of borohumate and silixol plus @ 0.5% twice at flowering and pre flowering stages. The experiment was carried out in a Randomized Block Design (RBD) with three replications, using groundnut variety VRI 2 as test crop.

Laboratory analysis

The periodic soil samples were collected at critical stages of groundnut *viz.*, flowering, peg formation and at harvest stages was taken and dried in shade, powdered, sieved and analysed for available nutrients (N, P, K, B and Si) and biological properties (bacteria, fungi and actinomycetes). In the soil samples, enzymatic activities *viz.*, urease, phosphatase and dehydrogenase were also analysed. The methods of analysis and techniques adopted for various estimations followed are given in Table 1.

Statistical analysis

The data obtained from the field experiments were statistically analysed as per the standard method (20). For significant results, the critical difference was worked at 5 % probability level

Results and Discussion

Kharif groundnut

Major nutrients availability in soil: The interaction between different levels of boron and silicon significantly influenced the availability of nitrogen, phosphorus and potassium in the soil and the data are depicted in Table 2. The treatment B_3S_3, which received boron as borohumate (1.5 kg B ha^{-1}) and silicon as diatomaceous earth (60 kg Si ha^{-1}), recorded the highest alkaline $KMnO_4$-N (163.55 kg ha^{-1}), Olsen-P (15.12 kg ha^{-1}) and NH_4OAc-K (205.71 kg ha^{-1}) at harvest. This was followed by the treatment pairs like B_3S_2, B_3S_1 and B_3S_0. The lowest alkaline $KMnO_4$-N, Olsen-P and NH_4OAC-K content was noticed in control (without boron and silicon).

The results of the field experiment indicated that, application of borohumate @ 1.5 kg B ha^{-1} + diatomaceous earth @ 60 kg Si ha^{-1} rated best in recording the highest alkaline $KMnO_4$-N, Olsen-P and NH_4OAC-K content in the soil. Addition of boron as micronutrient through borohumate applied treatments increased the nitrogenase activity thereby the availability of N is increased. Further, may be due to increase in mineralization and higher nitrogen use efficiency in that treatment. Lower nitrogen content was recorded in control treatment. The application of silicon has the potential to raise the optimum N rate thus enhancing productivity of existing crops in coastal saline soils and positive effect of added N on performance of Si fertilizer. These results are in accordance with the earlier reports (21). Further, increased available P content of soil might be due to increase in the concentration of orthosilicic acid resulted in the transformation of slightly soluble phosphates into plant available phosphates. Water soluble silicon played important role in increasing P-availability of soil by replacing adsorbed-P and by decreasing the P-adsorbing capacity of soil (22, 23). The addition of borohumate along with NPK fertilizers reduced the K fixation and more K was released due to the

Table 1. List of various analytical methodology followed in experiments

Sl. No	Characteristics	Methodology followed	References
1	Alkaline $KMnO_4$-N	Alkaline permanganate method	(12)
2	Olsen-P	Ascorbic acid modification of the molybdate blue colour method (0.5 M $NaHCO_3$, pH 8.5)	(13)
3	NH_4OAc-K	Neutral, normal ammonium acetate extraction (1:5 soil:neutral normal ammonium acetate) by flame photometer method	(14)
4	Available boron	Hot water-soluble boron method	(15)
5	Available silicon	0.5 M $CaCl_2$ extractant method	(16)
6	Urease activity	Urea distillation method	(17)
7	Phosphatase activity	*p*-Nitrophenol colorimetric method	(17)
8	Dehydrogenase activity	TTF colorimetric method	(18)
9	Bacterial population	Standard plate techniques (Soil microorganism)	(19)
10	Fungal population	Standard plate techniques (Soil microorganism)	(19)
11	Actinomycetes population	Standard plate techniques (Soil microorganism)	(19)

Table 2. Combined effect of different levels of boron and silicon fertilizer on the major nutrient availability (kg ha^{-1}) in soil at harvest stage of groundnut

NPK	B/S	B_0	B_1	B_2	B_3	Mean	Statistical analysis		
Alkaline $KMnO_4$-N	S_0	123.22	136.17	139.06	144.29	**135.69**		SE_D	CD (p = 0.05)
	S_1	137.18	140.42	144.59	150.02	**143.05**	B	0.86	1.76
	S_2	141.10	145.13	150.48	155.71	**148.11**	S	0.86	1.76
	S_3	144.49	149.65	156.29	163.55	**153.50**	BxS	1.73	3.52
	Mean	**136.50**	**142.84**	**147.61**	**153.39**				
Olsen-P	S_0	8.52	10.83	11.73	12.82	**10.98**		SE_D	CD (p = 0.05)
	S_1	11.11	11.71	12.56	13.54	**12.23**	B	0.13	0.26
	S_2	11.70	12.54	13.42	14.42	**13.02**	S	0.13	0.26
	S_3	12.38	13.39	14.31	15.12	**13.80**	BxS	0.25	0.51
	Mean	**10.93**	**12.12**	**13.01**	**13.98**				
NH_4OAc-K	S_0	153.78	167.70	174.11	180.90	**169.12**		SE_D	CD (p = 0.05)
	S_1	169.73	176.44	181.81	189.51	**179.37**	B	1.39	2.82
	S_2	175.50	184.07	190.53	197.16	**186.82**	S	1.39	2.82
	S_3	181.49	189.81	198.32	205.71	**193.83**	BxS	2.76	5.63
	Mean	**170.13**	**179.51**	**186.19**	**193.32**				

B_0 – Control; B_1 – 0.5 kg B ha^{-1}; B_2 – 1.0 kg B ha^{-1}; B_3 – 1.5 kg B ha^{-1}.

S_0 – Control; S_1 – 20 kg Si ha^{-1}; S_2 – 40 kg Si ha^{-1}; S_3 – 60 kg Si ha^{-1}.

clay complex site by the presence of humic substance like humic, fulvic acids and organic matter interaction contributing higher K to soil available pool (24, 25).

Boron and silicon availability in soil: The interaction effect between the different levels of borohumate and diatomaceous earth in improving the B and Si availability of soil was significant and the data are pertained in Table 3. Among all the treatment, the combined application of borohumate @ 1.5 kg B ha^{-1} along with diatomaceous earth @ 60 kg Si ha^{-1} (B_3S_3) which registered the highest B and Si availability of 0.59 mg kg^{-1} and 63.11 mg kg^{-1} at harvest stage. This was followed by the treatment pairs like B_3S_2 and B_3S_1, which recorded the B availability (0.55 and 0.48 mg kg^{-1}) and silicon availability (61.42 and 59.56 mg kg^{-1}) at harvest stage, respectively. The lowest B availability was noticed in control (B_0S_0).

The availability of B and Si in soil was significantly increased with the application of borohumate + diatomaceous earth. Among different treatments, the application of borohumate @ 1.5 kg B ha^{-1} + diatomaceous earth @ 60 kg Si ha^{-1} was associated with the increased availability of boron and silicon nutrients. The increased availability in soil might be due to increased plant growth and absorption of nutrients to applied and native nutrients. Further the stimulatory effect of boron and silicon on these nutrients also explains the reason for the higher availability (26, 27). With the increased availability of these nutrients with borohumate application, the added effect of applied borohumate in the transformation and mobilization of native and applied nutrients might have brought out higher availability (28). The silicon availability naturally showed a concomitant increase with application of silicon. The silicon availability increased from flowering stage to peg formation stage and then slightly decreased at harvesting stage this may due to the soil application of diatomaceous earth. This decrease may be due to increased absorption of silicon by the plant at vegetative and reproductive stages (29).

Rabi groundnut

Major nutrients availability in soil: The positive influence of B and Si fertilization either through soil or foliar and or both along with organics and recommended dose of NPK was also significantly increased the alkaline $KMnO_4$-N, Olsen-P and NH_4OAC-K content of the soil in the present investigation which are shown in Fig. 1. The application of recommended dose of NPK + borohumate @ 1.5 kg B ha^{-1} + diatomaceous earth @ 60 kg Si ha^{-1} by soil and foliar spray of borohumate @ 0.5% + silixol plus @ 1.0 % twice along with CCP @ 12.5 t ha^{-1} (T_{12}) registered the highest alkaline $KMnO_4$-N, Olsen-P and NH_4OAC-K content of 172.92, 18.64 and 221.74 kg ha^{-1} at harvest stages, respectively. This was followed by the treatments, application of boron and silicon either through soil or foliar alone or soil + foliar and recommended NPK along with organics significantly decreased the NPK availability as compared to above said treatment (both SA + FA). The treatment T_{10} was found to be comparable with treatment T_{11} (application of RDF + BH @ 0.5% + SP @ 0.5% through FA along with CCP). This was followed by the treatments arranged in the descending order like $T_7 > T_3 > T_4 > T_5 > T_6$ and T_2. These treatments were also statistically significant. The control treatment recorded the lowest soil NPK availability.

The results of the present study might be due to the addition of organics stimulated the growth and activity of

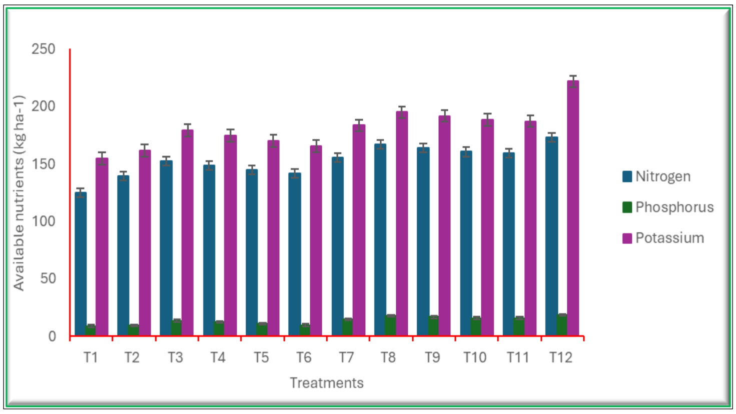

Fig. 1. Effect of composted coir pith boron and silicon fertilization on the major nutrients availability in soil at harvest stage of groundnut.

Table 3. Combined effect of different levels of boron and silicon fertilizer on the boron and silicon nutrient availability (mg kg^{-1}) in soil at harvest stage of groundnut

B / S	Hot water soluble boron					Available silicon				
	B_0	B_1	B_2	B_3	Mean	B_0	B_1	B_2	B_3	Mean
S_0	0.12	0.20	0.25	0.37	**0.23**	17.37	18.09	18.82	19.98	**18.57**
S_1	0.14	0.27	0.36	0.48	**0.31**	53.89	55.86	57.62	59.56	**56.73**
S_2	0.15	0.38	0.41	0.55	**0.37**	55.83	57.72	59.44	61.42	**58.60**
S_3	0.16	0.45	0.50	0.59	**0.42**	57.82	59.64	61.37	63.11	**60.49**
Mean	**0.14**	**0.32**	**0.38**	**0.49**		**46.23**	**47.83**	**49.31**	**51.02**	
		SE_D		CD (p = 0.05)			SE_D		CD (p = 0.05)	
B		0.01		0.02			0.33		0.66	
S		0.01		0.02			0.33		0.66	
BxS		0.01		0.03			0.65		1.32	

B_0 - Control; B_1 - 0.5 kg B ha^{-1}; B_2 - 1.0 kg B ha^{-1}; B_3 - 1.5 kg B ha^{-1}.

S_0 - Control; S_1 - 20 kg Si ha^{-1}; S_2 - 40 kg Si ha^{-1}; S_3 - 60 kg Si ha^{-1}.

microorganisms, which increased the nutrient release and the effect was further enhanced by the addition of NPK fertilizers (29, 30). Further organic manure on decomposition solubilizes insoluble phosphorus fractions through release of various organic acids and increases the available P status of soil. It also forms chelates with essential plant nutrients and prevent their fixation which favours availability of nutrient to crop (31, 32). The addition of organics along with NPK fertilizers increases the K fixation and more K was released due to the clay organic matter interaction contributing higher K to soil available pool (33, 34).

Boron and silicon availability in soil: From the Fig. 2 and 3 the highest boron and silicon content was observed in the treatment combining diatomaceous earth, borohumate, RDF and CCP. Among the various treatments, the highest hot water soluble boron and available silicon status at harvest stage (0.73 and 61.89 mg kg^{-1}) was recorded with the combined application of borohumate @ 1.5 kg B ha^{-1} + diatomaceous earth @ 60 kg Si ha^{-1} through soil and foliar spray of borohumate @ 0.5% and silixol plus @ 1.0% twice along with CCP @ 12.5 t ha^{-1} and recommended dose fertilizer (T_{12}). This was followed by the application of 100 % RDF + CCP + B @ 1.5 kg ha^{-1}+ Si @ 60 kg ha^{-1}through soil application (T_8), RDF + CCP + B @ 1.5 kg ha^{-1} + Si@ 1.0 % through foliar application (T_9) and application of RDF + CCP + DE @ 60 kg Si ha^{-1} (SA) through soil + BH @ 0.5% (FA) through foliar (T_{10}). However, treatment T_{10} found to be equally efficacious with the treatment T_{11} (RDF + CCP @ 12.5 t ha^{-1} + borohumate @ 0.5% and silixol plus @ 1.0% through foliar). Treatments without organic amendments (T7, T3, T4, T5 and T6) recorded significantly lower boron and silicon availability compared to those incorporating both boron, silicon and organic amendments. The control treatment (RDF alone) registered the lowest hot water soluble-B content and silicon content of 0.11 and 23.12 mg kg^{-1} at harvest stage of groundnut. The highest B content was recorded with the treatment diatomaceous earth+ borohumate + RDF along with CCP application. The increased use efficiency of applied fertilizer and their availability along with organics in complexing and mobilizing property might have increased the boron content of the soil (35-37).

Moreover, the beneficial effect of silicon and boron nutrition which increased the nutrients availability might be attributed to the direct addition of these nutrients by fertilizer and organic manures, which maintain maximum available Si and B status in post-harvest soil. Further the application of micronutrients with applied organics might have mobilized and increased the availability of Si and B in soil (38-40).

Microbial populations in soil: The data presented in Table 4 indicates the microbial populations of soil microorganisms *viz.*, bacteria, fungi and actinomycetes were significantly increased with different modes of boron and silicon application along with organics and recommended NPK. An increase in the microbial population up to peg formation stage, thereafter a decline trend was noticed at harvest stage of groundnut. The influence of boron, silicon and organics had positive effect on microbial populations in soil. The application of RDF + CCP @ 12.5 t ha^{-1} + borohumate @ 1.5 kg B ha^{-1} + diatomaceous earth @ 60 kg Si ha^{-1} through soil as well as foliar spray of borohumate @ 0.5 % and silixol plus @ 1.0 % twice at pre flowering and flowering stage (T_{12}) recorded the highest bacteria, fungi and actinomycetes activity of 26.89×10^{6} g^{-1}soil, 18.27×10^{5} g^{-1}soil and 10.54×10^{4} g^{-1}soil at peg formation, respectively. This was followed by the treatment T_8 (RDF + CCP + BH @ 1.5 kg ha^{-1}+ DE @ 60 kg Si ha^{-1} through soil alone), T_9 (RDF + CCP + BH @ 0.5% + SP @

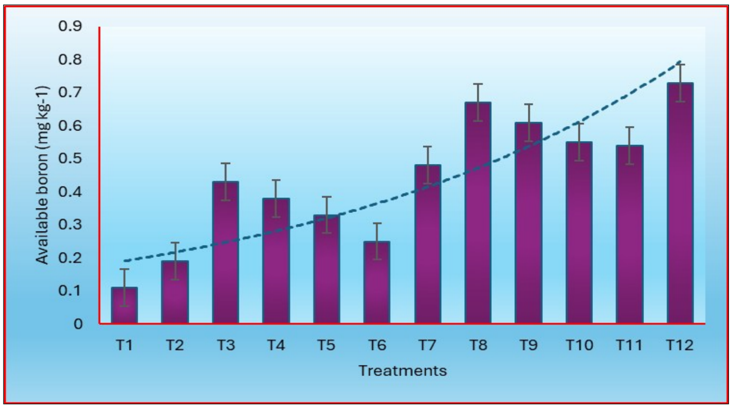

Fig. 2. Effect of composted coir pith boron and silicon fertilization on the boron availability in soil at harvest stage of groundnut.

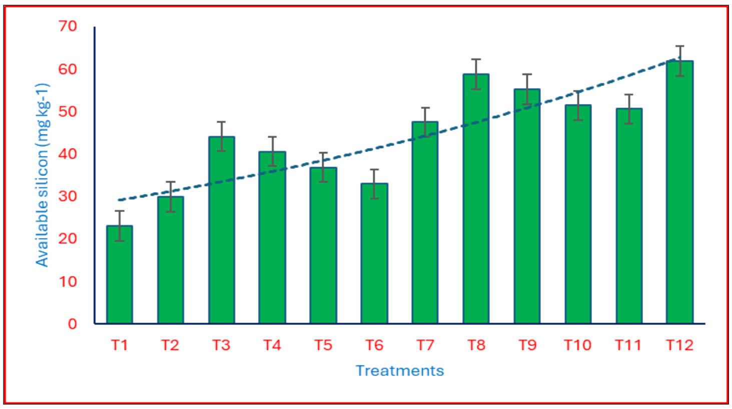

Fig. 3. Effect of composted coir pith boron and silicon fertilization on the silicon availability in soil at harvest stage of groundnut.

Table 4. Effect of composted coir pith boron and silicon fertilization on the microbial populations and enzyme activities of the soil at peg formation stage of groundnut

Treatments	Bacteria ($x10^6$ g^{-1}soil)	Fungi ($x10^5$ g^{-1}soil)	Actinomycetes ($x10^4$ g^{-1}soil)	Urease (mg NH_4-N/g soil/24 h)	Phosphatase (mg *p*-nitrophenol/g soil/h)	Dehydrogenase (mg TTF/g soil/24 h)
T_1	10.97	10.31	6.98	13.07	10.51	38.18
T_2	20.26	15.03	9.14	26.10	15.87	63.69
T_3	17.16	13.41	8.43	21.71	14.08	55.11
T_4	15.64	12.56	8.04	19.53	13.14	50.92
T_5	14.05	11.85	7.68	17.44	12.32	46.73
T_6	12.54	11.12	7.29	15.29	11.43	42.51
T_7	18.75	14.29	8.79	23.87	15.05	59.36
T_8	25.20	17.45	10.16	33.38	18.64	78.04
T_9	23.68	16.68	9.85	31.17	17.81	73.78
T_{10}	22.05	15.85	9.56	28.83	16.84	69.47
T_{11}	21.80	15.74	9.47	28.39	16.72	67.98
T_{12}	26.89	18.27	10.54	35.66	19.66	82.19
SE_D	0.68	0.32	0.13	0.91	0.36	1.91
CD (p = 0.05)	1.42	0.67	0.27	1.92	0.76	4.01

1.0% through foliar alone) and T_{10} (RDF + CCP + DE @ 60 kg Si ha^{-1} through soil + BH @ 0.5% through foliar). However, (treatment T_{10}) it was found to be equally efficacious with T_{11} (RDF + CCP + BH @ 0.5% + SP @ 1.0% through foliar alone). This was followed by the treatments addition of different mode of boron and silicon fertilization along with RDF (without organics) significantly arranged in the descending order like $T_7 > T_3 > T_4 > T_5$ and T_6. These treatments were also statistically significant and recorded the lowest bacteria, fungi and actinomycetes population counts as compared to above said organics applied treatments (boron, silicon and organics). The lowest microbial population was observed in control (NPK alone). In coastal saline sandy soil, the increased microbial counts in soil with application of CCP along with micronutrient as boron and beneficial element as silicon may be due to better soil biological environment of coastal saline soil (41, 42). Further, the availability of readily mineralized C and N improvement in the physico-chemical properties of the soil due to the application of organics might have increased the microbial population of the soil (43, 44).

Enzymatic activities in soil: The enzymatic activity of soil *viz*., dehydrogenase, phosphatase and urease was significantly increased with different modes of B and Si application along with organics and the data are pertained in Table 4. An increase in the enzymatic activity of soil up to peg formation stage and a decline thereafter was noticed at harvest stage. The influence of boron, silicon and organics in improving the alkaline phosphatase activity in coastal saline soil was significant. The maximum alkaline phosphatase activity was observed at peg formation stage of groundnut. At peg formation stage the highest urease, phosphatase and dehydrogenase activity of 35.66 mg NH_4-N/g soil/24 h, 19.66 mg *p*-nitrophenol/g soil/h and 82.19 mg TTF/g soil/24 h was recorded with application of recommended dose of NPK + CCP @ 12.5 t ha^{-1} + borohumate @ 1.5 kg B ha^{-1} and diatomaceous earth @ 60 kg Si ha^{-1} through soil and foliar application of borohumate @ 0.5% + silixol @ 1.0 % (T_{12}). This was followed by treatments T_8 (RDF + (BH + DE) SA + CCP), T_7 (RDF + BH (SA) + SP (FA) + CCP) and T_{10} (RDF + (BH + SP) FA + CCP). However, treatment T_{10} and T_{11} were found to be equally best in urease, phosphatase and dehydrogenase activity of soil. This was followed by the treatments significantly arranged in the descending order as $T_7 > T_3 > T_4 > T_5 > T_6$ and T_2. The lowest urease, phosphatase and dehydrogenase of soil was noticed in the application of NPK alone which recorded a value of 13.07 mg NH_4-N/g soil/24 h, 10.51mg *p*-nitrophenol/g soil/h and 38.18 mg TTF/g soil/24 h, respectively. The favourable effect of CCP on the activity of dehydrogenase in soil and it was more pronounced with application of organics along with NPK fertilizers which was attributed to increased mineralization of nutrients from microbial decomposition of organic matter (45, 46). The application of silicon at increasing rate can increases the enzyme activities such as urease, catalase and fluorescein diacetate hydrolase (FDA) and the results confirmed the capability of silicon to maintain or enhance the microbial activity in stimulating nutrient availability and to promote microbial deoxygenation of the micro environments (41, 47).

Conclusion

The two field experiments confirmed the effectiveness of borohumate + diatomaceous earth application in improving the groundnut productivity and soil properties of coastal saline soil. Further, the combined application of borohumate @ 1.5 kg B ha^{-1} + diatomaceous earth @ 60 kg Si ha^{-1} through soil as well as foliar spray of borohumate @ 0.5 % and silixol plus @ 1.0 % twice at pre flowering and flowering stage, along with recommended NPK and CCP, resulted in the highest availability of boron, silicon, major nutrients, enzymatic activities and microbial populations in soil. Future research will focus on silicon combinations with other nutrients to improve soil and crop productivity.

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Authors' contributions

DE carried out the whole research article writing and data analysis. RK carried out the field trail in farmer's field and laboratory analysis of samples. PAK and DG were involved in statistical analysis. AVA, MV, KM and SM contributed in citation management and overall article writing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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